INSTITUTE OF POLICY AND PLANNING SCIENCES

Discussion Paper Series

No. 905

Effects of Research and Extension Activities on
the Agricultural Production Technology
in Postwar Japan, 1957-1997

by

Yong-Sun Lee and Yoshimi Kuroda

February 2001

UNIVERSITY OF TSUKUBA
Tsukuba, Ibaraki 305-8573
JAPAN

Effects of Research and Extension Activities on the Agricultural Production Technology in Postwar Japan, 1957-1997

Yong-Sun Lee and Yoshimi Kuroda *

Abstract

This paper investigates the magnitude and the Hicksian output and input biases of technological change brought about by investments in public agricultural research and extension activities in Japan. For this objective, it estimates a translog multiproduct cost function for 1957-97. Empirical results show that the cost reduction effects were fairly large. The Hicksian biases were found to be livestock-augmenting, labor- and other-inputs-saving, and machinery- and intermediate-inputs-using. Except for other inputs, the directions of the biases are consistent with the Hicksian induced innovation hypothesis, which supports the public-sector-induced-innovation model proposed by Hayami and Ruttan and Ohtsuka.

Key words: cost reduction effects, output and input biases, public-sector-induced-innovation model, research and extension, translog restricted multiproduct cost function,

Technological change [1] has long been considered as a main source of productivity change. As a major driving force of technological change, research and development (R&D) activities have been emphasized in the literature (e.g., Evenson and Kislev, Romer, and Griliches). Along this line, early studies of productivity analysis in the agricultural sector have paid much attention on estimating the rate of return to agricultural R&D and extension (R&E in short hereafter) activities (e.g., Ruttan, Evenson and Pray, and Ito 1994). Several studies have analyzed the rate and factor biases of technological change where time trend variables are used to represent the state of technology (e.g., Binswanger, Kako 1978, Lee, and Kuroda 1988 and 1989).

Since technological knowledge as an outcome of R&E activities has a public good nature, especially in the agricultural sector, researchers have advocated the role of government or public institutions in investing in R&E. Indeed, the endeavor to enhance the current level of technology has been initiated and conducted substantially by the government or public institutions in many countries, apart from Japan. R&E activities will bring about technological changes, will affect the farmers' production decisions and the income distribution between them, and will furthermore influence the rest of an economy (especially a growing economy). In spite of its importance, there are few studies that analyze explicitly the impacts of R&E activities on the directions of biases and the magnitude of technological change [2].

Kuroda (1988), using time trend as the technology measure, investigates the output bias of technological change between crop and livestock products and explains the rapid drop of the price of livestock products relative to that of crop products in postwar Japan by the livestock-favoring bias of technological change. Huffman and Evenson estimate bias effects of technological change in U.S. crop products by utilizing direct measures of public and private research and extension services instead of a time trend variable. Ito (1992) constructs R&E stock data in Japan by accumulating the expenditures for investment in R&E activities and estimates the effect of R&E stock on the magnitude of technological change. Furthermore, Kuroda (1997) investigates the effects of R&E activities on the extent and directions of the factor input biases of technological change in the Japanese agricultural sector for the period 1960-90 [3].

---

[1] The terms, technological change and technical change, are used interchangeably in this paper.

[2] For the importance of studying technological change biases in the agricultural sector, Lee's summary will be very useful.

[3] Ito(1992) uses a restricted cost function, Huffman and Evenson employ a quadratic profit

1

This study will therefore investigate in detail the impacts of R&E activities *both* on the output bias and on the input bias as well as the magnitude of technological change brought about by these R&E activities in Japanese agriculture for the period 1957-97. In particular, in an attempt to explain the rapid decrease in the relative price between livestock and crop products from the supply side, we calculate the incremental (or marginal) cost elasticity of producing each product to test the Hicksian output bias.

In order to accomplish these objectives, we employ the framework of a restricted translog cost function which consists of two outputs and four-variable inputs and two exogenous variables. The two exogenous variables are land as a fixed input and a stock of knowledge based on R&E investments. The major reason for treating land as a fixed input unlike in Kuroda (1988 and 1997) is that the price of land (rent) during the postwar years was set at a certain low level by the government and therefore not a market price until at least 1975. If one uses such a land price in order to estimate a total cost function, he may suffer from biases in the estimated results since this covers almost a half of the whole samples for the study period.

In addition, to examine whether or not the multiproduct framework is preferable to the single product framework, weak separability of outputs and input nonjointness are tested. Moreover, the multiproduct function approach will enable us to examine the impacts of changes in output composition on the factor biases.

The rest of this paper is organized as follows. Section two presents the analytical framework. Sections three and four explain the data and estimation procedure, respectively. Section five presents empirical results. Finally, section six provides a brief conclusion.

Analytical Framework

Consider the following restricted (or variable) cost function

$$C = G(Q, P, Z) \tag{1}$$

function, Kuroda (1988) uses a multiproduct total cost function, and Kuroda (1997) introduces a single product total cost function.

where Q is a vector of outputs, P denotes a vector of input prices, and Z is a vector of exogenous variables. In this model, Q is disaggregated into crop product (Q_G) and livestock product (Q_A); Z is a vector that consists of a fixed input (land, Z_B) and a stock of technological knowledge (Z_R) which can be regarded as a productivity parameter external to all of the farms; and dummy variables are distinguished for period (D_p), farm sizes (D_s), and a weather condition (D_w).

For econometric analysis the following translog cost function is utilized.

$$
\begin{aligned}
\ln C = {} & \alpha_0 + \sum_{i=1}^{2} \alpha_i \ln Q_i + \sum_{k=1}^{4} \beta_k \ln P_k + \sum_{l=1}^{2} \beta_l \ln Z_l \\
& + \sigma_p D_p + \sum_{s=2}^{4} \sigma_s D_s + \sigma_w D_w \\
& + \frac{1}{2} \sum_{i=1}^{2} \sum_{j=1}^{2} \gamma_{ij} \ln Q_i \ln Q_j + \frac{1}{2} \sum_{k=1}^{4} \sum_{n=1}^{4} \delta_{kn} \ln P_k \ln P_n \\
& + \frac{1}{2} \sum_{l=1}^{2} \sum_{h=1}^{2} \theta_{lh} \ln Z_l \ln Z_h + \sum_{i=1}^{2} \sum_{k=1}^{4} \phi_{ik} \ln Q_i \ln P_k \\
& + \sum_{i=1}^{2} \sum_{l=1}^{2} \mu_{il} \ln Q_i \ln Z_l + \sum_{k=1}^{4} \sum_{l=1}^{2} \nu_{kl} \ln P_k \ln Z_l
\end{aligned} \tag{2}
$$

where i, j are outputs (G, A); k, n denote variable inputs each as labor (L), machinery (M), intermediate inputs (I), and other inputs (O); l, h are for land (B) and stock of technological knowledge (R) ; s denotes farm size dummies $(D_2, D_3,$ and D_4 for 0.5-1.0, 1.0-1.5, and 2.0 hectares and over, respectively); and ln indicates the natural logarithm. Applying the Shephard's lemma to the translog cost function (2), we obtain factor demand functions. Assuming that farm firms take factor prices as given, the following cost share equations are derived:

$$
\begin{aligned}
S_k &= \frac{\partial C}{\partial P_k} \frac{P_k}{C} = \frac{\partial \ln C}{\partial \ln P_k} \\
&= \beta_k + \sum_{n=1}^{4} \delta_{kn} \ln P_n + \sum_{i=1}^{2} \phi_{ik} \ln Q_i + \sum_{l=1}^{2} \nu_{kl} \ln Z_l
\end{aligned} \tag{3}
$$

$$ i = j = G, A $$

$$ k = n = L, M, I, O $$

$$ l = B, R. $$

3

The translog cost function can be used along with the profit-maximizing condition to derive additional equations representing the optimal choice of the endogenous outputs (Q_G and Q_A) (Fuss and Waverman, pp. 288-89).

$$
\begin{aligned}
R_i &= \frac{\partial C}{\partial Q_i}\frac{Q_i}{C} = \frac{\partial \ln C}{\partial \ln Q_i} \\
&= \alpha_i + \sum_{k=1}^{4} \phi_{ik}\ln P_k + \sum_{j=1}^{2} \gamma_{ij}\ln Q_j + \sum_{l=1}^{2} \mu_{il}\ln Z_l
\end{aligned}
\tag{4}
$$

$$i = j = G, A$$

$$k = n = L, M, I, O$$

$$l = B, R.$$

Note here, however, that the prices of both crop and livestock products have been supported by the government in one way or another, so that the prices of these products (P_G and P_A) are not the equilibrium prices in competitive markets. These prices are instead the sums of subsidies and market-clearing prices. Let us call these prices as the "effective prices" of the two products. Thus, we are assuming here that the farm-firm maximizes profits by equating the marginal revenue of each product, i.e., the effective price, to its marginal cost.

Introduction of the revenue share (R_i) equations into the estimation of the system of equations will in general lead to a more efficient estimation of the coefficients of, in particular, the output-associated variables due to the additional information provided by the revenue shares [4].

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (1) this requires that $\sum_{k=1}^{4}\beta_k = 1$, $\sum_{n=1}^{4}\delta_{kn} = 0$, $\sum_{k=1}^{4}\phi_{ik} = 0$, and $\sum_{l=1}^{2}\nu_{kl} = 0$ ($i = G, A; k = n = L, M, I, O; l = B, R$). The translog cost function (2) has a general form in the sense that the restrictions of input-output separability and neutrality with respect to Z_R are not imposed a priori. Instead, these restrictions will be statistically tested in the process of estimation of this function.

Cost Reduction Effect

---

[4]For a detailed discussion on the inclusion of the revenue share equations in the system of regression equations, see Ray and Capalbo.

Based on the estimated results of the restricted translog cost function, we can estimate the magnitude of technological progress due to an increase in the stock of technological knowledge, Z_R. Modifying slightly the procedure developed by Caves, Christensen, and Swanson (CCS) [5], we will estimate three indicators of technological progress in terms of elasticities. They are (1) the elasticity of variable cost with respect to Z_R (CRE), (2) the elasticity of inputs-saving technological progress with respect to Z_R with outputs held fixed (PGX), and (3) the elasticity of outputs-augmenting technological progress with respect to Z_R with inputs held fixed (PGY). According to CCS, $PGY = RTS \cdot PGX$ where RTS denotes returns to scale.

First, using the parameters of the variable translog cost function (2), the CRE is given by

$$
\begin{aligned}
CRE &= -\frac{\partial \ln C}{\partial \ln Z_R} = -\varepsilon_{CR} \\
&= -(\beta_R + \sum_{k=1}^{4} \nu_{kR} \ln P_k + \sum_{i=1}^{2} \mu_{iR} \ln Q_i + \sum_{h=1}^{2} \theta_{hR} \ln Z_h)
\end{aligned}
\tag{5}
$$

Second, the PGX is given by

$$
PGX = -\frac{\partial \ln C / \partial \ln Z_R}{1 - \partial \ln C / \partial \ln Z_B} = -\frac{\varepsilon_{CR}}{1 - \varepsilon_{CZB}}
\tag{6}
$$

where

$$
\begin{aligned}
\varepsilon_{CZB} &= \frac{\partial \ln C}{\partial \ln Z_B} \\
&= \beta_B + \sum_{k=1}^{4} \nu_{kB} \ln P_k + \sum_{i=1}^{2} \mu_{iB} \ln Q_i + \sum_{h=1}^{2} \theta_{BR} \ln Z_h
\end{aligned}
\tag{7}
$$

Finally, the PGY is given by

$$
PGY = -\frac{\partial \ln C / \partial \ln Z_R}{\sum_{i=1}^{2} \partial \ln C / \partial \ln Q_i} = -\frac{\varepsilon_{CR}}{\sum_{i=1}^{2} \varepsilon_{CQ_i}} = RTS \cdot PGX
\tag{8}
$$

where

$$
\varepsilon_{CQ_i} = \frac{\partial \ln C}{\partial \ln Q_i}
$$

---

[5]Ohta develops in much more comprehensive manner rates and biases of technological progress and returns to scale in the multi-product multi-input production.

$$= \alpha_i + \sum_{k=1}^{4} \phi_{ik} \ln P_k + \sum_{j=1}^{2} \gamma_{ij} \ln Q_j + \sum_{l=1}^{2} \mu_{il} \ln Z_l \qquad (9)$$

and

$$RTS = \frac{1 - \partial \ln C / \partial \ln Z_B}{\sum_{i=1}^{2} \partial \ln C / \partial \ln Q_i} = \frac{1 - \varepsilon_{CZB}}{\sum_{i=1}^{2} \varepsilon_{CQ_i}} \qquad (10)$$

which is defined as the cost-output elasticity (equivalent to the revenue share). As defined earlier, $i = j = G, A$, $k = n = L, M, I, O$, and $h = l = B, R$, in equations (5) through (10).

Bias Effects

In a multi-product and multi-input context, technological change can affect factor utilization and/or output composition differently. The neutrality of technological change can be defined in two ways along the lines of the Hicksian definition. One is the case of unchanging expansion path in the input space and the other is the case of unchanging expansion path in the output space.

Following Antle and Capalbo, we define the output and input biases.

Output Bias

In a two-output case, a measure of output bias is defined by

$$
\begin{aligned}
B_{GA}^{Q} &= \partial \ln(\frac{\partial C}{\partial Q_G} / \frac{\partial C}{\partial Q_A}) / \partial \ln Z_R \\
&= \partial \ln(\frac{\partial C}{\partial Q_G}) / \partial \ln Z_R - \partial \ln(\frac{\partial C}{\partial Q_A}) / \partial \ln Z_R \\
&= \frac{\partial \ln MC_G}{\partial \ln Z_R} - \frac{\partial \ln MC_A}{\partial \ln Z_R} \qquad (11)
\end{aligned}
$$

B_{GA}^{Q} measures the rotation of the production possibility frontier, at a given point in the output space, due to technological change. Therefore, technological change in the output space is defined as toward livestock products (toward crop products), or livestock-products augmenting or favoring (crop-products augmenting or favoring), if B_{GA}^{Q} is positive (negative) and neutral if B_{GA}^{Q} is zero.

In order to derive the elasticity of marginal cost of each output with respect to R&E stock, we take the following steps.

First, the cost-output elasticity ε_{CQ_i} represents incremental or marginal cost of each output in percentage terms. Noting that

$$\varepsilon_{CQ_i} = \frac{\partial \ln C}{\partial \ln Q_i} = (\frac{\partial C}{\partial Q_i})/(\frac{C}{Q_i}) = MC_i/(\frac{C}{Q_i})$$

we differentiate the logarithm of ε_{CQ_i} with respect to the log of R stock, holding outputs and factor prices constant. That is,

$$\frac{\partial \ln \varepsilon_{CQ_i}}{\partial \ln Z_R} = \frac{\partial \ln(MC_i/(\frac{C}{Q_i}))}{\partial \ln Z_R} = \frac{\partial \ln MC_i}{\partial \ln Z_R} - \frac{\partial \ln(\frac{C}{Q_i})}{\partial \ln Z_R}$$

Combining the above relation with

$$\frac{\partial \ln \varepsilon_{CQ_i}}{\partial \ln Z_R} = \frac{\mu_{iR}}{\varepsilon_{CQ_i}}$$

from equation (9) yields

$$\frac{\partial \ln MC_i}{\partial \ln Z_R} = \frac{\mu_{iR}}{\varepsilon_{CQ_i}} + \frac{\partial \ln(\frac{C}{Q_i})}{\partial \ln Z_R} \tag{12}$$

Thus, equation (11) can be rewritten as

$$B_{GA}^Q = \frac{\partial \ln MC_G}{\partial \ln Z_R} - \frac{\partial \ln MC_A}{\partial \ln Z_R} = \frac{\mu_{GR}}{\varepsilon_{CQ_G}} - \frac{\mu_{AR}}{\varepsilon_{CQ_A}} \tag{13}$$

Note here that $\partial \ln Q_i/\partial \ln Z_R = 0$, since both Q_i and Z_R are treated as exogenous variables in the cost function (1).

As mentioned earlier, technological change in the output space is defined as livestock-products augmenting (or favoring) if B_{GA}^Q is positive, crop-products augmenting (favoring) if B_{GA}^Q is negative, and neutral if B_{GA}^Q is zero.

Input Biases

Binswanger proposed a single relative measure of bias in factor inputs using changes in cost shares of factors of production. Antle and Capalbo extend Binswanger's definition of the bias measure to nonhomothetic and input-output nonseparable production technologies. According to their definition, the dual measure of input bias (B_k) contains two distinct effects: a scale effect owing to the movement

7

along the nonlinear expansion path $(B^s_{k_i})$, and a (pure) bias effect owing to the shift in the expansion path (B^e_k). If the technology is homothetic, the scale effect is zero. In the multiproduct case, a measure of (pure) bias effect, i.e., a measure of the shift in the expansion path, can be defined as

$$
\begin{aligned}
B^e_k &= \partial \ln S_k(Q,P,Z)/\partial \ln Z_R \Big|_{dC=0} \\
&= B_k - \left[\sum_{i=1}^{2}\big(\partial \ln S_k/\partial \ln Q_i\big)\big(\partial \ln C/\partial \ln Q_i\big)^{-1}\right]\left(\frac{\partial \ln C}{\partial \ln Z_R}\right) \qquad (14)
\end{aligned}
$$

where $B_k \equiv \partial \ln S_k(Q,P,Z)/\partial \ln Z_R$ $(k = L,M,I,O)$ which is the pure bias effect. The second term of equation is the scale effect.

If $B^e_k > 0$ (< 0), then technological change caused by changes in the R&E stock is said to be biased toward using (saving) the k-th factor. If $B^e_k = 0$, then technological change is said to be i-th factor neutral. Based on the estimated results of the B^e_k and the movements of the relative factor prices, one can examine whether or not the direction of the measured factor biases is consistent with the Hicksian induced innovation hypothesis.

Using the parameters of the translog cost function in the present study, equation (14) can be expressed as

$$
\begin{aligned}
B^e_k &= \frac{\nu_{k_R}}{S_k} + \left(\frac{\phi_{k_G}}{S_k} + \frac{\phi_{k_A}}{S_k}\right)\lambda \\
&= B_k + B^s_{k_G} + B^s_{k_A} \qquad (15)
\end{aligned}
$$

where

$$
\lambda = -\frac{\partial \ln C/\partial \ln Z_R}{\sum_{i=1}^{2} \partial \ln C/\partial \ln Q_i} = \frac{-\varepsilon_{CR}}{\sum_{i=1}^{2} \varepsilon_{CQ_i}} \qquad (16)
$$

Tests for the Structure of Production

This section deals with important concepts for representing the structure of production, namely, no technological change due to a change in R&E investments, weak separability of outputs, and input nonjointness.

No Technological Change

8

Since the major objective of the present study is to investigate the magnitude and biases of technological change due to an increase in R&E investments, it is critical to test the null hypothesis whether or not R&E activities result in technological change in agricultural production. For this purpose, we set up the following null hypothesis of no technological change due to a change in the stock of technological knowledge Z_R, using the parameters of the translog cost function given in (2).

$$H_0 : \beta_R = \sum_{l=1}^{2} \theta_{lR} = \sum_{i=1}^{2} \mu_{iR} = \sum_{k=1}^{4} \nu_{kR} = 0 \qquad (17)$$

$$i = G, A, \quad k = L, M, I, O, \quad l = B, R$$

Weak Separability of Outputs

According to Hall, a technology is weakly separable in outputs if and only if the cost function can be written as

$$C(Q, P, Z) = G(h(Q), P, Z)$$

For our study, the separable restricted cost function is approximated by a Taylor series expansion of

$$\ln C(Q, P, Z) = \ln G(h(\ln Q), \ln P, \ln Z)$$

around the point $Q_i = 1$, $P_k = 1$ for all $i = G, A$, $k = L, M, I, O$. Then the approximate cost function can be shown to have the following relationship

$$\frac{\partial^2 \ln C}{\partial \ln P_k \partial \ln Q_G} \cdot \frac{\partial \ln C}{\partial \ln Q_A} = \frac{\partial^2 \ln C}{\partial \ln P_k \partial \ln Q_A} \cdot \frac{\partial \ln C}{\partial \ln Q_G}$$

for all $k = L, M, I, O$.

In our translog form, in particular, weak separability requires that the parameters of the translog approximation satisfy the condition

$$\phi_{kG}\alpha_A = \phi_{kA}\alpha_G \qquad (18)$$

simultaneously for all $k = L, M, I, O$.

Input Nonjointness

A technology is nonjoint in inputs (or nonjoint in production) if and only if the cost function can be written as

$$C(Q, P, Z) = \sum_i G^i(Q_i, P, Z)$$

that is, the joint cost function can be represented as the sum of independent cost function for each output. Then the approximate translog cost function becomes

$$\ln C(Q, P, Z) = \ln \sum_i G^i(\ln Q_i, \ln P, \ln Z)$$

Since the input nonjointness requires that the marginal cost of one output be independent of the level of the other output, the hypothesis of nonjointness may be examined by testing whether the following relation

$$\gamma_{GA} = -\alpha_G \alpha_A \tag{19}$$

holds or not.

The Data and Estimation Procedure

The data required for the estimation of the variable cost function model consist of the variable cost (C), the revenue shares $(R_G$ and $R_A)$ and quantities of crop and livestock production $(Q_G$ and $Q_A)$, the prices and quantities of the four variable factors of production, labor $(P_L$ and $X_L)$, machinery $(P_M$ and $X_M)$, intermediate inputs $(P_I$ and $X_I)$, and other inputs $(P_O$ and $X_O)$, and the quantities of land (Z_B) and R&E stock (Z_R) as fixed and exogenous inputs. In addition, dummy variables for period, farm sizes, and weather are introduced. The details of the sources of data and the variable definitions are described in Appendix B.

For statistical estimation, since the quantities of outputs $(Q_G$ and $Q_A)$ on the right hand side of the restricted cost function (2) are in general endogenously determined, a simultaneous procedure should be employed for the estimation of the set of equations. This set of equations consist of the restricted translog cost function (2), three of the cost share equations (3) [6] , and two revenue share equations (4).

---

[6]Due to the linear-homogeneity-in-prices property of the cost function, one cost share equation

10

Note here that the estimation model is complete in a sense that it has as many (six) equations as endogenous variables (six). Therefore, the full information likelihood (FIML) method is selected. In this process, the restrictions due to symmetry and linear homogeneity in prices are imposed. The coefficients of the omitted (in our case, other inputs) cost share equation can easily be obtained after the system is estimated using the imposed linear homogeneity restrictions.

Empirical Results

The estimated parameters of the system and the associated asymptotic t-values are reported in Table 1. Goodness-of-fit statistics are given in Table 2.

First, production structure is tested in order to examine whether our model specification is valid or not. The test statistics for hypotheses on the production structure are given in Table 3. First of all, the test for no technological change due to a change in the stock of technological knowledge Z_R is strongly rejected both at the 1 % and at the 5 % levels of statistical significance. This implies that agricultural production is influenced by changes in R&E activities.

Second, the test for weak separability of outputs is rejected both at the 1 % and at the 5 % levels of statistical significance. This result implies that there could not exist a consistent aggregation of crop products and livestock products so as to make a single index of aggregate output.

Third, the null hypothesis of nonjointness in inputs is rejected both at the 1 % and at the 5 % significance levels. The result indicates that there does not exist input nonjointness, implying that a separate production function does not exist for each output.

In addition, based on the parameter estimates in Table 1, the monotonicity and concavity conditions are checked at each observation. Since all the estimated cost shares for both outputs and inputs are positive, the production technology satisfies the monotonicity condition. The concavity condition with respect to factor prices is satisfied at each observation [7]. Thus, we may say that the estimated cost function represents a second order approximation to the *true* data generating cost function

---

can be omitted from the simultaneous equation system for the statistical estimation. In this study the other inputs share equation is omitted.

[7] All the eigenvalues of the Hessian matrix were negative.

which satisfies the curvature conditions. The estimated parameters given in Table 1 are utilized for further analysis.

Second, Table 4 summarizes the indicators of cost reduction effects due to an increase in the stock of technological knowledge Z_R. They are the cost elasticity with respect to Z_R (CRE), the elasticity of the inputs-saving effect (PGX) with outputs held constant, the elasticity of the outputs-augmenting effect (PGY) with inputs held constant, and returns to scale (RTS). The estimates of CRE and PGX demonstrate that the larger the farm size is, the greater the effects of cost reduction: CRE ranges from 0.306 to 0.350 and PGX from 0.150 to 0.196. On the other hand, the estimates of PGY show that the smaller the farm size is, the greater the effect of cost reduction: it ranges from 0.299 to 0.267. This is because the smaller the farm size is, the larger the returns to scale [8]. Accordingly, we could not conclude which sizes of farms have enjoyed more rapid technological progress due to increases in the stock of technological knowledge through investments in R&E activities. However, we may at least say that investments in R&E activities carried out by the government or public institutions have enhanced the productivity of farms in all size classes to some considerable degree.

Third, Table 5 presents the estimates of the elasticity of marginal cost of each output with respect to the stock of technological knowledge Z_R and the Hicksian output bias of technological change attributed to an increase in Z_R. As in Table 4, they are presented in the form of averages for each farm size class. According to the table, the output bias effects, $B_{GA}^Q = MCGR - MCAR$, are positive in all size classes. This indicates that technological change in the output space is livestock-products augmenting in all farm size classes.

This result supports the hypothesis suggested by Kuroda (1988) that the rapid decrease in relative price of livestock products is due partly to the bias of technological change which has favored livestock production. Furthermore, this result appears to have been consistent with the agricultural production policies carried out by the MAFF which put stronger stresses on expansions of and improvements in livestock production than crop production during the study period, 1957-97 [9]. Finally, Ta-

---

[8]Kako (1979) and Chino obtained similar results to our finding. By estimating non-homothetic translog cost functions, they reported that smaller size farms enjoyed greater economies of scale than larger size farms in Japanese rice production for the 1960s and 1970s.

[9]Refer to *Nogyo Hakusho* (*Agricultural White Book*). It reports annually the directions for and promotions of R&D activities in agriculture which correspond to important policy issues to be executed by the MAFF.

ble 6 reports the Hicksian bias measures of factor inputs and their decompositions into each contributor. The results demonstrate that R&E activities during the study period had bias effects against labor and other inputs, and toward machinery and intermediate inputs. As seen in Table 6, large part of these Hicksian biases is explained by shifts in the expansion path.

The scale effect due to crop production indicates a fairly strong bias toward machinery, a strong bias against intermediate inputs, and a fairly strong bias against other inputs. The intermediate-inputs-saving effect has been consistent with the recent trend of reducing the usage of chemical fertilizers and agrichemicals in crop production. The scale effect due to livestock production exhibits fairly strong biases against labor and other inputs, and a very strong bias toward intermediate inputs (including feed as an important item).

These results, except for the case of other inputs, agree with Kuroda's (1988) findings where the time trend variable instead of the stock of technological knowledge was used to represent the state of production technology. That is, the directions of the biases of factor inputs, in particular, labor, machinery, and intermediate inputs, are against the movements of the relative factor prices, indicating the existence of induced innovations in factor usages. This in turn implies that the public sector R&D and extension institutions as suppliers of technological knowledge and new factor inputs do respond to new economic opportunities and incentives in postwar Japan. Accordingly, this finding supports the public-sector-induced-innovation model proposed by Hayami and Ruttan (Ch. 4, pp. 73-116) and Ohtsuka.

Conclusion

This study has investigated explicitly the rate and the directions of output and input biases of technological change which is considered to have been caused by public research and extension activities in Japanese agriculture. A restricted translog cost function with multiple outputs was specified and estimated for the period 1957-97. Public R&E stock data and aggregate data from four size classes of farm households for all Japan excluding Hokkaido district were utilized in the estimation procedure.

The major findings of the study are as follows. First, the rejection of both hypotheses of weak separability of outputs and input nonjointness implies that the multiproduct function approach is preferable when it comes to analyzing the agri-

13

cultural technology of postwar Japan.

Second, public R&E activities have caused reductions in the variable costs in all size classes. In other words, not only larger scale but also smaller scale farms have enjoyed a considerable extent of technological progress due to increases in investments in R&E activities.

Third, public R&E activities have brought about output bias toward livestock production in all farm size classes during the 1957-97 period. The degree of the livestock-production augmenting bias was greater for larger scale farms than smaller scale farms. This finding is consistent with the rapid growth in livestock production based on larger scale managements for the study period.

Finally, public R&E activities have had a considerable influence on the decision of allocating Japanese farm factor resources. Such activities have caused bias effects against labor and other inputs, but toward machinery and intermediate inputs. The directions of the biases in factor inputs have been consistent with the induced innovation hypothesis.

We may conclude from these findings that the public sector has behaved so as to respond to economic opportunities and incentives in postwar Japanese agriculture. This finding supports the public-sector-induced-innovation model proposed by Hayami and Ruttan and Ohtsuka. This implies that the growth and development of Japanese agriculture will have to be carried out by effective interactions among farmers and public research institutions.

One important caveat of this study is that we have not included research activities executed by agricultural colleges and private agricultural supply firms of seeds and infant trees, machinery, agri-chemicals, and fertilizers. Our results therefore may have over-estimated the effects of public R&E investments. This caveat should therefore be taken into consideration in the future research in order to shed more insights on the effects of R&E activities in public experiment and extension institutions.

Appendix A: Tables for Empirical Results

Table 1: Parameter Estimates of the Translog Cost Function for the Japanese Agricultural Sector, 1957-97

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	-0.449	-1.3	δ_{MO}	0.097	6.3
α_G	0.912	84.6	δ_{IO}	-0.078	-7.5
α_A	0.214	52.8	θ_{BB}	-0.028	-0.1
β_L	0.507	94.6	θ_{BR}	0.042	3.2
β_M	0.166	43.8	θ_{RR}	0.546	3.2
β_I	0.233	86.6	ϕ_{GL}	0.000	0.0
β_O	0.094	89.0	ϕ_{GM}	0.054	2.1
β_B	-0.871	-2.3	ϕ_{GI}	-0.032	-1.5
β_R	-0.330	-8.3	ϕ_{GO}	-0.022	-2.3
σ_P	-0.152	-3.0	ϕ_{AL}	-0.068	-6.4
σ_2	0.358	2.2	ϕ_{AM}	-0.010	-1.2
σ_3	0.548	2.2	ϕ_{AI}	0.057	8.9
σ_4	0.732	2.2	ϕ_{AO}	0.021	6.1
σ_w	-0.009	-1.0	μ_{GB}	0.220	2.9
γ_{GG}	0.132	1.7	μ_{GR}	-0.050	-1.4
γ_{GA}	-0.162	-7.7	μ_{AB}	0.033	1.6
γ_{AA}	0.176	21.8	μ_{AR}	-0.031	-2.4
δ_{LL}	0.050	1.9	ν_{LB}	0.020	0.6
δ_{MM}	0.019	0.6	ν_{MB}	-0.033	-1.2
δ_{II}	0.114	6.1	ν_{IB}	0.005	0.2
δ_{OO}	0.002	0.2	ν_{OB}	0.008	0.8
δ_{LM}	-0.055	-3.0	ν_{LR}	-0.067	-2.4
δ_{LI}	0.026	2.1	ν_{MR}	0.042	3.3
δ_{LO}	-0.021	-2.8	ν_{IR}	0.004	0.3
δ_{MI}	-0.062	-3.0	ν_{OR}	-0.002	-0.3

Note: The symmetry and homogeneity-of-degree-one-in-input-prices restrictions are imposed in the estimation.

16

Table 2: Goodness-of-fit Measures

Estimating Equations	R-squared	S.E.R.
Cost function	0.978	0.062
Labor share equation	0.764	0.028
Machinery share equation	0.693	0.021
Intermediate inputs share equation	0.687	0.015
Crop revenue share equation	0.829	0.061
Livestock revenue share equation	0.890	0.021

Note: S.E.R. denotes standard error of regression.

Table 3: Tests of the Production Structure

Hypothesis	Wald Test Statistic	Degrees of Freedom	Critical Value	
			0.05	0.01
No technological change	87.54	8	15.51	20.09
Weak Separability	96.21	3	7.81	11.34
Input Nonjointness	16.86	1	3.84	6.63

Table 4: Three Elasticities of Cost Reduction and Economies of Scale

Farm Size	CRE	PGX	PGY	RTS
I	0.306	0.150	0.299	2.099
	(0.243)	(0.117)	(0.227)	(0.133)
II	0.327	0.170	0.289	1.754
	(0.239)	(0.122)	(0.200)	(0.084)
III	0.336	0.180	0.278	1.573
	(0.231)	(0.120)	(0.181)	(0.051)
IV	0.350	0.196	0.267	1.351
	(0.218)	(0.115)	(0.159)	(0.025)
Average	0.330	0.174	0.283	1.694
	(0.231)	(0.119)	(0.192)	(0.287)

Notes:

1. I(0.5-1.0), II(1.0-1.5), III(1.5-2.0), and IV(2.0-hectares).

2. In order to express the three indicators of cost reduction effects in positive terms, they are all multiplied by minus one. That is, $CRE = (-1) \cdot (-\varepsilon_{CR})$; $PGX = (-1) \cdot (-\varepsilon_{CR})/(1 - \varepsilon_{CZB})$; $PGY = (-1) \cdot (-\varepsilon_{CR})/(1 - \sum_{i=1}^{2} \varepsilon_{CQ_i})$; and $RTS = (1 - \varepsilon_{CZB})/(\sum_{i=1}^{2} \varepsilon_{CQ_i})$.

3. Figures in parentheses are standard deviations.

Table 5: The Output Bias Measure

Farm Size	MCGR	MCAR	B_{GA}^{Q}
I	-0.065	-0.164	0.099
	(0.004)	(0.031)	(0.032)
II	-0.057	-0.161	0.104
	(0.004)	(0.046)	(0.047)
III	-0.052	-0.161	0.109
	(0.004)	(0.040)	(0.042)
IV	-0.048	-0.164	0.115
	(0.005)	(0.144)	(0.148)
Average	-0.056	-0.163	0.107
	(0.007)	(0.080)	(0.083)

Notes:
1. I(0.5-1.0), II(1.0-1.5), III(1.5-2.0), and IV(2.0-hectares).
2. $MCGR = \partial \ln MC_G / \partial \ln Z_R$, $MCAR = \partial \ln MC_A / \partial \ln Z_R$, and $B_{GA}^{Q} = MCGR - MCAR$.
3. Figures in parentheses are standard deviations.

Table 6: Factor Biases and Their Decompositions: Averages for the 1957-97 Period

Input	B_i	B_{iG}^s	B_{iA}^s	B_i^e
Labor	-0.133	-0.000	-0.037	-0.170
	(78.2)	(0.0)	(21.8)	(100.0)
Machinery	0.386	0.106	-0.020	0.472
	(81.8)	(22.5)	(-4.2)	(100.0)
Intermediate	0.015	-0.039	0.069	0.045
inputs	(33.3)	(-86.7)	(153.3)	(100.0)
Other inputs	-0.442	-0.070	0.069	-0.443
	(99.8)	(15.8)	(-15.6)	(100.0)

Notes: B_i is the total cost share change due to technical change; B_{iG}^s and B_{iA}^s are scale effects, and $B_i^e (= B_i + B_{iG}^s + B_{iA}^s)$ is the Hicksian factor input bias. Figures in parentheses indicate percentage contributions.

Appendix B: Variable Definitions

The major sources of data used to process these variables are the *Noka Keizai Chosa Hokoku* (*Survey Report on Farm Household Economy*) (FHE) and the *Noson Bukka Chingin Chosa hokoku* (*Survey Report on Prices and Wages in Rural Villages*) (PWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries (MAFF).

In each year of the 1957-97 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 (ha in short) or over, from all Japan excluding Hokkaido district because of the different size classification. Thus, the sample size is $41 \times 4 = 164$. Unfortunately, we could not directly obtain the data for the average farm in the smallest size class, 0.5 ha or less, because of changes in the size classification during the sample period. It should be noted that exclusion of farms in this size class may cause some bias in the estimated parameters since the share of the number of farms of this size class in the total number of farms has been fairly high.

The Törnqvist (1936) indexes of the quantity and price indexes of crop products (Q_G and P_G) were computed by the Caves-Christensen-Diewert's(CCD) (1982) multilateral index method. The CCD method is most relevant for the estimation of the Törnqvist index for a pooled cross-section of time-series data set. In the following paragraphs, wherever possible all indexes were obtained based on this method.

For the quantity and price indexes of crop products (Q_G and Q_A), ten categories of crop products were distinguished with price indexes for these categories taken from the FHE and 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 PWRV. It is noted here that the base year for the price indexes is 1985.

The quantity of labor (X_L) was the total number of male-equivalent labor hours of operator, family, and hired workers. The male-equivalent labor hours of female workers was estimated by multiplying the number of female labor hours by the ratio of female daily wage rate to the 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 obtained 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 1985 values and expressed in index terms.

The quantity and price indexes of machinery (X_M and P_M), intermediate inputs (X_I and P_I), and other inputs (X_O and P_O) were also constructed by the CCD method. The cost of machinery ($P_M X_M$) was defined as the sum of the expenditures on machinery, energy, and rentals; the cost of intermediate inputs ($P_I X_I$) is the sum of the expenditures on fertilizer, feed, agrichemicals, materials, clothes, and others; and the cost of other inputs ($P_O X_O$) is the sum of the expenditures on animals, plants, and farm buildings and structures.

The variable cost (C) was defined as the sum of the expenditures on these four categories of factor inputs, i.e., $C = \sum_{i=1}^{4} P_i X_i (i = L, M, I, O)$. The cost share ($S_i$) was obtained by dividing the expenditure on each category of factor inputs ($P_i X_i$) by the variable cost (C).

The period dummy (D_p) is defined as 1 for 1957-74, i.e., before the "oil crisis", and 0 for 1975-97, i.e., after the "oil crisis". The size dummies (D_s) are for size II (1.0-1.5), III(1.5-2.0), and IV(2.0 hectares or over). Weather dummy (D_w) is defined as 1 for bad harvest years and 0 for normal harvest years. The data was obtained from MAFF *Sakumotsu Tokei* (*Crop Statistics*).

The quantities of land (Z_B) and the stock of technological knowledge (Z_R) were obtained as follows.

The quantity of land (Z_B) was defined as the total area of arable land. This was divided by the 1985 value to express it in index term.

This study estimated the stock of technological knowledge (Z_R) by the perpetual inventory method. The data used for this estimation was public research and extension expenditures. The source of data is the *Norinsuisan Kankei Shiken Kenkyu Yoran* (*Abstract Yearbook of Experiment and Research on Agriculture, Forestry, and Fisheries*)(AYER) published annually by the MAFF. The basic procedures are basically the same as Ito (1992).

It is assumed that the stock of technological knowledge is determined by the annual investments on research activities and appropriate weights. The weights are determined by the lag structure and the speed (or rate) of obsolescence of the stock of technological knowledge.

The *Norinsuisan Shiken-Kenkyu Nenpo* (*Yearbook of Research and Experiments of Agriculture, Forestry, and Fisheries*) by MAFF reports researches on agriculture,

forestry, and fisheries in Japan by various national research institutions. It documents the beginning year, the ending year, and the number of years (i.e., the research period) of each research topic. Ito regarded this research period as the development lag of each research topic, and obtained the number of research topics for each development lag for 1967, 1977, and 1987. He then computed the weighted average year of research lag period with the numbers of research topics as weights for each of these three years and obtained roughly 6 years for these three years. As for the rate of obsolescence of the stock of technological knowledge, we assumed 10 % per year following Goto et al.

The stock of technological knowledge was estimated by the perpetual inventory method as follows. Suppose that R_t is the stock of technological knowledge at the end of year t. Then, the following equation can be obtained.

$$R_t = G_{t-6} + (1 - \delta_R)R_{t-1} \qquad (A.1)$$

where δ_R is the rate of obsolescence of the stock of technological knowledge and G_t is the research expenditure (investment) in year t which is added to the stock of technological knowledge with a 6-year lag. Assume at this point that the annual rate of change in this stock is g. Then, (A.1) can be written as

$$R_t = G_{t-6} + (1 - \delta_R)R_{t-1} = (1 + g)R_{t-1}$$

Thus, the stock at the bench mark year (in this study 1957) R_s can be expressed as

$$R_s = G_{s-5}/(\delta_R + g) \qquad (A.2)$$

Note that one cannot obtain the value of g before obtaining the stock of technological knowledge. We approximated this rate by 10 % of investment in research for the 1955-59 period when the stock of technological knowledge was still small. Using (A.1) and (A.2), we estimated the stock of technological knowledge for the period 1957-97.

Next, Ito (1992) did not introduce any lag structure for extension activities. That is, he added the flow amount of expenditures on extension activities to the stock of technological knowledge each year.

However, it appears to be more realistic to assume a certain lag structure for the case of extension activities, since it often takes several years for a new technology to be adopted and materialized in real agricultural production. This study assumes 5 years as the maximum for extension activities for a particular innovation. This assumption is based on personal discussions with extension people. Using a procedure similar to that used for the stock of technological knowledge, i.e. the benchmark year method, the capital stock of extension activities was estimated for a 5-year lag. In this case, 10% was assumed for the rate of growth of the capital stocks based on the growth rate of extension expenditures (investment) for the 1955-59 period which was very close to 10%. However, since there is no reliable information for the rate of obsolescence of the capital stock of extension activities, this study assumes simply 10% as in the case of the stock of technological knowledge.

This study, like Ito (1992), assumes that the two different stocks of technological knowledge based on R&E and extension activities together yield the stock of technological knowledge which is materialized on actual farms. Thus, the two capital stocks were added together for each year for the period 1957-97.

For a sensitivity analysis, this study assumes 5, 10, and 15 percent for the rate of obsolescence both for the stock of technological knowledge and for the capital stock of extension investments; 5, 6, 7, 8, 9, 10, and 11 years for research development lag; and 3, 4, and 5 years for extension lag. Thus, there are altogether $(3 \times 7) \times (3 \times 3) = 189$ different combinations. These 189 combinations of the R&E capital stocks were used for the sensitivity analysis based on the estimating equation system composed of Equations (2), (3), and (4).

As a result, the combination of 15% for the rate of obsolescence both for the stock of technological knowledge and for the capital stock of extension investments, a 7-year lag of research development, and a 3-year lag for extension activities gave the best results in terms of the R^2s and the asymptotic t-statistics of the coefficients as well as monotonicity and concavity conditions. Thus, this option was used for the variable Z_R in the present study [10].

---

[10]We also obtained the stock-of-technological-knowledge variables that are weighted sums of deflated past research and extension expenditures, G_{t-i} and H_{t-i}, respectively, given by

$$R_t = \sum_{i=1}^{m} w_{t-i} G_{t-i}$$

and

References

Antle, J.M. and S.M.Capalbo. "An Introduction to Recent Development in Production Theory and Productivity Measurement," *Agricultural Productivity: Measurement and Explanation*, ed. S.M.Capalbo and J.M.Antle. Washington, D.C.: Resources for the Future, Inc., 1988.

Binswanger, H.P. "The Measurement of Technical Change Biases with Many Factors of Production." *Amer. J. Agr. Econ.* 64 (1974):964-76.

Capalbo, S.M. "A Comparison of Econometric Models of U.S. Agricultural Productivity and Aggregate Technology," *Agricultural Productivity: Measurement and Explanation*, ed. S.M.Capalbo and J.M.Antle. Washington, D.C.: Resources for the Future, Inc., 1988.

Capalbo, S. M. and J. M. Antle. *Agricultural Productivity: Measurement and Explanation.* Washington, D.C.: Resources for the Future, 1988.

Caves, D.W., L.R. Christensen, and W.E. Diewert. "Multilateral Comparison of Output, Input, and Productivity Using Superlative Index Numbers," *Economic Journal* 92 (1982):73-86.

Caves, D.W., L.R. Christensen, and J.A. Swanson. "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74," *Amer. Econ. Rev.* 71 (1981): 994-1002.

Chino, J. "Inasaku Seisan Kozo no Keiryo Keizai Bunseki [An Econometric Analysis of the Structure of Rice Production]," *Special Bulletin* No. 42. College of Agriculture, Utsunomiya University, Utsunomiya, Japan, 1984.

Denny, M., M. Fuss, C. Everson, and L. Waverman. "Estimating the Effects of Diffusion of Technological Innovations in Telecommunications: The Production Structure of Bell Canada," *Canadian J. of Econ.* 14 (1981): 24-43.

$$E_t = \sum_{j=1}^{n} w_{t-j} H_{t-j}$$

where weights are normalized to sum to one as, for example, for $m = 7$, $w_{t-1} = w_{t-7} = 0.05$, $w_{t-2} = w_{t-6} = 0.1$, $w_{t-3} = w_{t-5} = 0.2$, and $w_{t-4} = 0.3$. For a sensitivity analysis, we assumed again 5, 6, 7, 8, 9, 10, and 11 years for research lag years and 3, 4, and 5 years for extension lag years as in the case of the benchmark year method. Thus, we tried $6 \times 3 = 18$ different combinations of the stocks of technological knowledge for the sensitivity analysis of the estimation of the system of the variable translog cost function and the factor share and revenue share equations. However, for none of them the concavity condition with respect to the stock of technological knowledge was satisfied.

Evenson, R.E. and C.E. Pray. *Research and Productivity in Asian Agriculture.* Ithaca and London: Cornell University Press, 1991.

Evenson, R.E. and Y. Kislev. *Agricultural Research and Productivity*, New Haven and London: Yale University Press, 1975.

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

Goto, A., N. Honjo, K. Suzuki, and S. Takino. "Kenkyu-Kaihatsu to Gijutsu-Shinpo no Keizai-Bunseki[An Economic Analysis of Research and Development and Technological Progress]". *Keizai Bunseki[Economic Analysis]*, No. 103. Tokyo: Keizai Kikakucho Keizai Kenkyu-sho [Institute of Economic Studies, the Bureau of Economic Planning], 1986.

Griliches, Z. "Productivity, R&D, and the Data Constraint," *Amer. Econ. Rev.* 84 (1994): 1-23.

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

Hayami, Y. and V. W. Ruttan. *Agricultural Development: An International Perspective*, Baltimore and London: The Johns Hopkins University Press, 1985.

Hicks, J. R. *The Theory of Wages.* London: Macmillan, 1932.

Huffman, W. E. and R. E. Evenson. "Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other Policies," *Amer. J. Agr. Econ.*, 71(1989): 761-773.

Ito, J. "Nogyo Kenkyu Toshi no Keizai Bunseki [An Economic Analysis of Investment in Agricultural Research and Extension Activities in Japan]," *Keizai Kenkyu [The Economic Review]*, 43 (1992): 237-247.

Ito, J. *Nogyo Toshi no Shuekisei to Toshi-Kettei [Returns to and Decisions of Agricultural Investments]*. Tokyo: Norin Tokei Kyokai, 1994.

Japan, Ministry of Agiculture, Forestry, and Fisheries. *Norinsuisan Shiken-Kenkyu Nenpo [Yearbook of Research and Experiments of Agriculture, Forestry, and Fisheries]*. Tokyo: Secretary Bureau of Technological Council of the Ministry of Agriculture, Forestry, and Fisheries, various issues.

Japan, Ministry of Agiculture, Forestry, and Fisheries. *Norinsuisan Kankei Shiken Kenkyu Yoran [Abstract Yearbook of Experiment and Research on Agriculture, Forestry, and Fisheries]* Tokyo: Statistical Bureau of the Ministry of Agriculture,

Forestry, and Fisheries, various issues.

Japan, Ministry of Agriculture, Forestry, and Fisheries. *Noson Bukka Chingin Chosa Hokoku* [*Survey Report on Prices and Wages in Rural Villages*]. Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, various issues.

Japan, Ministry of Agriculture, Forestry, and Fisheries *Noka Keizai Chosa Hokoku* [*Survey Report on Farm Household Economy*]. Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, various issues.

Japan, Ministry of Agriculture, Forestry, and Fisheries. *Sakumotsu Tokei* [*Crop Statistics*]. Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, various issues.

Kako, T. "Decomposition Analysis of Derived Demand for Factor Inputs," *Amer. J. Agr. Econ.* 60 (1978): 628-35.

Kako, T. "Inasaku niokeru Kibo no Keizai no Keisoku [Measurement of Economies of Scale in Rice Production]," *Kikan Riron Keizaigaku*[*Economic Studies Quarterly*] 30 (1979): 160-171.

Kuroda, Y. "Biased Technological Change and Factor Demand in Postwar Japanese Agriculture, 1958-84 *Agr. Econ.*, 2 (1988): 101-122.

Kuroda, Y. "Impacts of Economies of Scale and Technological Change on Agricultural Productivity in Japan," *J. Japanese and International Economies* 3 (1989): 145-73.

Kuroda, Y. "Research and Extension Expenditures and Productivity in Japanese Agriculture, 1960-1990," *Agr. Econ.* 16 (1997): 111-124.

Lee, J.H. "The Measurement and Sources of Technological Change Biases, with an Application to Postwar Japanese Agriculture," *Economica* 50 (1983): 159-73.

Norin Tokei Kyokai (Association of Agriculture and Forestry Statistics *Nogyo Hakusho (Nogyo White Book)*, Tokyo: Norin Tokei Kyokai, various editions.

Ohta, M. "Rates and Biases of Technocal Progress and Returns to Scale in the Multi-Output Multi-Input Production: Primal versus Dual, Output-Augmenting versus Input-Saving and Long-Run versus Short-Run," *J. Econ. Rev.* 49 (1998): 284-309.

Ohtsuka, K. "Nogyo Kenkyu Toshi no Kettei-In [Determinants of Investments in Agricultural Research]." *Nogyo Kaihatsu no Riron to Jissho* [*Theory and Empirical Analyses of Agricultural Research and Development*], ed. M. Morishima and M. Akino. Tokyo: Yokendo, 1982.

Ray, S.C. "A Translog Cost Function Analysis of U.S. Agriculture, 1933-1977," *Amer. J. Agr. Econ.*, 64 (1982): 490-98.

Romer, P.M. "Endogenous Technological Change," *J. Polit. Econ.* 98 (1990): S71-S102.

Ruttan, V.W. *Agricultural Research Policy.* Mineapolis: University of Minnesota Press, 1982.

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

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