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〔論　説〕

Impacts of R&E Activities on the Production Structure of the Japanese Rice Sector, 1956-92*

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Abstract

This study investigates the impacts of investment in public research and extension (R&E) activities on the Japanese rice production for the period 1956-92 by estimating the translog total cost function. It was found that the larger the farm size class, the greater the cost-reducing effects and the shadow prices of the R&E capital stock. This finding is consistent with Schultz' hypothesis that larger farms enjoy more benefits from public R&E activities that do smaller farms. Furthermore, changes in the stock of technological knowledge had bias effects toward using machinery and intermediate inputs, and saving labor, land, and other inputs during the 1956-92 period, which is consistent with the Hicksian induced-innovation hypothesis.

JEL Classification Numbers: O3 (Technological Change) ; Q16 (R&D, Agricultural Technology, Agricultural Extension Services)

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1 Introduction

In general, new technology in agriculture is generated by the R&D efforts of public and private organizations and by the efforts of farmers themselves. In particular, public research and extension (R&E in short hereafter) activities are overwhelmingly important in generating new technologies for agriculture in many countries (Hayami and Ruttan 1971).

The objective of this paper is to quantitatively analyze the impacts of public R&E activities on the production structure of the Japanese rice sector for the period 1956-92. For this objective, a translog total cost function framework is introduced where the stock of technological knowledge instead of a time trend is explicitly employed as a specific proxy variable for technological change. Here, the stock of technological knowledge is defined as an accumulated capital stock of current and past investments in public R&E activities for rice production. To be more specific, this paper presents the estimates of factor demand and substitution elasticities and economies of scale as well as the cost-reducing effect, the shadow price, and the factor biases of the stock of technological knowledge in the rice sector.

Basically, this paper aims at extending a comprehensive study conducted by Ito (1989) on the effects of public R&E activities on the Japanese rice sector for the period 1954-87. It uses a very similar translog total cost function framework as employed by Ito. The major difference in the cost function framework is that it adds another variable factor input, other inputs, to the four variable factor inputs (labor, machinery, intermediate inputs, and land) and one quasi-fixed input (the stock of technological knowledge) specified by Ito. However, this paper has the following six distinct features from Ito's study.

First, Ito (1989) used in his empirical estimation the data for the average rice farm of all Japan for the period 1954-87 taken from the *Bei-Baku Seisanhi Chōsa Hōkoku* [*Suruey Report on Production Costs of Rice, Wheat, and Barley*] (SRPCRWB) published annually by the Ministry of Agriculture, Forestry, and Fisheries (MAFF). This gives him only 34 observations for the 21 independent variables in his translog cost function. On the contrary, the present study uses the data for the average rice farm of each of the six size classes stratified in the SRPCRWB for the 1956-92 period[1]. This means that 222 observations are available for the 28 independent variables in the translog cost function in this study, indicating much greater degrees of freedom than in the case of Ito. This gives us at least two advantages over Ito's study. One is that a stronger robustness may be expected in the estimated results. In addition, it is possible to obtain various economic indicators specifically for the six size classes and to compare them among different size classes.

Second, Ito (1989) did not report the estimates of the basic economic indicators of the technology structure of the rice sector such as factor demand and substitution elasticities as well as economies of scale. This paper, on the contrary, presents the own-price demand elasticities for the five factor inputs, the Allen partial elasticities of substitution (AES) between the pairs of the five factor inputs, and the degrees of economies of scale.

Third, Ito (1989) tested an important and intriguing hypothesis proposed by Schultz (1964) that the larger the farm size, the greater the economic benefits from R&E activities in agriculture. The reasoning underlying this hypothesis is that larger farms are more market-oriented and more eager to obtain access to new innovations developed through R&E activities. Ito tested this hypothesis in the following procedure. To begin with, he estimated the cost-reducing effect of the stock of technological knowledge by computing the elasticity of total cost (C) with respect to the stock of technological knowledge (R), i. e., $\partial \ln C / \partial \ln R$ which is to be defined as the cost-R&E elasticity in the next section of the present study. This cost-R&E elasticity is in turn a function of the logarithms of the factor prices, the output scale, and the stock of technological knowledge. Ito then checked the sign of the coefficient of the cost-R&E elasticity function with respect to the output scale, β_{yr}, where y and r designate the output scale and the stock of technological knowledge in his paper. If the sign of β_{yr}, is *negative,* an increase in output scale will result in an *increase* in the cost-reducing effect of R&E activities, indicating that larger scale farms will gain greater benefits from R&E activities. However, he obtained the positive sign for the coefficient β_{yr}, against his expectation[2]. This implies that the smaller the farm scale, the more benefits from R&E activities, which is against the Schultz' hypothesis.

The present study re-tests the Schultz' hypothesis by a more complete procedure than Ito's. The test procedure is as follows. To begin with, as in Ito's case, the cost-R&E elasticity is estimated for the study period 1956-92.[3] In this case, however, the cost-R&E elasticity is estimated for all the six size classes, so that the direct comparison of the cost-reducing effects of the stock of technological knowledge can immediately be carried out. In addition, the present study com-

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[1] See section three for the details of the size classification.

[2] The elasticity was 0.147 and statistically significant at the 5 percent level.

putes the shadow price (or marginal productivity) of the stock of technological knowledge which may be used as the degree of the efficiency of investments in public R&E activities for rice production. This computation is executed for all the six size classes for the entire 1956-92 period. This again makes it possible to directly compare the efficiency levels with regard to the utilization of the stock of technological knowledge among different size classes.

Fourth, Ito (1989) investigated the biasedness of technological change due to changes in the stock of technological knowledge. He obtained the biases toward saving labor and using machinery, intermediate inputs, and land. According to him, the directions of the biases of the first three factor inputs were the ones as he expected. However, the land-using bias was against his expectation. For this investigation of the technological change biasedness, Ito employed the rather conventional Binswanger's (1974 a) procedure. That is, the partial derivative of the i-th cost share function with respect to the logarithm of the stock of technological knowledge ($B_i = \partial S_i / \partial \ln R$) was computed. If $B_i > 0$, $B_i = 0$, or $B_i < 0$, then the bias is said to be the i-th factor using, neutral, or saving. However, this procedure focuses only on the pure bias effect which is interpreted as a shift in the expansion path. It ignores the scale effect which is defined as a movement along the nonlinear expansion path. According to Antle and Capalbo (1988), the change in optimal cost shares due to technological change can be decomposed into the pure bias effect and the scale effect.

This study thus modifies the bias measure proposed by Antle and Capalbo (1988) to be applicable for the case where the stock of technological knowledge instead of a time trend is used for the technology index. Based on this procedure, the factor biases are investigated for the five factor inputs. In addition, this study goes one step further than Ito (1989) by testing the induced-innovation hypothesis originally proposed by Hicks (1963) and elaborated by Hayami and Ruttan (1971) for the case of the agricultural sector. The basic idea of the induced-innovation hypothesis is that biases of technological change will depend on relative factor prices. As the relative factor prices change, technological change will be biased to save the factor that has become relatively more expensive. To test this hypothesis, measured biases are related to the relative factor price movements, and thus the correlation of factor-saving biases to rising factor prices and vice versa is inspected.

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[3] Of course, it is very easy in this process to investigate the sign of the coefficient of the cost-R&E elasticity with respect to the output scale (Q), μ_{QR}, in our case as specified in the next section.

Fifth, it has always been problematic to define the price of land (rent) when it comes to estimating either a profit function or a cost function for the postwar Japanese agriculture. The main reason for this is that the price of land reported in the SRPCRWB published by the MAFF was a regulated rent until 1970 when the Land Act was revised by the MAFF. It was set to the level below the market rent. After 1971, the "market" rent has been reported. However, this market rent does not seem to reflect the marginal productivity (or shadow price) of land due perhaps to certain regulations in the form of the "standard" rent presented by the Agricultural Council in each region. Egaitsu and Shigeno (1983) and Kuroda (1992) showed that the market rent was much lower than the shadow price in rice production. Mainly because of these shortcomings, the estimated translog total cost function using the land price reported in the SRPCRWB did not satisfy the regularity conditions[4]. Ito (1989) utilized for the estimation of his translog cost function this problematic land price with some modifications only for 1954 and 1955.

Instead, this study introduces a new procedure for estimating the translog total cost function based on the estimated land price and land cost suggested by Egaitsu and Shigeno (1983) and Kuroda (1992). To begin with, a variable cost function is first defined where the quantity of land is introduced as a quasi-fixed input and the other four factor inputs (labor, machinery, intermediate, and other inputs) are defined as the variable inputs. Specifying this variable cost function as a translog type, the shadow price of land is estimated. Then, by assuming that the farm-firm optimizes with respect to land as a quasi-fixed input and the four variable factor inputs, this shadow price of land is regarded as the market price of land (rent)[5] and used in the estimation of the translog cost function in the present study.

Sixth, as mentioned earlier, both Ito (1989) and this paper define the stock of technological knowledge R as an accumulated capital stock of current and previous investments in public R&D and extension activities for rice production[6]. To be more specific, Ito summed up for each year of the study period, 1954-87, the capital *stock* of public R&D investments obtained with an appropriate lag structure and the *flow* (or current value) of the expenditures on public extension activi-

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[4] The translog cost function is specified in equation (6) in the next section.

[5] For the details of the theoretical discussions on and empirical applications of the shadow prices of quasi-fixed factor inputs, refer to McKay, Lawrence and Vlastuin (1983), Schankerman and Nadiri (1986), and Squires (1987).

[6] The reasons for the aggregation of the investments in public R&D and extension activities are discussed in detail in the next section.

ties. In this paper, however, it is considered to be more realistic to assume a certain lag structure for public extension activities also, since it often takes several years for a new technology to be adopted and materialized in the real rice production. Thus, the stock of technological knowledge is defined as the sum of the capital *stock* of public R&D expenditures and the capital *stock* of public extension expenditures[7].

This study is organized as follows. Section two introduces the translog cost function framework to examine the factor demand and substitution elasticities, scale economies, and the impacts of the stock of technological knowledge. The impacts will be measured in terms of the cost-reducing effect, the shadow price, and the factor biases of the stock of technological knowledge. Section three explains the data sources and variable specifications together with the procedure of the statistical estimation. Appendix gives the details of the data processing for the empirical estimation of the translog cost function. Section four presents the empirical results. Finally, summary and concluding remarks are given in section five.

2 Methodology

This study introduces a cost function framework to measure the technology structure and the impacts of the stock of technological knowledge defined as an accumulated capital stock of *R&E* expenditures on the extent and direction of the bias of technological change in the Japanese rice sector.

It is assumed that the rice farm has a production function which satisfies the neoclassical regularity conditions.

$$Q = F\,(X, TK) \tag{1}$$

where Q is the quantity of output, X is a vector of factor inputs, and TK is the *flow* of technological knowledge. This TK implies research output and may be assumed to be produced through a research production function:

$$TK = \phi\,(R) \tag{2}$$

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[7] The details of the procedure of processing the R&E capital stock is presented in Appendix.

where R is the *stock* of technological knowledge which is associated with current and prior investments in research. It is implicitly assumed that an increase in R will increase TK, i. e., $dTK/dR > 0$ (Anderson 1991). Using equation (2), the production function (1) can now be rewritten as:

$$Q = F(X, \phi(R)) \tag{3}$$

It is further assumed that the rice farm employs a certain combination of factor inputs so as to minimize the total cost given a certain level of output and the prices of factor inputs, and that the state of technology is represented by the research production function (2). Then, there exists a cost function which is a dual of the production function (Diewert 1974).

$$C = H(Q, P, \phi(R)) \tag{4}$$

or

$$C = G(Q, P; R) \tag{5}$$

where P is a factor price vector which corresponds to a factor input vector (X) composed of labor (X_L), machinery (X_M), intermediate inputs (X_I), land (X_B), and other inputs (X_O); $C = \sum_{i=1}^{5} P_i X_i$ ($i = L, M, I, B, O$) is the minimized total cost, and R is defined in the present study as the stock of technological knowledge[8] and regarded as a quasi-fixed factor.

It may be relevant here to point out three important qualifications on the use of the variable R. First, the accumulated capital *stock* of research and extension expenditures is explicitly defined for R, because it is considered that the R&E capital stock instead of its annual *flow* produce technological knowledge through the research production function (Anderson 1991). Second, R is a simple sum of the capital stock of expenditures on research and extension activities. Measuring the impact of the capital stock of extension expenditures on agricultural productivity separately from that of research expenditures is quite ambiguous. If extension's role is distinct from that of research, a separate extension variable should be used in the production and hence the cost functions. Nevertheless, if extension's role can be viewed as improving the quality of labor and other inputs, its effect on productivity can be considered similar to that of research. Consequently,

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[8] The terms, the stock of technological knowledge, the capital stock of R&E, and the R&E capital stock are used interchangeably in this study.

it would be difficult to distinguish between the contributions of research and extension. The latter case is assumed to be the appropriate situation in the present study. Therefore, the capital stocks of research and extension expenditures are combined.[9] A third qualification is that since the R&E expenditures in this study do not include the private sector research expenditures, the estimated effects of the R&E capital stock on productivity and factor biases would tend to be overestimated.[10]

In order to obtain quantitatively the technology structure and the impacts of the R&E capital stock on the extent and the direction of the bias of technological change in the Japanese rice sector, the following translog form is specified for the cost function (5).

$$\begin{aligned}\ln C = {} & \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^{5} \alpha_i \ln P_i + \alpha_R \ln R \\ & + \frac{1}{2}\gamma_{QQ} (\ln Q)^2 + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5} \gamma_{ij} \ln P_i \ln P_j \\ & + \sum_{i=1}^{5} \delta_{Qi} \ln Q \ln P_i + \mu_{QR} \ln Q \ln R \\ & + \sum_{i=1}^{5} \mu_{iR} \ln P_i \ln R + \frac{1}{2}\beta_{RR} (\ln R)^2 \\ & + d_{ST} D_{ST} + \sum_{k=2}^{6} d_{Sk} D_{Sk}, \end{aligned} \qquad (6)$$

where $\gamma_{ij} = \gamma_{ji}$, $i = j = L, M, I, B, O,$ and $k = 2, 3, 4, 5, 6$.

Here, in order to take into account heterogeneous intercepts with respect to the two different periods, before and after the introduction of setaside programs in rice production (1956-68 and 1969-1992), and the six size classes, period dummy D_{ST} (each year for 1956-68=1 and each year for 1969-92=0) and size dummies D_{Sk} (k = 2, 3, 4, 5, 6) were introduced[11].

The cost share (S_i) are derived through the Shephard's (1970) lemma as

$$S_i = \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \frac{\partial \ln C}{\partial \ln P_i}$$

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[9] Indeed, several cost function models where the two capital stock variables of research and extension expenditures are introduced as separate variables were empirically estimated in order to obtain the distinct effects of them on rice production. However, none of these trials was successful due mainly to the multicolinearity between these two variables.

[10] In order to capture the impacts of the investments associated with the private sector research and farmers' education, a time variable (t) was added as a proxy for these variables in the cost function. In this case too, the empirical estimation was not successful due to the multicolinearity between R and t.

[11] However, homogeneous slopes were assumed with respect to the other exogenous variables in the total cost function.

$$= \alpha_i + \sum_{j=1}^{5} \gamma_{ij} \ln P_j + \delta_{Qi} \ln Q + \mu_{iR} \ln R \qquad (7)$$

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

The translog cost function can be used along with the profit-maximizing condition to generate an additional equation representing the optimal choice of the endogenous output (Q) (Fuss and Waverman, 1981, pp. 288-289).

Taking the derivation of the cost function (6) with respect to the endogenous output Q, we have

$$\frac{\partial \ln C}{\partial \ln Q} = \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{PQ}{C}$$

where P is the price of output[12]. Denoting PQ/C as S_Q, the revenue share equation can be written as

$$S_Q = \alpha_Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \mu_{QR} \ln R \qquad (8)$$

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

Including the revenue share equation in the estimation of the system of equations will in general lead to more efficient estimation of the coefficients, in particular, of the output-associated variables due to an additional information provided by the revenue share[13].

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (6) this requires that $\Sigma_{i=1}^{5}\alpha_i = 1$, $\Sigma_{i=1}^{5}\gamma_{ij} = 0$, $\Sigma_{i=1}^{5}\delta_{Qi} = 0$, and $\Sigma_{i=1}^{5} \mu_{iR} = 0$ ($i = j = L, M, I, B, O$). The translog cost function (6) has a general form in the sense that the restrictions of homotheticity and neutrality with respect to R are not imposed a priori. Instead, these restrictions will be statistically tested in the process of estimation of this function.

First, if the primal production function is homothetic, then the dual cost function can be written as $C = I\ (Q, R) \cdot J\ (P, R)$. This implies the following set of restrictions on the translog cost function (6); $\delta_{Qi} = 0$ ($i = L, M, I, B, O$), implying that changes in output level do not have any effect on the cost shares.

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[12] In this case, the rice farmer is assumed to equate the marginal revenue to the government-supported rice price, since the output price P includes the government subsidy payments.

[13] For a detailed discussion on the inclusion of the revenue share equation in the system of regression equations, see Ray (1982) and Capalbo (1988).

Next, constant returns to scale can also be easily tested in the cost function framework. If the primal production function exhibits constant returns to scale, then the cost function can be written as $C\ (Q,\ P,\ R) = Q \cdot J\ (P,\ R)$. This implies the following set of parameter restrictions on the translog cost function (6); $\alpha_Q = 1, \gamma_{QQ} = \delta_{Qi} = \mu_{QR} = 0\ (i = L, M, I, B, O)$.

Furthermore, the test of neutrality with respect to the stock of technological knowledge R implies that the cost shares are not influenced by changes in the R&E capital stock. This implies $\mu_{iR} = 0\ (i = L, M, I, B, O)$ in the translog cost function (6).

2.1 Factor Demand and Substitution Elasticities and Economies of Scale

To begin with, the Allen (1938) partial elasticity of substitution (AES) can be estimated as (Binswanger 1974b):

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \qquad i, j = L, M, I, B, O. \qquad i \neq j \tag{9}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \qquad i = L, M, I, B, O. \tag{10}$$

Next, the own and cross price elasticities are obtained by:

$$\epsilon_{ii} = S_i \sigma_{ii} \qquad i = L, M, I, B, O. \tag{11}$$

$$\epsilon_{ij} = S_j \sigma_{ij} \qquad i,j = L, M, I, B, O. \qquad i \neq j \tag{12}$$

Furthermore, following Caves, Christensen, and Swanson (1981), scale economies (SCE) for the case of the total cost function of this study can be estimated as follows:

$$SCE = (\partial \ln C / \ln Q)^{-1} = \varepsilon_{CQ^{-1}} \tag{13}$$

where the cost-output elasticity (ε_{CQ}) is given by,

$$\varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \mu_{QR} \ln R \tag{14}$$

$$i = L, M, I, B, O.$$

2.2 Impacts of the Stock of Technological Knowledge

First, the impacts of the stock of technological knowledge on agricultural productivity can be measured by estimating the cost elasticity with respect to the R&E capital stock (cost-R&E elasticity, hereafter). The negative of the cost-R&E elasticity ($-\varepsilon_{CR}$) gives the cost-reducing effect due to changes in the stock of technological knowledge.

$$-\varepsilon_{CR} = -\frac{\partial \ln C}{\partial \ln R} = -\left(\alpha_R + \mu_{QR} \ln Q + \sum_{i=1}^{5} \mu_{iR} \ln P_i + \beta_{RR} \ln R \right) \tag{15}$$

$$i = L, M, I, B, O.$$

Next, the bias effects of changes in the stock of technological knowledge, if any, can be captured by non-neutral changes in factor shares due to changes in the R&E capital stock. This study modifies the bias measure proposed by Antle and Capalbo (1988). They proposed a Hicksian (1963) measure of technological change in input space in both single-product and multi-product cases by extending Binswanger's (1974 a) 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 nonlinear expansion path) and a pure bias effect (interpreted as a shift in the expansion path). In the single-product case of this study where the technology index is represented by the stock of technological knowledge, the Hicksian bias measure may be defined as

$$\begin{aligned} B_i^e &= \partial S_i (Q, P, R) / \partial \ln R \,|_{dC=0} \\ &= B_i + \left(\frac{\partial \ln S_i}{\partial \ln Q} \right) \left(\frac{\partial \ln C}{\partial \ln Q} \right)^{-1} \left(-\frac{\partial \ln C}{\partial \ln R} \right) \end{aligned} \tag{16}$$

where $B_i \equiv \partial \ln S_i (Q, P, R) / \partial \ln R$ $(i = L, M, I, B, O)$. If $B_i^e > 0$ (< 0), then technological change caused by changes in the R&E capital stock is said to be biased toward using (saving) the i-th factor. If $B_i^e = 0$, then technological change is said to be i-th factor neutral. Based on the estimated results of the B_i^e, one can examine whether or not the direction of the measured factor biases is consistent with the Hicksian (1963) induced-innovation hypothesis.

Using the parameters of the translog cost function in the present study, equation (16) can be expressed as

$$B_i^e = \frac{\mu_{iR}}{S_i} + \frac{\delta_{Qi}}{S_i} \left(-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}} \right) \tag{17}$$

$$i = L, M, I, B, O.$$

Since homotheticity implies $\partial S_i / \partial \ln R = 0$, i.e., $\delta_{Qi} = 0$ for all i $(= L, M, I, B, O)$, the scale effect vanishes. Thus, the Hicksian bias measure contains only the effect of a shift in the expansion path.

Finally, another measure of the evaluation of the effect of the stock of technological knowledge on rice production is the extent of the efficiency of investment in R&E activities. This is measured by estimating the marginal productivity (*MP*) (or shadow price) of the stock of technological knowledge.

The *MP* of the stock of technological knowledge can be obtained, in the translog cost function framework of this study, by[14]

$$MP=\frac{\partial Q}{\partial R}=\left(-\frac{\partial C}{\partial R}\right)/\frac{\partial C}{\partial Q}=\left(-\frac{\partial \ln C}{\partial \ln R}/\frac{\partial \ln C}{\partial \ln Q}\right)\frac{Q}{R}=\left(-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}}\right)\frac{Q}{R} \qquad (18)$$

Equation (18) indicates that the *MP* of the stock of technological knowledge can be obtained by multiplying the negative of the cost-R&E elasticity ($-\varepsilon_{CR}$) normalized by the cost-output elasticity (ε_{CQ}) by the average productivity of the stock of technological knowledge (Q/R). Note here that *MP* as well as all the other indicators which are obtained based on the estimates of the translog cost function can be estimated for all the individual rice farms used for the estimation of the cost function (6).

3 The Date and Statistical Estimation

The variables required to estimate the cost function model are; the total cost (C); the price (P) and quantity (Q) of total output; the prices (P_i) and cost shares (S_i) of the five factors of production, i.e., labor (X_L), machinery (X_M), intermediate inputs (X_I), land (X_B), and other inputs (X_O); the revenue share (S_Q); and the stock of technological knowledge (R). In each year of the period 1956-92, the average rice farm was taken from each of the six size classes, i.e., 0.3-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-3.0 and 3.0 hectares and over for all Japan. Thus, the total sample size is 37 (*years*) × 6 (*size classes*) = 222.

The major sources of date are *Bei-Baku Seisanhi Chōsa Hōkoku* [*Survey Report on Production Costs of Rice, Wheat, and Barley*] (SRPCRWB) and *Nōson Bukka Chingin Chōsa Hōkoku* [*Survey Report on Prices and Wages in Rural Villages*] (SRPWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) .

The details of the variable definitions and additional date sources for estimating the system of the translog cost function and the cost and revenue share equations are described in Appendix.

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[14] Ito (1992) presents a compact mathematical derivation of marginal productivity of the stock of technological knowledge in the cost function framework (pp.245-246).

For statistical estimation, there is potentially an endogeneity problem involving output *Q*, because the profit maximization condition was used in deriving the revenue share equation (Fuss and Waverman, 1981, p.293). A simultaneous estimation procedure should be then employed in the estimation of the set of equations consisting of the translog cost function (6), four of the five cost share equations (7), and one revenue share equation (8). Thus, the method chosen was iterative three stage least squares (*I3SLS*). The required instrumental variables consisted of variables exogenous to the cost structure—output and input prices (P and P_i) and the stock of technological knowledge R. In this process, the restrictions due to symmetry and linear homogeneity in prices were imposed. The coefficients of the omitted cost share equation were obtained using the linear homogeneity restrictions after the system was estimated.

4 Empirical Results

In the process of estimation of the system of the cost function, and the factor and revenue share equations, the three hypotheses, i.e., homotheticity, constant returns to scale, and Hicks neutrality with respect to the stock of technological knowledge, were statistically tested applying a Wald-Chi square test procedure. The computed Chi-square statistics for these three tests were 1441.6, 5041.8, and 90.2 with degrees of freedom 4, 6, and 4, respectively. All the three hypotheses concerning the structure of production technology were strongly rejected at the one percent significance level.

Thus, no further restrictions other than those for the symmetry and homogeneity-in-input-prices were imposed in estimating the system of equations. The coefficients of the omitted (in the present case, the other inputs) cost share equation were obtained using the parameter relations for the linear homogeneity restrictions. The results are presented in Table 1. As shown in Table 1,the adjusted R^2s were considerably high for all the equations except for the labor cost and the revenue share equations. Though a little low, the adjusted R^2s for these equations, 0.734 and 0.737, are fairly high. Thus, the fit of the model as a whole may be said to be good. In addition, monotonicity and concavity of the cost function were checked and satisfied for the approximation point as well as for the whole sample points. This set of estimates is referred to as the final specification of the model and will be used for further analyses.

Before going into further analyses, it may be worth saying a word about the heterogeneity of

Table 1: Paramenter Estimates of the Translog Cost Function for the Japanese Rice Sector, 1956-92

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	7.155	879.7	γ_{IB}	−0.031	−10.6
α_Q	0.869	382.7	γ_{IO}	−0.036	−7.3
α_L	0.273	184.9	γ_{BO}	−0.014	−4.2
α_M	0.168	116.3	δ_{QL}	−0.031	−16.7
α_I	0.112	159.5	δ_{QM}	−0.028	−15.7
α_B	0.427	334.0	δ_{QI}	0.005	4.6
α_O	0.019	24.8	δ_{QB}	0.052	33.5
β_R	−0.081	−8.3	δ_{QO}	0.002	2.1
γ_{QQ}	0.032	12.6	μ_{QR}	−0.036	−9.2
γ_{LL}	0.010	1.3	μ_{LR}	−0.000	−0.0
γ_{MM}	−0.074	−9.9	μ_{MR}	0.038	5.0
γ_{II}	0.068	10.9	μ_{IR}	0.027	5.5
γ_{BB}	0.143	46.5	μ_{BR}	−0.028	−6.0
γ_{OO}	0.009	1.5	μ_{OR}	−0.037	−7.0
γ_{LM}	0.061	11.1	β_{RR}	−0.011	−1.1
γ_{LI}	−0.016	−4.4	d_{ST}	−0.008	−0.8
γ_{LB}	−0.087	−22.8	d_{S2}	0.027	3.1
γ_{LO}	0.032	7.9	d_{S3}	0.028	3.0
γ_{MI}	0.016	2.8	d_{S4}	0.016	1.6
γ_{MB}	−0.012	−3.6	d_{S5}	0.008	0.8
γ_{MO}	0.009	1.9	d_{S6}	0.020	1.7

Estimating Equations	$\bar{R}^2$
Cost function	0.996
Labor share equation	0.734
Machinery share equation	0.915
Intermediate inputs share equation	0.850
Land share equation	0.964
Revenue share equation	0.737

intercepts with respect to the period dummy and size dummies. To begin with, it was found that d_{ST} was not statistically significant, indicating that no intercept heterogeneity existed between the two periods, 1956-68 and 1969-92. However, in the case of the size dummies, it was found that d_{S2} and d_{S3} were statistically significant while d_{S4}, d_{S5}, and d_{S6} were not at the conventional 5 percent level, indicating that smaller size classes had a tendency of higher total costs.

Based on the parameter estimates, the economic indicators such as factor demand and substitution elasticities, and economies of scale were estimated in order to capture the basic structure of the production technology of the Japanese rice sector. In addition, in order to evaluate the effects of the stock of technological knowledge on the rice sector, the cost-reducing effect, the shadow price, and the factor biases of the stock of technological knowledge were estimated.

4.1 Factor Demand and Substitution Elasticities

Factor demand elasticities with respect to the own prices at the approximation point are -0.689 (23.2), -1.271 (28.6), -0.286 (5.2), -0.238 (33.0), and -0.496 (1.5) for labor, machinery, intermediate inputs, land and other inputs, respectively (the figures in parentheses are the computed absolute t-values) . As expected from the magnitudes of the computed t-values, these elasticities were considerably consistent for the whole samples except for the other inputs. It was found that the demands for labor, intermediate inputs, land, and other inputs are all inelastic. Above all, the demand for land is the least elastic among the five factor inputs. However, machinery demand is fairly elastic with respect to its own price. This implies that a decrease in the machinery price will lead to further mechanization. These results support basically the results of previous studies conducted by other researchers such as Kako (1978) and Chino (1984, 1990), though their actual estimates are not presented here in order to save space.

The AESs were computed at the approximation point and are reported in Table 2. At least, two points are worth mentioning about the results in the table. First, the AESs between labor and machinery, labor and intermediate inputs, labor and land, and labor and other inputs are respec-

Table 2: Allen Partial Elasticities of Substitution at the Approximation Point

Factor input	Labor	Machinery	Intermediate inputs	Land	Other inputs
Labor	−2.522	2.329	0.462	0.257	7.001
	(−23.2)	(19.4)	(3.8)	(7.9)	(9.1)
Machinery		−7.549	1.839	0.834	3.784
		(−28.6)	(6.0)	(18.3)	(2.5)
Intermediate			−2.546	0.360	−15.8
inputs			(−5.2)	(5.9)	(−6.9)
Land				−0.558	−0.669
				(−33.0)	(−1.7)
Other inputs					−25.7
					(−1.5)

Notes:

1. The AESs were estimated at the approximation point using equations (9) and (10).
2. Figures in ( ) are computed t-statistics.

tively 2.33, 0.46, 0.26, and 7.00, indicating that all the inputs other than labor are substitutes of labor. Above all, the large values of substitution elasticities between labor and machinery, and labor and other inputs indicate that machinery and other inputs are fairly good substitutes for labor. As exposed in Appendix, other inputs are composed of farm buildings and land improvement equipment which are strongly related to mechanization. These findings are consistent with the rapid mechanization of rice production during the study period 1956-92. Furthermore, the AES between labor and machinery of this study, 2.3, are comparable with other researchers' results mentioned above.

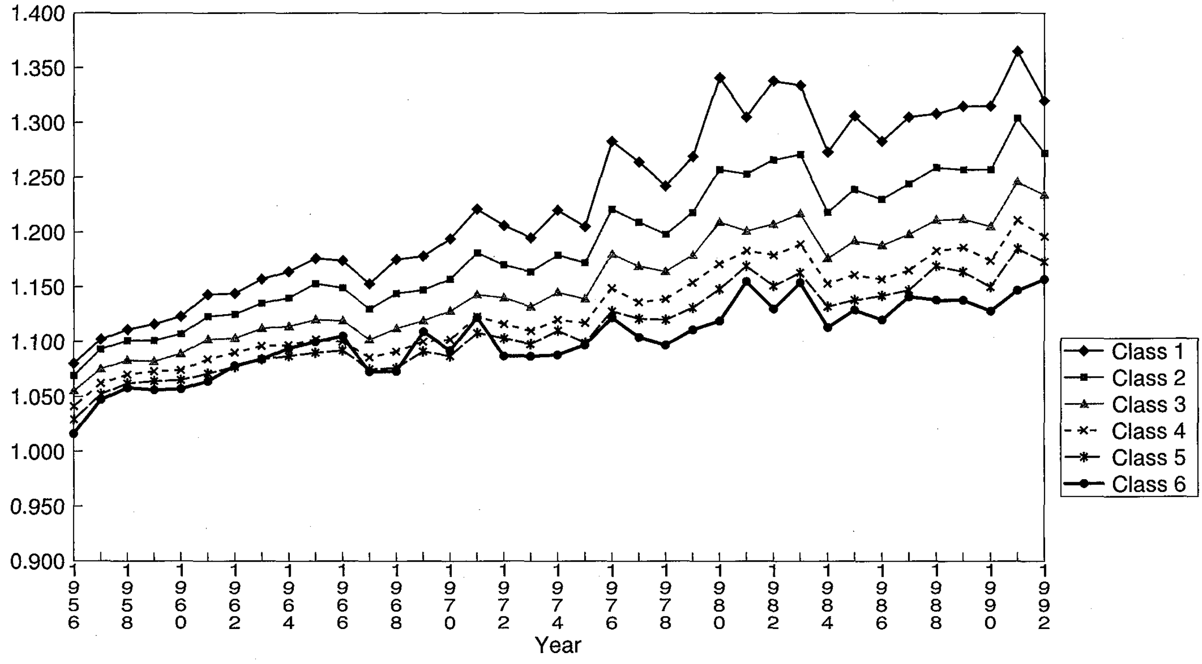
Second, the AES between land and machinery is positive (0.83). This supports the positive values obtained by the above-mentioned researchers. The positive elasticity of substitution between land and machinery indicates that these factor inputs are substitutes in the Japanese rice sector. This seems to capture the actual movement of the rapid mechanization on the limited paddy field of the rice farm. That is, the relative decline in the machinery price has induced rice producers to promote the rapid mechanization. This finding is in turn contradictory to the induced-innovation hypothesis proposed by Hayami and Ruttan (1971) where land and machinery are hypothesized as complements. However, this hypothesis is based on the development pattern of U. S. agriculture, i.e., a relatively land abundant agriculture. In their article, too, the test of the hypothesis of the land-machinery complementarity was not successful for Japanese agriculture which is characterized by a relatively land scarce agriculture, although the test for the case of U. S. agriculture was successful (Hayami and Ruttan, 1971, Tables 6-3a and 6-3b, pp.130-31).

4.2 Economies of Scale

Economies of scale were estimated using equations (13) and (14) for all the six size classes for the period 1956-92. The results are presented in Figure 1. Several findings are worth mentioning from the figure. First, average farms in all size classes were found to have faced increasing returns to scale for the entire period. Second, it was found that the smaller the size class, the greater the degree of scale economies also for the entire study period. This is consistent with the shape of a normal average cost curve where the rate of decrease in the average cost becomes slower as the amount of output scale gets larger.

Finally, the degrees of scale economies increased over time. In order to interpret this phenomenon, it may be convenient to divide the period 1956-92 into two sub-periods, 1956-67 and

Figure 1. Economies of Scale, 1956-92 (All Japan)



Note: Economies of scale were estimated using equations (13) and (14).

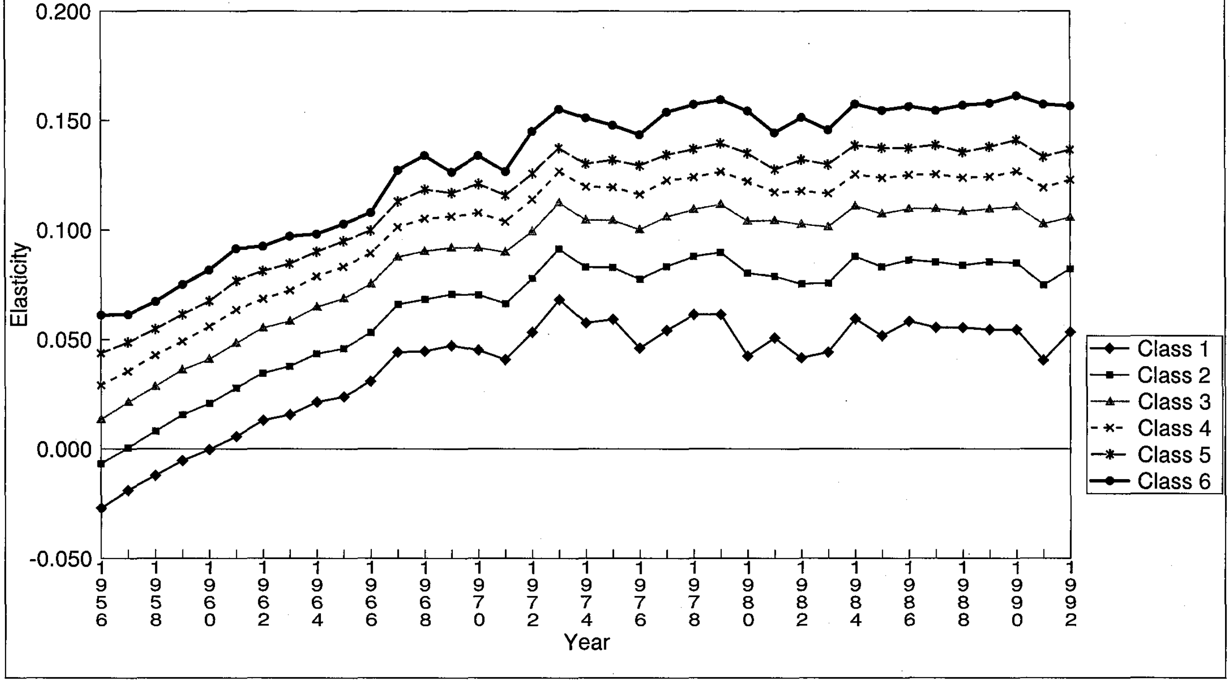
1968-1992. The first period may be characterized by a rapid introduction of smaller-scale power tillers, while the latter period may be featured by a larger-scale mechanization represented by riding-type tractors and rice-transplanters. The mechanized production technology during the latter period must have had stronger indivisibility compared to the one during the first period, which may have caused increases in the degrees of scale economies during the latter period.

The finding of scale economies in this paper is consistent with the results by Kako (1979a) and Chino (1984) who found scale economies in the Japanese rice sector during the 1960s and 1970s by estimating translog cost functions.

4.3 Cost-Reducing Effects of the Stock of Technological Knowledge

To begin with, let us examine the impacts of the stock of technological knowledge on rice production by scrutinizing the estimate of the negative of the cost-R&E elasticity $(-\varepsilon_{CR})$ in Figure 2 which was estimated for all the six size classes. At least, two distinct features emerge from this figure. First, the $(-\varepsilon_{CR})$s of all the size classes increased fairly rapidly from 1956 to 1973, although they showed a slowdown from 1969 to 1971 due perhaps to the introduction of the paddy setaside program in 1969. For the two decades after 1973, the movements of the $(-\varepsilon_{CR})$s were in general very stable maintaining the levels of 1973. However, a more careful investigation may of-

Figure 2. The Negative of the Cost-R&E Elasticity, 1956-92 (All Japan)



Note: The elasticity was estimated using equation (15).

fer slightly different pictures for the different size classes. That is, while the $(-\varepsilon_{CR})$s of the size classes 1 through 5 seem to have reached their plateaus or have been slightly decreasing after 1973,that of the largest size class six seems to have been slightly increasing even after 1973.

Second, it is very clear from the figure that the larger the farm size, the greater the negative of the cost-R&E elasticity $(-\varepsilon_{CR})$, i.e., the greater the cost-reducing effect. Schultz (1964) points out that the larger the farm size, the greater the economic benefits from R&D in agriculture. The reasoning underlying this hypothesis is that larger farms are more market-oriented and more eager to obtain access to new innovations. The result obtained in this study is consistent with the Shultz' hypothesis.

This result is contradictory to the one obtained by Ito (1989). He obtained a positive value for the parameter μ_{QR} (in his case β_{yr}), 0.147 (t-value = 2.2), indicating that, other conditions being equal, an increase in output scale will decrease the cost-reducing effect. This is inconsistent with the Schultz' hypotheses. On the contrary, μ_{QR} in the present study was significantly negative as seen in Table 1; -0.036 (t-value = -9.2). This indicates that an increase in output scale will increase the cost-reducing effect, which is again consistent with the Schultz' hypothesis.

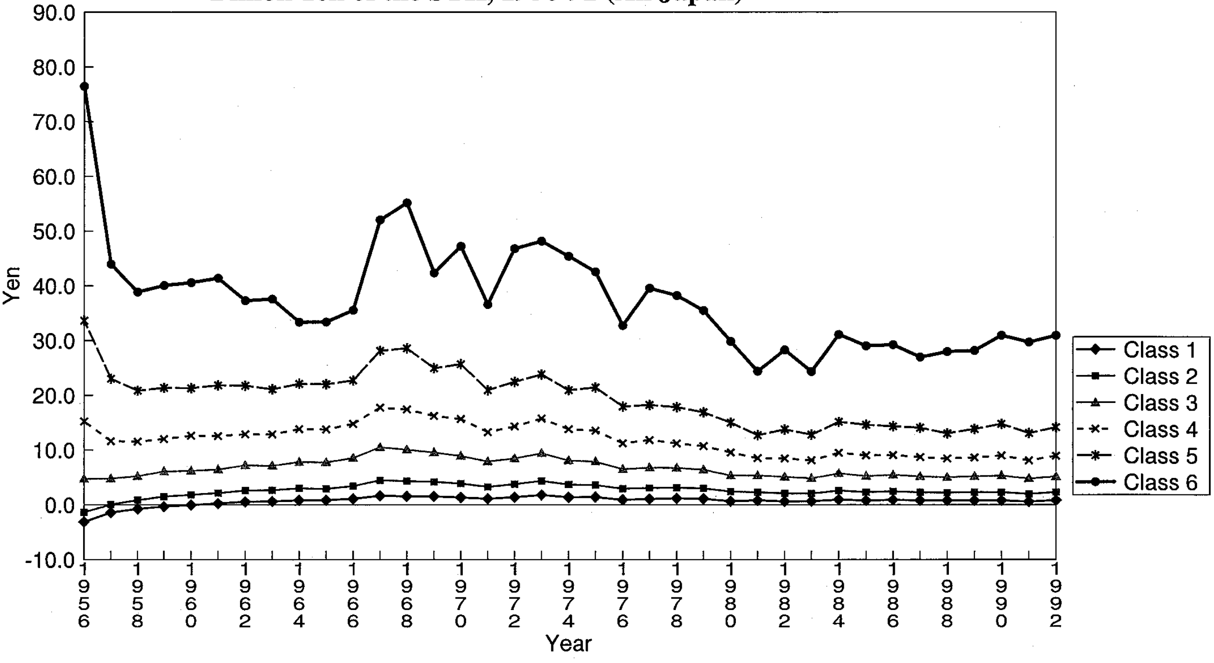
Ito obtained his result using the data set of the average farm for all Japan for the period 1954 -87, implying only 34 observations for the 21 independent variables in his translog cost function model. The present study, however, used explicitly the six size classes for all Japan for the 1956-92 period, i.e., 222 observations which gave much greater degrees of freedom in the estimation of the translog cost function (28 independent variables) . Furthermore, the data for the price of land used in this study (i.e., the shadow price of land) may behave better than the one used in Ito (1989) reported in the SRPCRWB which may not be regarded as the market price[15]. Because of these reasons, it is argued that the present result is more reliable than Ito's.

4.4 Shadow Price of the Stock of Technological Knowledge

Next, it may be meaningful to investigate at this point the estimated results of the Shadow price (or, marginal productivity, *MP*) of the stock of technological knowledge in order to confirm the above test results of the Schultz' hypothesis, since the *MP* is intimately related to the magnitude of the negative of the cost-R&E elasticity as shown in equation (18).

The Shadow price (*MP*) of the stock of technological knowledge was estimated using equation (18) for each of the six size classes for each year of the period 1956-92. It is expressed in yen per billion yen of the stock of technological knowledge. The results are shown in Figure 3. At

Figure 3. Shadow Price of the Stock of Technological Knowledge (STK) in Yen per Billion Yen of the STK, 1956-92 (All Japan)



Note: The shadow price was estimated using equation (18).

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[15] See, for example, Egaitsu and Shigeno (1983) and Kuroda (1992) who estimated the shadow prices of land which were higher than the reported land rent.

least, two important features are noteworthy from the figure.

First, the *MP* s of the stock of technological knowledge of size classes 1 through 5 showed almost parallel movements for the whole period except for the 1956 values of classes 4 and 5. That is, the *MP* s increased very slowly until 1966, reached the highest point in 1967 and 1968 with a slight jump, and then gradually decreased from 1969. On the other hand, the movement of the *MP* of the largest size class is slightly different from those of the other classes. It showed a decreasing trend from 1956 to 1964. But, it increased rapidly from 1965 to 1968 when it reached the maximum. Then, it had a decreasing trend from 1969 to 1983. After 1983, however, the *MP* seems to have an increasing trend, though not that strong.

Second, it is very clear that the larger the farm size, the larger the *MP* of the stock of technological knowledge. In particular, the *MP* of the largest size class (3 hectares and more) is much greater than those of the smaller size classes for the whole study period. This implies that newly developed technologies due to R&E activities have been utilized most efficiently on larger scale rice farms. This finding together with the above finding of the greater cost-reducing effects of the R&E stock on larger scale farms is consistent with the Shultz' hypothesis. These results may imply that in order to utilize the stock of technological knowledge more efficiently, a larger scale farming should be emphasized more positively in the Japanese rice sector.

4.5 Bias Effects of the Stock of Technological Knowledge

The directions of the factor biases due to changes in the stock of technological knowledge can be evaluated by equation (18). The estimates of B_i^e's are presented in Table 3. They are expressed in terms of elasticities and are averages of all the observations[16]. They show that changes in the stock of technological knowledge had bias effects toward machinery-and intermediate inputs-using, and labor-, land-, and other inputs-saving during the period 1956-92. For the machinery-using, intermediate inputs-using, land-saving, and other inputs-saving biases, the pure bias effects (shifts in the expansion path) were found to be dominant, while the scale effect (movements along the nonlinear expansion path) was found to be dominant for the labor-saving bias.

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[16] The factor biases of the six size classes were estimated for all the years of the study period 1956-92. The directions and the trends of the factor biases over the study period were almost the same among the six size classes. However, it was found that the larger the size class, the greater the degree of labor-saving bias.

Table 3: Factor Biases with respect to the Stock of Technological Knowledge at the Approximation Point

Factor input	B_i	B_i^Q	B_i^e
Labor	0.001	−0.010	−0.009
	(0.0)	(−16.7)	(−2.4)
	[−17.1]	[117.1]	[100.0]
Machinery	0.224	−0.016	0.208
	(5.0)	(−15.7)	(4.7)
	[107.5]	[−7.5]	[100.0]
Intermediate imputs	0.240	0.004	0.244
	(5.5)	(4.6)	(5.6)
	[98.4]	[1.6]	[100.0]
Land	−0.067	0.011	−0.055
	(−6.0)	(33.5)	(−5.0)
	[120.3]	[−20.3]	[100.0]
Other inputs	−1.895	0.012	−1.883
	(−7.0)	(2.1)	(−7.0)
	[100.6]	[−0.6]	[100.0]

Notes:
1. The biases were estimated at the approximation point using equation (17).
2. B_i is the pure bias effect (μ_{iR}/S_i), B_i^Q is the scale effect ((δ_{Qi} / S_i)($-\varepsilon_{CR}/\varepsilon_{CQ}$)) and, B_i^e is the total effect ($B_i + B_i^Q$).
3. Figures in ( ) are computed t-statistics.
4. Figures in [ ] are the relative percentage contributions.

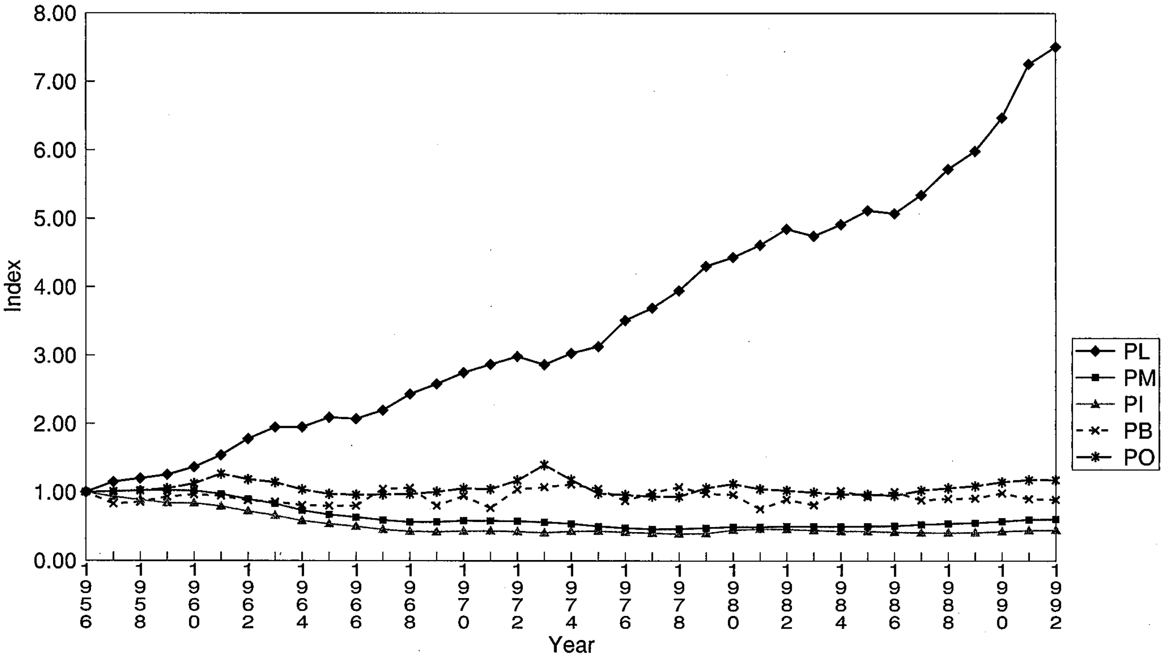
These results roughly support the ones obtained by Ito (1989) except for the case of land. Ito obtained land-using bias instead of land-saving bias. The main reason for this may have been due to the difference of the land prices used in his and our studies. Ito used the land rent reported in the SRPCRWB for his study period 1954-87. This means that he had to use the regulated land rent for the period from 1954 to 1970 when the regulation was repealed due to the revision of the Land Act. Even after 1971, however, land rent has been semi-regulated in the form of so-called the "standard" land rent for each region proposed by the Agricultural Council in each region. On the other hand, the present study used the estimated shadow price (or, marginal productivity) of land which was estimated based on the variable cost function where land is defined as a quasi-fixed input.

Let us now proceed to test the induced-innovation hypothesis originally proposed by Hicks (1963). The basic idea of the induced-innovation hypothesis is that biases of technological change will depend on relative factor prices. As the relative factor prices change, technological change will be biased to save the factor that has become relatively more expensive. To test this hypothesis, measured biases are related to the relative factor price movements, and thus the correlation of factor-saving biases to rising factor prices and vice versa is inspected.

The directions of the factor biases are associated, respectively, with the rising trends of the price of labor and with the declines in the prices of machinery and intermediate inputs relative to the output price as shown in Figure 4. Though not that clear as in the case of the price of labor, the prices of land and other inputs relative to the output price had rising trends over the study period. The land- and other inputs-saving biases may thus be said to be associated with these trends. In this sense, the directions of the biases with respect to changes in the stock of technological knowledge are consistent with the Hicksian induced-innovation hypothesis. This implies that the public research sector has been sensitive to changes in these factor prices in executing R&E activities.

These results support in general the findings by Kako (1979b) who tested the Hicksian induced-innovation hypothesis for the Japanese rice sector for the period 1953-70. He estimated the translog cost function similar to the one in this paper based on a pooled cross-section of time-series data for Kinki distirict. However, he used a time trend instead of the stock of technological knowledge as a proxy variable for technological change. Using Binswanger's (1974a) procedure,

Figure 4. Factor Prices Relative to Output Price, 1956-92: All Japan (Class 6)



Note: Factor prices were estimated using basically the C-C-D (1982) procedure. By setting the 1956 values of size class 6 to be unity, the relative factor prices were reorganized for the six size classes.

he obtained labor-saving, machinery-using, and fertilizer-using biases, which were found to be consistent with the Hicksian induced-innovation hypothesis. As for land, he obtained land-saving bias, land-neutral, and land-using bias for the periods 1953-59, 1960-64, and 1965-70, respectively. Although the result of this study may in general support the land-saving bias for the period 1953-59, it does not support the land-neutral and land-using bias for the latter two periods. This rather strange result by Kako (1979b) may have come from the usage of the regulated land price (rent) reported in the SRPCRWB as in the case of Ito (1989).

An intriguing study similar to ours was published for U.S. agriculture by Huffman and Evenson (1989). They found that, for the period 1949-74, public and private crop research caused relative input bias effects in favor of fertilizer usage and against farm labor and machinery inputs. The direction of the biases for fertilizer and labor are consistent with the induced-innovation hypothesis. Fertilizer is an important component of intermediate inputs. It is thus noted here that labor-saving and intermediate inputs-using effects due to agricultural R&E activities have been found to be consistent with the induced-innovation hypothesis in both countries. For machinery, however, the opposite bias directions were found in the two countries.

5 Summary and Concluding Remarks

This study has investigated the impacts of investment in public R&E activities on the technology structure of the Japanese rice sector for the period 1956-92 by estimating the translog total cost function. The major empirical findings may be summarized as follows.

1. It was found that the demands for labor, intermediate inputs, land, and other inputs were inelastic, while that for machinery was fairly elastic during the period 1956-92.
2. Labor and machinery were found to be good substitutes, which was consistent with the rapid mechanization during the study period.
3. There existed economies of scale in all the six size classes, indicating that an increase in output scale will reduce the average cost in all the size classes.
4. The cost-reducing effects of the stock of technological knowledge of all the size classes increased fairly rapidly for period 1956-73 and became stable after that maintaining the levels of 1973. In addition, it was found that the larger the size class, the greater the cost-reducing effects of the stock of technological knowledge. This finding is consistent with

the Schultz' hypothesis that larger farms enjoy more benefits from public R&E activities than do smaller farms.

5. It was found that the lager the size class, the larger the shadow price of the stock of technological knowledge for the entire study period. This finding is also consistent with the Schultz' hypothesis. In addition, it is essential to note that the shadow prices of stock of technological knowledge had decreasing trends from 1969 in all the six size classes, although the largest size class seems to have an increasing trend after 1983.
6. Changes in the stock of technological knowledge had bias effects toward using machinery and intermediate inputs, and saving labor, land, and other inputs during the 1956-92 period. The directions of the factor-using biases with respect to machinery and intermediate inputs were found to be associated with the decreasing trends of their prices relative to output price. On the other hand, the directions of the factor-saving biases with respect to labor, land, and other inputs were associated with the rising trends of their relative prices. These findings are consistent with the Hicksian induced-innovation hypothesis. This implies that the public research sector has been sensitive to movements in these factor markets and hence the conditions of factor endowments in executing the R&E activities.

As a concluding remark, a policy implication may be derived from the last three findings. It is clear from these findings that in order to raise the efficiency of the public R&E activities for the rice sector, the cost-reducing effect and the marginal productivity of the stock of technological knowledge have to be increased. For this objective, the rice production structure has to be changed toward large-scale farming. To attain this goal, various policy measures have to be introduced to encourage movements of paddy fields from small-scale rice farmers to large-scale and entrepreneurial rice farmers.

Appendix: Data Processing

As indicated in section three, the variables required to estimate the total cost function are defined in this section. Since the data given in the SRPCRWB are expressed in per 10 ares terms, it is necessary to multiply the needed variables by the planted area in order to obtain them in per farm terms. Furthermore, wherever necessary and applicable, the Törnqvist-Theil index was obtained by the Caves-Christensen-and Diewert (CCD) (1982) method. The CCD method is most relevant when it comes to estimating the Törnqvist-Theil index for a pooled cross-section of time-series data set. In applying this method, the base year was set at 1985.

The quantity of total output (Q) was obtained by multiplying the amount of production (kilograms) per 10 ares by the planted area. The total revenue TR can also be obtained by multiplying the total revenue per 10 ares by the planted area. The price of output (P) is the price index for total rice reported in the SRPWRV.

The cost of labor input ($C_L=P_LX_L$) was defined as the sum of the wage bills for family and hired labor expressed in thousand yen per farm. The price of labor was obtained as follows. First, the quantity of labor (X_L) was defined as the total number of male-equivalent labor hours of family and hired workers per farm. The number of male-equivalent labor hours by female workers was estimated by multiplying female labor hours by 0.8. This ratio was obtained by dividing the female daily wage rate by the male daily wage rate for temporary hired agricultural labor, reported annually in the PWRV (roughly 0.8 for almost all years for the study period). Then, the price of labor (P_L) per farm was obtained by dividing the labor cost (C_L) by the number of male-equivalent labor hours (X_L).

The cost of machinery input ($C_M=P_MX_M$) was defined as the sum of the expenditures on machinery, energy, and rentals expressed in thousand yen per farm. The price of machinery input (P_M) was defined as the price index for machinery and large tools reported in the SRPWRV.

The cost of intermediate inputs ($C_I=P_IX_I$) was defined as the sum of the expenditures on seed, fertilizers, agri-chemicals, and materials in thousand yen per farm. The price of intermediate inputs (P_I) was estimated by the Caves-Christensen-and-Diewert (CCD) (1982) method. The price indexes necessary for this estimation were taken from the PWRV.

The cost of other inputs ($C_O=P_OX_O$) was defined as the sum of the expenditures on farm buildings and land improvement equipment in thousand yen per farm. The price index (P_O) was the price index for farm buildings and land improvement equipment reported in the SRPWRV.

This study has introduced a new procedure for estimating the land price and land cost. Land price reported in the SRPCRWB was a regulated rent until 1970 when the Land Act was revised by the Ministry of Agriculture, Forestry, and Fisheries. It was set to the level under the market rent. After 1971, the "market" rent has been reported. However, this market rent does not seem to reflect the marginal productivity (or shadow price) of land due perhaps to certain regulations in the form of the "standard" rent presented by the Agricultural Council in each region. Egaitsu and Shigeno (1983) and Kuroda (1992) showed that the market rent was much lower than the shadow price in rice production. Mainly because of these shortcomings, the estimated translog total cost function using the land price reported in the SRPCRWB did not satisfy the regularity conditions.

It was thus worthwhile introducing a similar procedure into the present study suggested by Egaitsu and Shigeno (1983) and Kuroda (1992). This study first defined a variable cost function $VC=G\ (Q,\ P\,;\ X_B,\ R)$ where land X_B was introduced as a quasi-fixed input and labor, machinery, intermediate, and other inputs were defined as the variable inputs as in the total cost function given in equation (5). Specifying this variable cost function as a translog type[17], the shadow price of land was estimated by the following equation.

$$P_B^S = \frac{\partial Q}{\partial X_B} = \left(-\frac{\partial VC}{\partial X_B}\right) / \frac{\partial VC}{\partial Q} = \left(-\frac{\partial \ln VC}{\partial \ln X_B} / \frac{\partial \ln VC}{\partial \ln Q}\right)\frac{Q}{X_B}$$

$$= \left(-\frac{\varepsilon_{VCX_B}}{\varepsilon_{VCQ}}\right)\frac{Q}{X_B} \qquad \text{(A. 1)}$$

where ε_{VCX_B} and ε_{VCQ} are respectively the elasticities of the variable cost with respect to land and output. They can easily be estimated using the needed parameter estimates of the variable cost function. By assuming that the farm-firm optimizes with respect to land as a quasi-fixed input and the four variable factor inputs, this shadow price of land is regarded as the market price of land (rent). Note here that the estimated translog variable cost function using the whole 222 samples satisfied the regularity conditions for the whole samples. Multiplying the estimated shadow price of land (P_B^S) expressed in thousand yen per 10 ares by the planted area X_B, the land cost (C_B) was obtained for each sample in the size classes for each year of the 1956-92 period.

Now, the total cost C was obtained as $C = C_L + C_M + C_I + C_B + C_O$. The cost share of each factor input and the revenue share can be obtained as $S_i = C_i/C,\ i = L,\ M,\ I,\ B,\ O$ and $S_Q = TR/C$.

As for the stock of technological knowledge (R), the present study employed the estimating procedure and the basic data for public research and extension activities used in Ito (1989). These basic data are already deflated by an appropriate deflater by Ito and expressed in 1985 prices.

According to Ito, the stock of technological knowledge is determined by the annual investments on research activities and the appropriate weights. The weights are determined by the lag

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[17] As in the case of the translog total cost function (6), the period dummy D_{ST} and size dummies D_{SK} (k = 2, 3, 4, 5, 6) were introduced in order to take care of heterogeneous intercepts

structure and the speed (or rate) of obsolescence of the stock of technological knowledge.

Nōrinsuisan Shiken-Kenkyū Nenpō [*Yearbook of Research and Experiments of Agriculture, Forestry, and Fisheries*] by the 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 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 five years for both 1967 and 1987. As for the rate of obsolescence of the stock of technological knowledge, Ito derived it as 10 percent per year based on his observation that 50 percent of registered patents of agricultural technologies vanish roughly after seven years.

Ito estimated the stock of technological knowledge by the benchmark year 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.

$$R_t = G_{t-5} + (1-\delta_R) R_{t-1} \qquad \text{(A. 2)}$$

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 5-year lag. Assume at this point that the annual rate of change in this stock is g. Then, (A.2) can be written as $R_t = G_{t-5} + (1-\delta_R)\ R_{t-1} = (1+g)\ R_{t-1}$. Thus, the stock at the bench mark year (in this study 1960) Rs can be expressed as

$$R_s = G_{s-4} / (\delta_R + g) \qquad \text{(A. 3)}$$

Note that one cannot obtain the value of g before obtaining the stock of technological knowledge. Ito approximated this rate by the growth rate 10 percent of investment in research for the 1957-59 period when the stock of technological knowledge was still small.

Using (A.2) and (A.3), Ito estimated the stock of technological knowledge for the period 1960-87. Using the same procedure, this study extended the estimates up to 1992 by extrapolating the expenditures on agricultural research up to 1990. Furthermore, for a sensitivity analysis, this study obtained another series of stocks of technological knowledge for the 1956-92 period assuming 8-year lag, since there were still 10 to 50 research topics with 8-year development lags for the above-mentioned two years, 1967 and 1987. In there cases, however, the same rates, 10 percent, were also assumed for both δ_R and g.

Next, Ito 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 thus assumes five years as the maximum for extension activities for a particular innovation.[18] In addition, for a sensitivity analysis purpose, it assumes a 3-year lag also. Using a procedure similar to that used for the stock of technological knowledge, i.e., the benchmark year method, two series of capital stocks of extension activities were estimated for 3- and 5-year lags. In this case, one percent was assumed for the rate of growth of the capital stocks based on the growth rate of extension expenditures (investment) for the 1957-59 period which was very close to one percent. However, since there is no reliable information for the rate of obsolescence of the capital stock of extension activities, this study assumes simply 10 percent as in the case of the stock of technological knowledge.

Following Ito, this study assumes that the capital stock of R&D investments and the capital stock of extension investments 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 1956-92. Since two series of stocks for technological knowledge and two series of stocks for extension expenditures were estimated, there are altogether four different combinations. These four combinations of the R&E capital stocks were used for the sensitivity analysis for the equation system composed of equations (6), (7), and (8). The estimated results for these four options of the R&E capital stocks were in general very similar. However, the combination of 8-year lag for research and 3-year lag for extension investments gave the best results in terms of the R^2s and the t-statistics of the coefficients as well as monotonicity and concavity conditions. Thus, this option was regarded as the best and used for the variable R in the present study.

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[18] This assumption is based on personal discussions with extension people.

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