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The Output Bias of Technological Change in Postwar Japanese Agriculture

by

Yoshimi Kuroda

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Yoshimi Kuroda is associate professor of economics in the Institute of Socio-Economic Planning at the University of Tsukuba, Japan. The author wishes to acknowledge constructive comments and suggestions of John M. Antle, Y. Yamamoto, and an anonymous referee on earlier drafts. He also thanks Bruce Lambert for his editing of the English. The responsibility for any errors, however, rests solely with the author.

Japanese agriculture experienced a drastic change in its output mix over the past three decades. This change was caused mainly by a remarkable growth in livestock production as shown in table 1. The value of livestock production increased five-fold from 1955 to 1984; the annual growth rate was as high as 5.6% for this period. In contrast, crop production was stagnant for the same period, especially from 1965 to 1984; the annual rate of growth for the 1955-84 period was only 0.2%. This pattern of crop production was mainly due to the relative decline in rice production whose share of total agricultural production declined from 47.2% in 1955 to 30.2% in 1984. As a result, the livestock share of total agricultural production increased substantially, from 7.9% in 1955 to 27.5% in 1984. Livestock production is now as important as rice production in Japanese agriculture.

The basic factor that influenced this high growth rate in livestock production was a strong and persistent demand for livestock products due to rapid per capita income growth in the Japanese economy since the mid-1950s. Thus, one standard explanation for the rapid restructuring of output in Japanese agriculture is that, with the favorable relative price due to shifts in the structure of food demand, livestock production grew faster than crop production with the production possibility frontier remaining unchanged or shifting in a parallel fashion. However, this demand-side-oriented explanation is clearly incomplete, since, as observed in table 1, the price of livestock products was unfavorable relative to crops during the last three decades.

Therefore, an alternative hypothesis is proposed in this study to explain the more rapid growth in livestock production. It is hypothesized that technological change has been biased on the output side towards livestock production. That is, livestock production in general was managed by younger, higher-quality producers with more positive attitudes towards technological and managerial improvements, associated with larger numbers of animals and an abundant supply of cheap feed grains from abroad. On the other hand, field crop production, especially rice production, was managed by less skilled farmers who were often the older, part time, and less specialized. The major objective of this study is to test this hypothesis by empirically investigating the production structure of Japanese agriculture.

Furthermore, this drastic change in the output mix was accompanied by large changes in relative factor use. This period saw a sizable transfer of agricultural labor to the nonagricultural sectors, accompanied by the rapid mechanization of agricultural production. Although changes in relative factor prices surely influenced these changes in factor inputs, the large change in agricultural output also must have affected the relative uses of factor inputs.1/ Therefore, a second objective of this study is to investigate the effects of changes in the output mix on input allocations in agriculture during the last three decades.

One contribution of this study is the empirical measurement of the output bias caused by technological change in Japanese agriculture. Although several empirical studies have employed models of multiproduct cost and profit or revenue functions (Brown, Caves, and Christensen; Burgess; Denny and Pinto; Fuss and Waverman; Lopez; Ray; Shumway; Weaver), only a few studies have explicitly treated output biases in technological change,[2] and almost none in agricultural economics. Furthermore, several studies have yielded empirical estimates of factor biases in technological change (Binswanger, Kako 1979, Antle); however, they have failed to investigate the impacts of changes in output composition on the factor biases because their models employ single-output translog cost or profit functions. This study introduces a multiproduct framework in which the impacts of the output mix on factor biases can be measured.

For these objectives, the framework of a multiproduct translog (or translog joint) cost function is utilized. Although the translog cost function has been extensively applied in the analysis of Japanese agriculture (e.g., Kako 1978, Abe, Nghiep, Chino, and Kuroda), all these studies have used a single aggregate output. This implies that input allocation decisions are separable and independent of output allocation decisions.[3] Thus, separability between inputs and outputs is treated in this study as an important hypothesis. It will be tested statistically along with hypotheses concerning the biases in technological change. The multiproduct translog cost function will be estimated for the period 1958-84 using aggregate farm data.

Methodology

The cost function approach was chosen for the following 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 to lack of competition, so that farmers failed to maximize profits through marginal cost pricing even though they may have achieved optimal input allocations. Under this situation, a profit or revenue function approach may not be appropriate. Moreover, in the late 1960s the Japanese government introduced an allotment program for rice production in order to balance supply with demand. Such programs mean that the level of crop production (of which rice is most important in Japan) could then be treated as exogenous to producers. Second, the cost function approach yields direct estimates of the various Allen partial elasticities of substitution and biases in technological change. Third, the cost function approach allows the use of duality theory without imposing restrictions on returns to scale in the underlying technology.

This study defines the following multiproduct cost function.

$$(1) \qquad C = G(Q_G, Q_A, P_L, P_M, P_I, P_T, P_0, t)$$

where C is the minimized total cost; Q_G and Q_A are crop and livestock products, respectively; P_L, P_M, P_I, P_T, and P_0 are the prices of labor (X_L), machinery (X_M), intermediate inputs (X_I), land (X_T), and other inputs (X_0), respectively; and t is time as an index of technological change.

For econometric estimation, the following input-output nonseparable and Hicks-nonneutral form is employed for (1).[4]

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

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

Assuming that farmers take factor prices as given and using the Shephard's lemma, the cost share equations are 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, I, T, O; k = G, A; and $S_i = P_i X_i / C$.

The first objective of this study is achieved by introducing a measure of the bias of technological change in outputs following Antle and Capalbo. For 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 defined as

$$(4)\qquad B_{ij}^{Q} \equiv \partial \ell n\left(\frac{\partial C}{\partial Q_i}\Big/\frac{\partial C}{\partial Q_j}\right)\Big/\partial t$$
$$= \frac{\partial \ell nMC_i}{\partial t} - \frac{\partial \ell nMC_j}{\partial t}$$
$$= G(MC_i) - G(MC_j)$$

where G(·) denotes the rate of growth. B_{ij}^{Q} measures the rotation of the production possibility curves at a point due to technological change, as illustrated in figure 1. The initial expansion path is $e(t_1)$ and the 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 from P_1 which is tangent to T_1T_1 to P_2 which is tangent to T_2T_2. Thus, $B_{ij}^Q = 0$ if and only if technological change is Hicks neutral in the sense that it leaves the expansion path unchanged. Otherwise technological change is biased.

Thus, technological change in output space may be defined as biased towards output j (or against output i) if $B_{ij}^Q > 0$, neutral if $B_{ij}^Q = 0$, or biased towards output i (or against output j) if $B_{ij}^Q < 0$.

For the multiproduct translog cost function used in this study, the growth rate of the marginal cost of each output is derived as follows. First, the cost-output elasticity (or logarithmic marginal cost) of output i (ϵ_{CQ_i}) is obtained by

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

where i, k = G, A and j = L, M, I, T, O. Next, note that $\partial \ell nC_i / \partial \ell nQ_i = (\partial C/\partial Q_i)/(C/Q_i) = MC_i/AC_i$, i.e., the ratio between the marginal and average costs of output i. The differentiation of the logarithm of this ratio with respect to time holding outputs and factor prices constant yields

$$\frac{\partial \ell n}{\partial t}\left(\frac{MC_i}{AC_i}\right) = \frac{\partial \ell nMC_i}{\partial t} - \frac{\partial \ell nAC_i}{\partial t} = G(MC_i) - G(AC_i).$$

But,

$$\frac{\partial \ell n}{\partial t}\left(\frac{\partial \ell nC}{\partial \ell nQ_i}\right) = \left(\frac{\partial \ell nC}{\partial \ell nQ_i}\right)^{-1} \frac{\partial}{\partial t}\left(\frac{\partial \ell nC}{\partial \ell nQ_i}\right) = \frac{\mu_{it}}{\epsilon_{CQ_i} \cdot t} .$$

Combining these relations, the growth rate of the marginal cost of each output is obtained by

$$(6) \qquad G(MC_i) = \frac{\mu_{it}}{\epsilon_{CQ_i} \cdot t} + G(AC_i), \quad i = G, A.$$

Using (6), B^Q_{ij} in (4) can be computed for any subperiod as well as for the overall 1958-84 period. A positive value of B^Q_{GA} (= $G(MC_G) - G(MC_A)$) is expected, i.e., livestock-favoring technological change, for the period under question to validate the hypothesis.

This study also investigates how changes in the output mix affected relative factor uses during the last three decades. We will compute the elasticities of demand for factor inputs with respect to output quantities.[5/] In addition, the biased impacts of technological change on relative factor uses will be measured.

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

$$e_{ik} = \frac{\partial \ell nX_i}{\partial \ell nQ_k} = \frac{\partial \ell nC}{\partial \ell nQ_k} + \frac{\partial \ell n}{\partial \ell nQ_k}\left(\frac{\partial \ell nC}{\partial \ell nP_i}\right)$$

by utilizing the relation $S_i = P_iX_i/C = \partial \ell nC/\partial \ell nP_i$ (i = L, M, I, T, O; k = G, A). Making use of the parameters of the translog joint cost function, e_{ik} is expressed as,

$$(7) \qquad e_{ik} = \alpha_k + \sum_{i=1}^{5} \rho_{ki} \ell nP_i + \sum_{k=1}^{2} \gamma_{k\ell} \ell nQ_\ell + \mu_{kt} \ell nt + \frac{\rho_{ki}}{S_i} ,$$

$$i = L, M, I, T, O; \quad k, \ell = G, A.$$

Antle and Capalbo proposed an Hicksian 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 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 (a movement along the expansion path) and a bias effect(interpreted as a shift in the expansion path). In the multiproduct case, the Hicksian bias measure is defined as,

$$(8) \qquad B_i^e = B_i + \left[\sum_{j=1}^{m} \frac{\partial \ell n S_i(Q,P,t)}{\partial \ell n Q_j} \cdot \left(\frac{\partial \ell\, nC}{\partial \ell n Q_j}\right)^{-1} \right] \left(-\frac{\partial \ell n C}{\partial t}\right),$$

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 (the second term of (8)) is eliminated. Thus the Hicksian bias measure contains only the effect of a shift in the expansion path.

For the translog joint cost function, the cost-output elasticities ($\epsilon_{CQ_j} = \partial \ell n C/\partial \ell n Q_j$) are computed by equation (5) and the negative of the rate of cost diminution ($\lambda = -\partial \ell n C/\partial t$) is obtained by:

$$(9) \qquad \lambda = -\frac{\partial \ell n C}{\partial t} = -\left(\epsilon_t + \sum_{i=1}^{2} \mu_{it} \ell n Q_i + \sum_{j=1}^{5} \nu_{jt} \ell n P_j + \epsilon_{tt} \ell n t\right)/t,$$

where i = G, A and j = L, M, I, T, O. Thus, the Hicksian bias is measured by,

$$(10) \qquad B_i^e = B_i + \frac{\lambda}{S_i} \cdot \frac{\rho_{Gi}}{\epsilon_{CQ_G}} + \frac{\lambda}{S_i} \cdot \frac{\rho_{Ai}}{\epsilon_{CQ_A}} \quad .$$

The first term of the right hand side measures the bias attributed 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.

The Data

The data required to estimate the model include total cost, quantities of crop and livestock production, and the prices and cost shares of labor, machinery, intermediate inputs, land, and other inputs. The sources of data 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. The FHE data are compiled by sampling methods each year. The "average" data are obtained by simply averaging data of sample farms. Since technologies practiced by Japanese farms in producing either crops or livestock, separately or jointly, are similar across all size classes, the simple pooling of these four cross-sectional units should not cause significant bias in the estimates of the translog cost function.

The quantity and price indexes of crop products (Q_G and P_G) were computed by the Törnqvist approximation method of the Divisia index. Ten categories of crop products were distinguished with price indexes for these categories 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 for these indexes is 1958.

The quantity of labor (X_L) was the total number of male-equivalent labor hours of operators, family and hired workers. The 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. 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 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 expressed in index terms.

The quantity and price index of machinery (X_M and P_M), intermediate inputs (X_I and P_I), and other inputs (X_0 and P_0) were also constructed by the Törnqvist method. The cost of machinery ($P_M X_M$) was defined as the sum of the costs for machinery, energy, and rentals; the cost of intermediate inputs ($P_I X_I$) was the sum of the expenditures on fertilizer, feed, agri-chemicals, materials, clothes, and others; and the cost of other inputs ($P_0 X_0$) was the sum of the expenditures on animals, plants, and farm buildings and structures.

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

Finally, 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).

Statistical Methods

Any cost function must satisfy linear homogeneity in factor prices as a regularity condition. In the translog joint cost function this requires 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, I, T, O; k = G, A). Using the price index of other inputs (P_O) as a numeraire and imposing these parameter restrictions, the translog cost and factor cost share functions (2) and (3) are rewritten as:

$$(11) \quad \begin{aligned} \ell nC/P_O = {} & \alpha_0 + \sum_{i=1}^{2} \alpha_i \ell nQ_i + \sum_{j=1}^{4} \beta_j \ell nP_j/P_O + \epsilon_t \ell nt \\ & + \frac{1}{2} \sum_{i=1}^{2} \sum_{k=1}^{2} \gamma_{ik} \ell nQ_i \ell nQ_k + \frac{1}{2} \sum_{j=1}^{4} \sum_{\ell=1}^{4} \delta_{j\ell} \ell nP_j/P_O \ell nP_\ell/P_O \\ & + \sum_{i=1}^{2} \sum_{j=1}^{4} \rho_{ij} \ell nQ_i \ell nP_j/P_O + \sum_{i=1}^{2} \mu_{it} \ell nQ_i \ell nt \\ & + \sum_{j=1}^{4} \nu_{jt} \ell nP_j/P_O \ell nt + \frac{1}{2} \epsilon_{tt} (\ell nt)^2 \end{aligned}$$

$$(12) \quad S_j = \beta_j + \sum_{j=1}^{4} \delta_{j\ell} \ell nP_j/P_O + \sum_{i=1}^{2} \rho_{ij} \ell nQ_i + \nu_{jt} \ell nt$$

$$i, k = G, A, \quad j, \ell = L, M, I, T.$$

The coefficients of the cost share equation of other inputs (S_O) are obtained by using the parameter relationships of the linear homogeneity restrictions after the system is estimated. The system of the five equations in (11) and (12) will be jointly estimated for the 1958-84 period.

Since the right-hand-side variables Q_i (i=G,A) may be endogenously determined, a simultaneous equations estimation procedure should be employed.[6/] The method chosen was iterative three-stage least squares. The required instrumental variables consisted of variables exogenous to the cost structure: output prices, factor prices, and time. Following Antle and Crissman, the translog specification was used to obtain the fitted values of the instrumental variables, $\ell n\hat{Q}_i$ and $(\ell n\hat{Q}_i)^2$, i = G, A. Since these measures of the instrumental variables are exogenous, the estimates of the translog joint cost function are free of simultaneous equations bias.

Empirical Results

In this section, the empirical results are reported for tests of statistical hypotheses concerning the functional form, output bias, output-quantity demand elasticities of factor inputs, and factor biases.

Tests of statistical hypothesis and final specification

The translog cost function (11) and the four cost share equations in (12) were estimated first by ordinary least squares in order to check the goodness of fit. The $\overline{R^2}$'s were 0.9946 for the translog cost function and 0.9257, 0.6184, 0.6654, and 0.8789 for labor, machinery, intermediate inputs, and land, respectively, indicating a fairly good fit.

Validating the model through the following statistical tests concerning with the functional form is of critical importance to analyze input and output biases in technological change and factor demand elasticities. The first hypothesis tested was input-output separability. The following null hypothesis was tested conditional on maintained hypothesis of cost minimization (i.e., across-equations equality)[7] : $\sum_{i=1}^{2} \alpha_i = 1$; $\sum_{i=1}^{2} \gamma_{ij} = 0, \forall_j$; $\sum_{i=1}^{2} \mu_{it} = 0$; and $\rho_{ik} = 0, \forall_{i,k}$ (i, j = G, A; k = L, M, I, T, O).[8] The computed F with the degrees of freedom (12,504) was 81.4. Since the critical F's with these degrees of freedom are 1.75 and 2.18, at the 5% and 1% significance levels, respectively, this hypothesis is strongly rejected. Thus input and output decisions are not independent of each other. That is, the marginal rates of substitution between pairs of factor inputs are not independent of output composition, and the marginal rate of transformation between the two outputs is not independent of factor input composition.

Hicks neutrality of technological change can also be tested. In the input-output nonseparable case the following null hypothesis again is tested conditional on the maintained hypothesis of cost minimization: $\mu_{it} = 0, \forall_i$ and $\nu_{jt} = 0, \forall_j$ (i = G, A; j = L, M, I, T, O). Technological change in this case is defined as extended Hicks-neutral technological change in a multiproduct version (Blackorby, Lovell, and Thursby). The computed F was 9.8 with the degrees of freedom (6,504), and decisively rejected since the critical F's are 2.10 and 2.80 at the 5% and 1%

levels, respectively. This result implies biases in technological change in input space, output space, or both. Which space is biased should be examined by investigating the estimated coefficients of $\hat{\mu}_{it}$ (i = G, A) and $\hat{\nu}_{jt}$ (j = L, M, I, T, O) when the final estimates of the translog cost function are provided.[9]

Based on these tests, the system of equations was jointly estimated with the non-rejected restrictions imposed. Only the across-equations equality restrictions of the cost minimization hypothesis were imposed. The implied estimates of the parameters of the system of equations are obtained by using the parameter relationships of the linear homogeneity restrictions. The estimates of the translog joint cost function are presented in table 2. Monotonicity and concavity were checked at each observation based on the parameter estimates in table 2 and they were satisfied. This set of estimates, called the final specification, is used for the empirical analysis.

The output bias of technological change

To examine the rapid growth of livestock production on the supply side during the last three decades, a bias of technological change towards livestock production was hypothesized, that is, $B^Q_{GA} = G(MC_G) - G(MC_A) > 0$. To test this hypothesis, the annual growth rate of the marginal costs of crop and livestock production and B^Q_{GA} were computed using equations (4) and (6) for several subperiods as well as the overall 1958-84 period.[10] These estimates are provided in table 3.

Table 3 shows that the marginal cost of crop production grew faster than that of livestock production for all subperiods during the

1958-84 period. This implies $B^Q_{GA} > 0$ as shown in column 4, indicating that technological change during the 1958-84 period was biased towards livestock production. The unusually high growth rates of the marginal costs of both crop and livestock production from 1970 to 1975 apparently caused by drastic increases in prices of factors of production due to the world-wide energy crisis during this period.

This output bias of technological change is clearly captured by a diagrammatic interpretation. By changing the horizontal and vertical axes in figure 1 from Q_i to Q_G and from Q_j to Q_A, the shift of the production possibility frontiers from, say, T_1T_1 to T_2T_2 corresponds to technological change biased towards livestock production. This implies a shift (an increase) in the marginal rate of transformation from P_1 to P_2. The estimated B^Q_{GA} (> 0) in table 3 is consistent with this shift.

Output-quantity demand elasticities and factor biases in technological change

The elasticities of demand for factor inputs with respect to output quantities were computed using equation (7) to investigate the effects of changes in the output mix on relative factor uses. In addition, the biased impacts of Hicks-nonneutral technological change on the relative factor uses were measured based on equation (10). These equations clearly show that the elasticities and technological change biases are affected by output composition due to the model's nonseparable and Hicks-nonneutral property (e.g., $\hat{\rho}_{ij}$ and $\hat{\mu}_{it}$ are not all zeros where $i = G, A$ and $j = L, M, I, T, O$). The computed results of output-quantity demand elasticities and factor biases are provided in tables 4 and 5, respectively.

Several important findings emerge from the output-quantity demand elasticities reported in table 4. First, the demand elasticity of labor with respect to crop output ($\hat{Q}_G$), 0.66, is almost ten times as large as that with respect to livestock output ($\hat{Q}_A$), 0.07. Thus expanding livestock production requires less labor than expanding crop production. In turn the rapid growth of livestock production during the period under question had a stronger impact on the rapid migration of labor from the agricultural to nonagricultural sectors than did an increase in crop production.

Second, the demand for machinery with respect to $\hat{Q}_G$ was fairly elastic, while the demand with respect to $\hat{Q}_A$ was much less elastic; the values of elasticities are 0.96 and 0.03, respectively. This may imply that expanding crop production requires greater machinery input than does livestock production.

Finally, the demand elasticity of land with respect to $\hat{Q}_G$ was much greater than for $\hat{Q}_A$ (1.21 and 0.03, respectively). This may reflect the Japanese practice of raising livestock mainly with purchased grain feed, which does not require substantial pasture land.

The Hicksian bias measures (B_i^e) in table 5 show that technological change during the 1958-84 period was strongly biased towards labor-saving and machinery-using technology. Furthermore, these Hicksian bias measures indicate that technological change was biased towards intermediate inputs, against land, and almost neutral for other inputs. Much of these Hicksian biases is explained by shifts in the expansion path (B_i).

This finding supports the results of 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 and land increased relative to prices of machinery and intermediate and other inputs during the last three decades, this result as well as those by Kako and Chino is consistent with the induced innovation hypothesis (Hayami and Ruttan). Furthermore, table 5 shows that the biases against labor and towards machinery are fairly large compared with other factor inputs. Hence these biased effects of labor-saving and machinery-using technological change must have contributed substantially to the labor-machinery substitution during the sample period.

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 strongly towards machinery and land and slightly against labor, intermediate inputs, and other inputs. On the other hand, the scale effect due to livestock production was fairly strongly against labor, strongly against machinery and land, and strongly towards intermediate and other inputs. The result that the livestock-production scale effect is strongly towards intermediate inputs (including feed as an important item) and other inputs (of which animals and buildings and structures for livestock production are most important items) but strongly against land is consistent with the Japanese practice of raising livestock mainly with grain feed in barns.

Although both crop and livestock production had labor-saving scale effects, the labor-saving effect due to livestock production was greater than that due to crop production. This finding may indicate that an expansion of livestock production requires a relatively smaller amount of labor than an expansion of crop production. Combining this result with the finding that technological change favored livestock production and with a lower demand elasticity of labor with respect to livestock production than for crop production suggests that the rapid expansion of livestock production during the sample period contributed positively to the rapid exit of labor from agriculture.

Concluding Comments

This study has investigated the factors responsible for the sharp growth of livestock production and the related impacts on factor inputs use in Japanese agriculture during the last three decades. A multi-output multi-input translog cost function was specified and estimated for the period 1958-84 using aggregate farm data for all Japan excluding the Hokkaido region.

The major findings of the empirical analysis are as follows. Technological change biased towards livestock production largely explains the rapid growth in livestock production on the supply side during the last three decades. Furthermore, changes in the composition of crop and livestock outputs had significant impacts on the relative uses of factor inputs. Above all, an expansion of livestock production requires relatively less labor input than an expansion of crop production. This finding implies that the sharp 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.

The first finding is consistent with the hypothesis that livestock production in postwar Japanese agriculture was managed by younger, higher-quality farmers with more positive attitudes towards technological and managerial improvements, whereas field crop production, especially rice production, was managed by less skilled farmers who were often the older, part time, and less specialized. One policy implication of this result is as follows: Japanese agriculture is now urgently required to raise efficiency in production under pressures of free trade. Under such a situation, it is strongly recommended that the Japanese government take necessary steps to offer a better economic environment where higher-quality farm managers can engage in not only livestock but also field crop production.

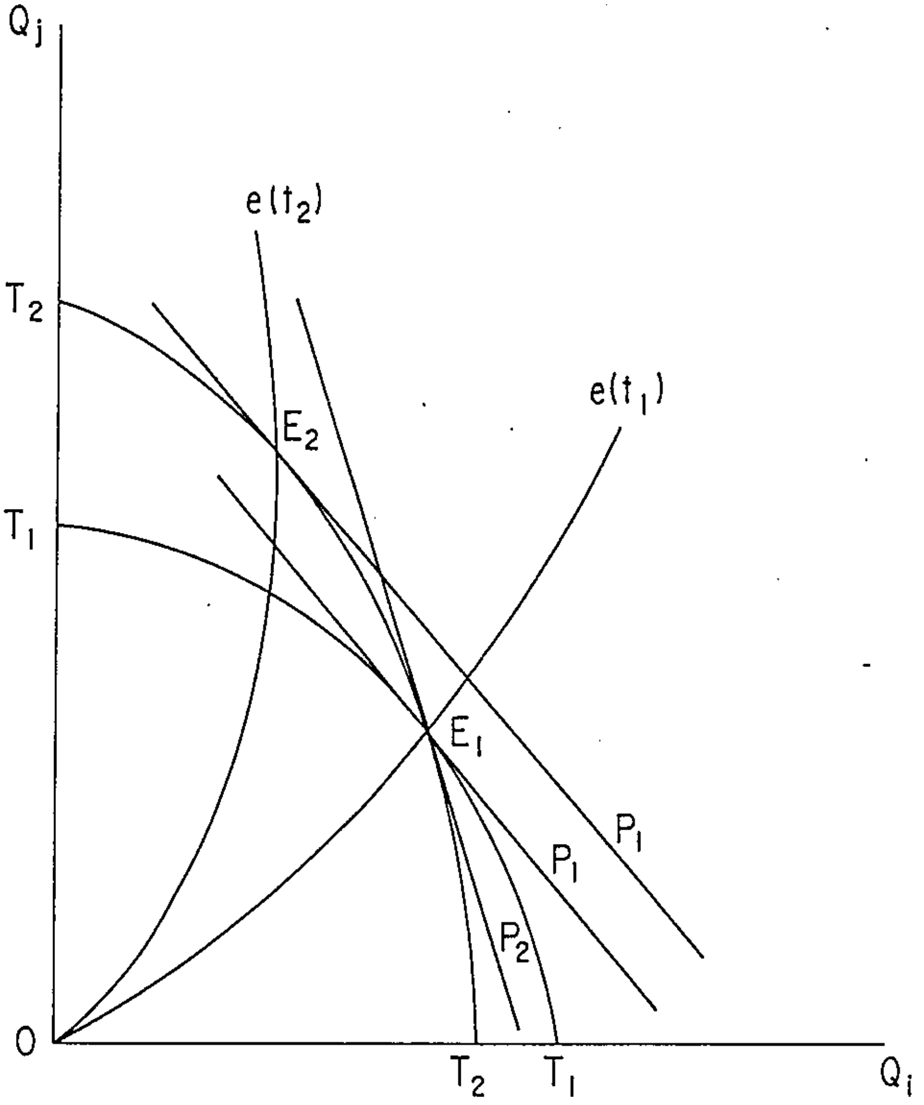

Figure 1. Biased Technological Change in Output Space in a Multiproduct Cost Function Framework

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

(Unit: 10 billion yen at 1980 prices)

Year	Crops		Livestock	Others	Total Production	P_G	P_A
	Total	Rice					
1955	8,006 (87.6)	4,313 (47.2)	726 (7.9)	403 (4.5)	9,135 (100.0)	100	100
1965	8,768 (80.3)	4,437 (40.6)	1,710 (15.7)	442 (4.0)	10,920 (100.0)	158	142
1975	8,751 (73.5)	4,390 (36.9)	2,563 (21.5)	594 (5.0)	11,908 (100.0)	344	321
1984	8,509 (66.6)	3,853 (30.2)	3,518 (27.5)	743 (5.8)	12,770 (100.0)	439	337

Sources: Ministry of Agriculture, Forestry, and Fisheries, Japan, Social Accounts of Agriculture and Farm Households, and Report on Prices and Wages in Rural Villages, various editions.

Notes:

1. Others include cocoons and agricultural services.
2. Figures in parentheses are percentage shares in total production.
3. P_G and P_A are the price indexes of crop and livestock products, respectively. They were obtained by the Törnqvist approximation procedure. The details of the estimation are given in the data section of this study. The base year of these indexes is however 1958.

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

Parameter	Coefficient	Parameter	Coefficient	Parameter	Coefficient
α_0	0.023	δ_{TT}	0.057*	ρ_{GT}	0.041*
α_G	0.776*	δ_{00}°	0.017*	ρ_{G0}°	-0.012*
α_A	-0.070	δ_{LM}	0.017**	ρ_{AL}	-0.029*
β_L	0.637*	δ_{LI}	-0.015**	ρ_{AM}	-0.020*
β_M	0.069*	δ_{LT}	-0.005	ρ_{AI}	0.040*
β_I	0.174*	δ_{L0}°	0.005	ρ_{AT}	-0.008
β_T	0.040*	δ_{MI}	-0.036**	ρ_{A0}°	0.018*
β_0°	0.080*	δ_{MT}	-0.020*	μ_{Gt}	-0.012**
ϵ_t	0.032	δ_{M0}°	-0.034*	μ_{At}	0.099**
γ_{GG}	-0.144*	δ_{IT}	-0.022*	ν_{Lt}	-0.037*
γ_{AA}	0.133	δ_{I0}°	0.022*	ν_{Mt}	0.036*
γ_{GA}	-0.067	δ_{T0}°	-0.010**	ν_{It}	0.014*
δ_{LL}	-0.003	ρ_{GL}	-0.039*	ν_{Tt}	-0.004
δ_{MM}	0.074*	ρ_{GM}	0.028*	ν_{0t}°	-0.009*
δ_{II}	0.051*	ρ_{GI}	-0.018*	e_{tt}	-0.095*

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

Table 3. Growth Rates of Marginal Costs and the Output Bias Measure, 1958-84 (Selected Periods)

(Unit: % per year)

Period	$G(MC_G)$	$G(MC_A)$	$B^Q_{GA} = G(MC_G) - G(MC_A)$
1958-65	6.8	5.1	1.7
1965-70	5.7	2.2	3.5
1970-75	10.7	10.4	0.3
1975-80	4.2	1.5	2.7
1980-84	0.9	-2.0	2.9
1958-84	5.9	4.4	1.5

Notes: 1. The growth rates of marginal costs were computed based on equation (6).

2. Subscripts G and A refer to crop and livestock production, respectively.

Table 4. Demand Elasticities with Respect to Output Quantities (Averages for 1958-84)

	Labor	Machinery	Intermediate inputs	Land	Other inputs
With respect to $\hat{Q}_G$	0.660 (0.020)	0.959 (0.045)	0.655 (0.008)	1.213 (0.204)	0.589 (0.010)
With respect to $\hat{Q}_A$	0.068 (0.006)	0.026 (0.087)	0.317 (0.054)	0.034 (0.010)	0.359 (0.061)

Notes: 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. Refer to text for the details of the estimation procedure.

Table 5. Factor Biases in Technological Change

(Averages for 1958-84)

(Unit: %)

	B_i	B^S_{iG}	B^S_{iA}	B^e_i
Labor	-0.73 (61)	-0.16 (13)	-0.30 (25)	-1.19 (100)
Machinery	2.72 (119)	0.41 (18)	-0.84 (-37)	2.29 (100)
Intermediate inputs	0.64 (44)	-0.16 (-11)	0.98 (67)	1.46 (100)
Land	-0.58 (176)	0.88 (-267)	-0.63 (191)	-0.33 (110)
Other inputs	-0.95 (3167)	-0.29 (967)	1.21 (-4033)	-0.03 (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 Hicksian bias effect.

2. Percentage contributions are in parentheses.

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.

4/ 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, since a specific functional form places a systematic structure on the form of substitution elasticities and technological change biases, we can circumvent the Diamond-Mcfadden-Rodoriguez "impossibility" problem and simultaneously identify substitution elasticities and biases of technological change (Diamond, McFadden, and Rodoriguez; Berndt and Khaled).

[5] With a translog joint cost function, 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. To study such impacts in detail, a single output translog cost function should be specified separately for each output. However, it then is impossible to investigate output-favoring technological change.

[6] The Törnqvist quantity indexes of the two outputs (Q_G and Q_A) explained earlier could not be obtained without assuming profit maximizing behavior of farm-firms. Thus, the observed output levels are implicitly treated as endogenous to input decisions and total cost.

[7] The across-equations equality was also tested to validate the cost minimization assumption. The computed F was 1.60 with the degrees of freedom (32,472). The critical F's are 1.46 and 1.70 at the 5% and 1% levels of statistical significance, respectively. Thus, the assumption of cost-minimizing behavior is valid at the 5% level.

[8] Here, the multiplicative (or strong) input-output separability (Hall) is tested. Weak separability could be tested as well, although it would require a complicated test for the validity of nonlinear parameter restrictions (Denny and Pinto).

[9] Under input-output separability, Hicks neutrality can be tested separately in output space and in input space.

[10] All of the variables necessary to compute the MC's and the following parameters are the weighted averages where the weights are 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).

References

Abe, J. "Partial Elasticities of Factor Substitution in Japanese Agriculture." Theory and Applications of Modern Farm Management Science (in Japanese), ed. Faculty of Farm Management Science, Obihiro University of Agriculture and Veterinary Medicine, Tokyo: Meibun Publishing Co., 1978.

Antle, J.M. "The Structure of U.S. Agricultural Technology, 1910-78." Amer. J. Agr. Econ. 66(1984): 414-21.

Antle, J.M. and S.M. Capalbo. "An Introduction to Recent Developments in Production Theory and Productivity Measurement." Agricultural Productivity: Measurement and Explanation, ed. S.M. Capalbo and J.M. Antle. Washington D.C.: Resource for the Future, Inc. (in Press).

Antle, J.M. and C.C. Crissman. "The Market for Innovations and Short-Run Technological Change: Evidence from Egypt." Econ. Devel. and Cultural Change, forthcoming.

Berndt, E.R. and M.S. Khaled. "Parametric Productivity Measurement and Choice among Flexible Functional Forms." Jour. Polit. Econ. 87 (1979): 1220-1245

Binswanger, H.P. "The Measurement of Technical Change Biases with Many Factors of Production." Amer. J. Agr. Econ. 64(1974): 964-976.

Blackorby, C., C.A.K. Lovell, and M.C. Thursby. "Extended Hicks Neutral Technical Change." Econ. Jour. 86(1976): 845-852.

Brown, R.S., D.W. Caves, and L.R. Christensen. "Modelling the Structure of Cost and Production for Multiproduct Firms." Southern Econ.

Jour. 46(1979): 256-273.

Burgess, D.F. "A Cost Minimization Approach to Import Demand Equations." Rev. Econ. and Statist. 56(1974): 225-234.

Chino, J. "Econometric Analysis of Technical Structure in Rice Production." Special Bulletin, No.42, the College of Agriculture, Utsunomiya University, 1984. (In Japanese)

Denny, M., M. Fuss, and L. Waverman. "The Measurement and Interpretation of Total Factor Productivity in Regulated Industries, with an Application to Canadian Telecommunications." Productivity Measurement in Regulated Industries, ed. T.G. Cowing and R.E. Stevenson. New York: Academic Press, 1981.

Denny, M. and C. Pinto. "An Aggregate Model with Multi-Product Technologies." Production Economics: A Dual Approach to Theory and Applications, Vol.2, ed. M. Fuss and D. McFadden. Amsterdam: North-Holland Publishing Co., 1978.

Diamond, P., D. McFadden, and M. Rodoriguez. "Measurement of the Elasticity of Factor Substitution and Bias of Technical Change." Production Economics: A Dual Approach to Theory and Applications, Vol.2, ed. M. Fuss and D. McFadden. Amsterdam: North-Holland Publishing Co., 1978.

Fuss, M. and L. Waverman. "Regulation and the Multiproduct Firm: The Case of Telecommunications in Canada." Studies in Public Regulation, ed. G. Fromm. Cambridge, Mass.: The MIT Press, 1981.

Hall, R.E. "The Specification of Technology with Several Kinds of Output." Jour. Polit. Econ. 81(1973): 878-892.

Hayami, Y. and V.W. Ruttan. Agricultural Development: An International

Perspective. Baltimore and London: The Johns Hopkins Press, 1971.

Hicks, J.R. The Theory of Wages (2nd ed.). London: Macmillan, 1963.

Kako, T. "Decomposition Analysis of Derived Demand for Factor Inputs: The Case of Rice Production in Japan." Amer. J. Agr. Econ. 60(1978): 628-35.

Kako, T. "Estimation of the Characteristics of Technical Progress in Rice Production." Noringyo Mondai Kenkyu (in Japanese). 15(1979): 18-25.

Kuroda, Y. "The Production Structure and the Demand for Labor in Postwar Japanese Agriculture, 1952-82." Amer. J. of Agr. Econ. 69(1978): 328-337.

Leibenstein, H. Beyond Economic Man: A New Foundation for Microeconomics. Cambridge, Mass: Harvard Univ. Press, 1976.

Lopez, R.E. "Estimating Substitution and Expansion Effects Using a Profit Function Framework." Amer. J. of Agr. Econ. 66(1984): 358-367.

Ministry of Agriculture, Forestry, and Fisheries. Survey Report on Farm Household Economy (in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, annual edition.

Ministry of Agriculture, Forestry, and Fisheries. Survey Report on Prices and Wages in Rural Villages (in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, 1983.

Ministry of Agriculture, Forestry, and Fisheries. Social Accounts of Agriculture and Farm Households (in Japanese). Tokyo: Statistical

Bureau of the Ministry of Agriculture, Forestry, and Fisheries, various issues.

Nghiep, L.T. "The Structure and Changes of Technology in Prewar Japanese Agriculture." Amer. J. Agr. Econ. 61(1979): 687-693.

Ray, S.C. "A Translog Cost Function Analysis of U.S. Agriculture, 1939-77." Amer. J. Agr. Econ. 64(1982): 490-498.

Sato, R. Theory of Technical Change and Economic Invariance: An Application to Lie Groups. New York: Academic Press, 1981.

Sato, R. and P.S. Calem. "Lie Group Methods and the Theory of Estimating Total Productivity." Developments in Econometric Analyses of Productivity: Measurement and Modeling Issues, ed. A. Dogramaci. Boston: Kluwer-Nijhoff Publishing, 1983.

Shephard, R.W. Theory of Cost and Production. Princeton: Princeton University Press, 1970.

Shumway, C.R. "Supply, Demand, and Technology in a Multiproduct Industry: Texas Field Crops." Amer. J. Agr. Econ. 65(1983): 748-760.

Törnqvist, L. "The Bank of Finland's Consumption Price Index." Bank of Finland Monthly Bulletin, no.10(1936): 1-8.

Weaver, R.D. "Multiple Input, Multiple Output Production Choices and Technology in the U.S. Wheat Region." Amer. J. Agr. Econ. 65 (1983):45-56.