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Research and Extension Expenditures and Productivity in Japanese Agriculture, 1960-90

by

Yoshimi Kuroda

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Yoshimi Kuroda

Institute of Socio-Economic Planning
University of Tsukuba
Tsukuba, Ibaraki 305, JAPAN

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Abstract

This paper investigates the cause for the decline in the growth of productivity since the late 1960s in Japanese agriculture. For this objective, it investigates the effects of R&E expenditures on the extent and the direction of the bias of technological change in Japanese agriculture for the 1960-90 period based on the translog cost function framework. Empirical results show that the cost-reducing effects of R&E measured in terms of the absolute value of the cost-R&E elasticity increased slightly from 0.194 in 1960 to 0.205 in 1965 and then decreased consistently to 0.110 in 1990. This finding is in general consistent with the finding of the decline or stagnation in agricultural productivity since the late 1960s. The bias of R&E was found to be toward labor, intermediate inputs, and other inputs saving, and machinery and land using. Labor-saving and machinery-using biases are consistent with the Hicksian induced innovation hypothesis.

Key words: agricultural productivity, R&E, translog cost function, cost-R&E elasticity, factor biases of R&E, induced innovation

1 Introduction

The growth of total factor productivity (TFP) has played an important role in increasing the growth of total output of postwar Japanese agriculture (Hayami 1975; Van Der Meer and Yamada 1990; Kuroda 1995). However, according to Kuroda(1995), the rate of growth of TFP has declined considerably since the late 1960s; it was 2.82 percent per annum for the 1960-68 period but reduced to 1.11 percent for the 1969-90 period.

As is well-known, the growth rate of TFP can be decomposed into the effect due to scale economies and the effect due to technological change (Denny, Fuss, and Waverman 1981). Using this procedure, Kuroda (1995) has found that on average 90 percent of the TFP growth rate is explained by the effect due to technological change for the 1960-90 period. Therefore, it may safely be said that the decline or stagnation in the growth rate of TFP since the late 1960s has been caused dominantly by decline or stagnation in technological progress.

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 1985).

The major objective of this study is then to investigate the effects of R&E on the extent of technological change in order to detect the cause for the decline or stagnation in the TFP growth rate since the late 1960s. Furthermore, several researchers have found that the bias of technological change (in particular, labor-saving and machinery-using) is consistent with the Hicksian induced-innovation hypothesis (Kawagoe, Ohtsuka, and Hayami 1986; Kako 1979; Kuroda 1988; Kuroda 1995). However, this result is based on the models where time is used as an index of technological change. Instead, the present study employs a more direct proxy variable for the index of technological change, i.e., R&E rather than time. Thus, the second objective of this study is to examine whether or not the bias due to R&E activities has been consistent with the Hicksian induced-innovation hypothesis. This examination is tantamount to investigating whether or not R&E activities have been sensitive to the movements of agricultural factor markets. To the best of our knowledge, this area of investigation is still relatively new and is therefore expected to offer a better understanding of technological change of the postwar Japanese agriculture.

This study is organized as follows. Section two introduces a translog cost function framework to examine the impacts of R&E on the magnitude as well as on the bias of technological change. Section three presents empirical results. The data necessary for the empirical estimation of the translog cost function as well as the indices of total output, total input, and TFP are given in Appendix. In section four, the results are summarized and some concluding remarks are offered.

2 Methodology

This study introduces an aggregate cost function framework within which the impacts of R&E on the extent and the direction of the bias of technological change can conveniently be measured. The most important reason for the introduction of the cost function instead of the production function approach is that it is much easier to obtain the characteristics of production technology such as scale elasticity and elasticities of factor demand and substitution by estimating the cost function rather than the production function (Christensen and Greene 1976).

It is assumed that the agricultural sector 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 a flow of technological knowledge. This TK implies research output and may be assumed to be produced through a research production function:

$$TK = \psi(R) \tag{2}$$

where R is a stock of technological knowledge which is associated with current and prior investments in research and 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:

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

It is further assumed that the agricultural sector 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. Then, there exists a cost function which is a dual of the production function (Diewert 1974).

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

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); $C = \sum_{i=1}^{5} P_i X_i$ is the minimized total cost, and R is defined in the present study as the accumulated capital stock of research and extension (R&E) expenditures.

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 capital stock of R&E expenditures instead of the annual flow of them produce technological knowledge through the research production function (Anderson 1991). Second, R is a simple sum of the capital stock of expenditures on research activities and the capital stock of expenditures on extension activities. Measuring exclusively the impacts of the capital stock of extension expenditures on agricultural productivity 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 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, 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.[1] 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 capital stock of R&E expenditures on productivity and factor biases would tend to be overestimated.[2]

In order to obtain quantitatively the impacts of the capital stock of R&E on the extent and the direction of the bias of technological change, the following translog form is specified for the cost function (4).

$$\begin{aligned} \ln C &= \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^{5} \alpha_i \ln P_i + \alpha_R \ln R \\ &\quad + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5} \gamma_{ij} \ln P_i \ln P_j \end{aligned}$$

[1]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 agricultural productivity. However, none of these trials was successful due mainly to the multicolinearity between these two variables.

[2]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.

$$+\sum_{i=1}^{5}\delta_{Qi}\ln Q\ln P_i+\mu_{QR}\ln Q\ln R$$
$$+\sum_{i=1}^{5}\mu_{iR}\ln P_i\ln R+\frac{1}{2}\beta_{RR}(\ln R)^2, \qquad (5)$$

where $\gamma_{ij}=\gamma_{ji}$ and $i=j=L,M,I,B,O$.

The cost share (S_i) and revenue share (S_Q) equations are derived through the Shephard's lemma as[3]

$$\begin{aligned} S_i &= \frac{\partial C}{\partial P_i}\frac{P_i}{C}=\frac{\partial \ln C}{\partial \ln P_i} \\ &= \alpha_i+\sum_{j=1}^{5}\gamma_{ij}\ln P_j+\delta_{Qi}\ln Q+\mu_{iR}\ln R \end{aligned} \qquad (6)$$

$$\begin{aligned} S_Q &= \frac{\partial C}{\partial Q}\frac{Q}{C}=\frac{\partial \ln C}{\partial \ln Q} \\ &= \alpha_Q+\sum_{i=1}^{5}\delta_{Qi}\ln P_i+\gamma_{QQ}\ln Q+\mu_{QR}\ln R \end{aligned} \qquad (7)$$

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

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (5) this requires that $\sum_{i=1}^{5}\alpha_i=1$, $\sum_{i=1}^{5}\gamma_{ij}=0$, $\sum_{i=1}^{5}\delta_{Qi}=0$, and $\sum_{i=1}^{5}\mu_{iR}=0$ $(i=j=L,M,I,B,O)$. The translog cost function (5) has a general form in the sense that the restrictions of homotheticity and neutrality with respect to R&E 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 that the

[3]The revenue share equation is also derived since this provides an additional information to identify the coefficients of the output-associated variables in the regression. For a detailed discussion on the inclusion of the revenue share equation in the system of regression equations, see Ray (1982) and Capalbo (1988).

following set of restrictions on the translog cost function (5); $\delta_{Qi} = 0$ ($i = L, M, I, B, O$), implying that changes in output level do not have any effect on the cost shares.

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 (5); $\alpha_Q = 1$, $\gamma_{QQ} = \delta_{Qi} = \mu_{QR} = 0$ ($i = L, M, I, B, O$).

Furthermore, the test of neutrality with respect to the R&E capital stock 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 (5).

Now, the impacts of the R&E capital stock 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 R&E capital stock .

$$-\varepsilon_{CR} = -\frac{\partial \ln C}{\partial \ln R} = -(\alpha_R + \mu_{QR} \ln Q + \sum_{i=1}^{5} \mu_{iR} \ln P_i + \beta_{RR} \ln R) \qquad (8)$$
$$i = L, M, I, B, O.$$

Next, the bias effects of R&E, 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) 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 R&E, the Hicksian bias measure may be defined as

$$
\begin{aligned}
B_i^e &= \partial S_i(Q,P,R)/\partial \ln R|_{dC=0} \\
&= B_i + (\frac{\partial \ln S_i}{\partial \ln Q})(\frac{\partial \ln C}{\partial \ln Q})^{-1}(-\frac{\partial \ln C}{\partial \ln R})
\end{aligned}
\tag{9}
$$

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 R&E 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 induced innovation hypothesis.

Using the parameters of the translog cost function in the present study, equation (9) can be expressed as

$$
\begin{aligned}
B_i^e = \frac{\mu_{iR}}{S_i} + \frac{\delta_{Qi}}{S_i}(-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}}) \\
i = L, M, I, B, O
\end{aligned}
\tag{10}
$$

where (ε_{CQ}) is the cost-output elasticity and can be estimated through the translog cost function (5) by

$$
\varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \mu_{QR} \ln R \qquad i = L, M, I, B, O.
\tag{11}
$$

Since homotheticity implies $\partial \ln S_i/\partial \ln R = 0$, 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.

For statistical estimation, since the right-hand-side variable Q in the cost function (4) is in general endogenously determined, a simultaneous estimation procedure should be employed in the estimation of the set of equations consisting of the cost function, four of the five cost share equations, and one revenue share equation. 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 and R&E. 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.

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

3 Empirical Results

In the process of estimating 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 R&E, were statistically tested applying a Wald-Chi square test procedure. The computed Chi-square statistics for these three tests were 15.1, 319.6, and 37.8 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 rather high for all the equations except for the labor cost and revenue share equations. Though a little low, the adjusted R^2s for these equations, 0.672 and 0.456, are not that bad. Thus, the fit of the model as a whole may be said to be good and reasonable. In addition, monotonicity and concavity of the cost function were checked and satisfied for the approximation point. This set of estimates is referred to as the final specification of the model and will be used for further analyses.

3.1 Cost-Reducing Effects of R&E

To begin with, let us examine the impacts of R&E on agricultural productivity by scrutinzing the estimate of the negative of the cost-R&E elasticity ($-\varepsilon_{CR}$) which is presented in Table 2. This table shows that this elasticity increased from 0.194 in 1960 to 0.205 in 1965 and stuck to that level until 1966 (i.e., 0.204) before it declined to around 0.200 in 1967 and stuck again to that magnitude until 1971. Thereafter, it decreased consistently to 0.110 in 1990. This finding in general supports the one obtained by Ito (1992) who estimated the restricted cost function with land being a fixed input using the micro data of average farm for each of five size classes. However, the magnitudes of the elasticities in the present study are consistently larger than those for the five size classes obtained by Ito (by, roughly speaking, 0.05 to 0.08). It is likely that Ito might have failed to capture amply the spill-over effect of R&E activities due to the usage of micro-data rather than the macro data for the agricultural sector.

The present result indicates that the cost-reducing effect of R&E increased for the period 1960-66 and reached a plateau for the 1967-71 period at a slightly lower level than that of the 1965-66 period. However, after 1972 this effect declined consistently for the rest of the whole study period. This movement of the cost-reducing effect of R&E is in general consistent with that of the TFP of the agricultural sector as stated in the very beginning of this study. That is, the TFP grew fairly rapidly for the 1960-68 period with the annual average growth rate of 2.82 percent. However, it grew much more slowly for the 1969-90 period with 1.11 percent per annum. It can thus be said that although there was a lag of several years before the cost-reducing effect of R&E started declining, the movement of the cost-reducing effect of

R&E traces very well that of the TFP for the whole study period. This indicates that the decline in the cost-reducing effect of R&E has been a major cause for the slowdown in the growth of the TFP.

What were then the causes for the decline in the cost-reducing effect of R&E? To answer this question, it is convenient to rewrite the negative of the cost-R&E elasticity given in equation (8) as $-\varepsilon_{CR} = -\partial \ln C/\partial \ln R = (-\partial C/\partial R)(R/C) \doteq (-\partial C/\partial \psi)(\partial \psi/\partial R)(R/C)$. The last expression has been derived based on the cost function (4). That is, the cost-reducing effect of R&E can be decomposed into (1) the shadow value or the efficiency of utilization of research "outputs" in agricultural production $(-\partial C/\partial \psi)$, (2) the shadow value or the efficiency of technological knowledge to produce research "outputs" in research production $(\partial \psi/\partial R)$, and (3) the ratio of the stock of R&E to the total cost of agricultural production (R/C). Let us then evaluate these factors.

To begin with, the R/C ratio increased consistently over the whole 1960-90 period as shown in Table 2. [4]

Next, what about the efficiency of agricultural research output production $(\partial \psi/\partial R)$? As evident from equation (2), an increase in current and past investments in research and extension activities will increase research achievements through an increased stock of technological knowledge which was defined in section 2 as an accumulated capital stock of R&E expenditures. Table 3 presents the annual expenditures on research and extension activities and the accumulated capital stock of R&E expenditures. They are deflated by the research expenditure deflator and expressed in 1985 prices. According to this table, the R&E capital stock increased fairly sharply from the early-1970s through the mid-1980s (the annual compound growth rate for the 1971-85 period was 7.1 %) then the rate of increase started declining after the mid-1980s (the annual compound growth rate for the 1985-90 period was 2.6 %). These movements reflect the rather sharp increase in research

[4] This ratio does not mean the share of the capital stock of R&E expenditures in the total cost of agricultural production since the former is treated as a shift parameter in the cost function (4).

and extension expenditures in the 1960s and the stagnation in these expenditures since the early 1970s up to the mid-1980s. It may be inferred from this observation that the efficiency of research output production was high for the period from the early-1970s through the mid-1980s and then started declining since then. It is likely that this efficiency will further decline in the future if the trend of stagnant expenditures on research and extension activities continues.

Finally, what about the efficiency of utilization of research outputs for agricultural production $(-\partial C/\partial\psi)$? It is very likely that the efficiency of utilization of research outputs may have declined because of dampened incentives of farmers to utilize newly developed technologies due largely to the acreage setaside programs for rice production since 1969. [5] In addition, substitutions of domestic farm products for imported farm products, either crop products or livestock products, may have limited the chances of newly developed technologies to materialize.

These observations and inference may indicate that declines in the efficiency, both in research output production and research output utilization, more than offset the positive effect due to the increase in the ratio of the R&E capital stock to the total cost. As a result, the cost-reducing effect of R&E decreased consistently since the early-1970s.

3.2 The Bias Effects of R&E

The direction of the factor biases due to changes in the R&E capital stock can be evaluated by equation (10). The estimates of B_i^es are presented in Table 4. They are expressed in terms of elasticities and significant at the conventional five percent significance level. They show that changes in the R&E capital stock had bias effects toward machinery and land using, and

[5] In order to show the mechanism of why acreage setaside programs cause the decline in farmers' production incentives, Ito (1994) showed rigorously that acreage setaside programs in rice production have effects which disturb farmers in choosing the optimum technology.

labor, intermediate inputs, and other inputs saving during the study period. For the labor-saving and land-using biases, the pure bias effects (shifts in the expansion path) were found to be dominant, while the scale effects (movements along the nonlinear expansion path) are fairly significant for the machinery-using, intermediate inputs-saving, and other inputs-saving biases. These results roughly support the ones obtained by Ito (1992) and Kuroda (1995).

Let us now proceed to test for 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 movements, and thus the correlation of factor-saving biases to rising factor prices and vice versa is inspected.

The direction of the factor biases is associated, respectively, with the rising trends of the prices of labor and with the declines in the prices of machinery relative to the output price. In this sense, the direction of the biases with respect to changes in the R&E capital stock is consistent with 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.

However, one would have expected land-saving bias since the price of farmland relative to the price of output increased very rapidly. In addition, intermediate inputs-using bias would have been expected since the prices of these inputs relative to the output price decreased. Against these expectations, the estimated results for these inputs were land-using and intermediate inputs-saving biases. Even with such a result, the validity of the induced-innovation hypothesis may be kept intact. The concept of the Hicksian induced-innovation hypothesis implicitly assumes that the historical innovation possibility is neutral. However, the innovation possibility curve, which is the envelope of all unit isoquants, may shift in a nonneutral manner (Kennedy, 1964; Ahmad, 1966). If, for example, it is comparatively easier to develop technology that will use relatively more of a single factor, say, land, one could say that the innovation possibility function is biased in a land-using and machinery-using direction. Thus, biasedness of technological change need not be intimately associated with factor price changes.

Along this line of thought, this study argues that innovation possibilities may have been biased towards land-using and intermediate inputs-saving regardless of the role of factor prices in determining biases. In particular, the innovation possibility curve might have shifted in the land-using direction, considering the fact that farm mechanization in general requires larger scale land area for efficient utilization of machinery. Another argument is that the parallel movement of the land price and the land-using bias implies that the land price might have been largely endogenous, suggesting that technological change bias seems to have been an important factor which affected the movement of land price during the period in question.

4 Summary and Concluding Remarks

This study has investigated the impacts of investment in public R&E activities on the productivity of the Japanese agricultural sector for the 1960-90 period by estimating the translog total cost function. The empirical findings may be summarized as follows.

(1) The cost-reducing effect of the R&E capital stock increased and remained at fairly high level during the 1960-71 period. However, it declined consistently for the rest 1972-90 period. Roughly speaking, this finding is consistent with the movements in the growth of TFP of the agricultural sector for the 1960-90 period. Thus, a major reason for the declines in the growth rates of TFP after 1969 may be considered to have been the decline in the cost-reducing effect of the R&E capital stock for the corresponding period. (2) The major causes for the decline in the cost-reducing effect of the

R&E capital stock were found to have been sharp declines in the efficiency both in the production and in the utilization of new technologies. This in turn may have been due to the stagnation in R&E investments from the early-1970s up to the mid-1980s and dampened incentives of farmers to utilize new technologies caused by acreage setaside programs and substitutions of domestic farm products by imported farm products. (3) The direction of the factor biases due to R&E activities was toward machinery and land using, and labor, intermediate inputs, and other inputs saving. The finding of labor-saving and machinery-using biases is consistent with the Hicksian induced-innovation hypothesis. This implies that the public research activities have been sensitive to the movements in these factor markets and hence the conditions of factor endowments.

As a concluding remark, a policy implication may be derived from the first two findings. It is clear that in order to raise the growth of TFP of the agricultural sector, the cost-reducing effect of the R&E capital stock has to be increased. For this purpose, it is essential for policy makers to give high incentives for entrepreneurial farmers to utilize newly developed technologies in their production. One way to do this is to modify the existing acreage setaside program for rice production which forces acreage restrictions uniquely to all farmers, entrepreneurial or not. A new direction of such a modification may take a form where farmers can choose from at least two options: that is, farmers can either utilize their entire farmlands but without price supports or follow the setaside program with guaranteed prices.

Appendix[6]

The basic data required to estimate the Törnqvist indices of total output, total input, and total factor productivity (TFP) are the value and price index of each item of outputs and inputs. These basic data are also used to estimate the system of the translog cost function and the cost and revenue share equations. However, it is more convenient to start from the variable definitions of and data processing of the latter. After that, those of the former will be explained.

The variables required to estimate the cost function model are the total cost, the revenue, the quantity of total output, the prices and cost shares of the five factors of production, i.e., labor, intermediate inputs, machinery, land, and other inputs, and the capital stock of research and extension (R&E) expenditures. The data were collected and processed for the Japanese agricultural sector for the 1960-90 period.

The quantity and price indices of total output (Q and P) were computed by the Törnqvist approximation method of the Divisia index. For this computation, eleven categories of farm products were distinguished, from among crop and livestock products as well as agricultural services. The base year of these and the following indices were set at 1985.

The source of data for the values of products is **National Accounts of Agriculture and Food-Related Industries** (NAAF), 1992 edition, published annually by the Ministry of Agriculture, Forestry, and Fisheries (MAFF). The data source for the price indices of products is the NAAF, 1992.

The quantity and price indices of labor input (X_L and P_L) were obtained in the following manner. The number of work-hours per year of male and female agricultural workers for the period 1960-81 were taken from Yamada (1984) (Appendix Table 9, p.145). The work-hours data for the years 1982-90 were obtained using Yamada's (1982) method. The sources of data for this computation are various issues of the **Statistical Yearbook of the**

[6]The data set will be provided on request.

Ministry of Agriculture, Forestry, and Fisheries (SY) and the **Survey Report on Farm Household Economy** (FHE) published annually by the MAFF.

Using the data for the national average farm household from the FHE, the number of labor hours per day per male and female family workers were obtained by dividing the total agricultural work hours per year by the corresponding quality-adjusted total labor days per year. These numbers of hours are also assumed for hired labor.

Dividing the total numbers of work-hours for the agricultural sector by the above numbers of work-hours per day, the total numbers of work-days per year were obtained for male and female workers separately (X_L^m and X_L^f).

For the prices of male and female labor, the daily wage rates of temporarily-hired workers were obtained from the PWRV. These wage rates were then inflated by the boarding rates which were obtained separately for male and female labor obtained by translating the values of meals into money value. These boarding rates were taken from Izumida (1987). They were important especially for the 1950s and 1960s. These inflated wages were designated as P_L^m and P_L^f. Using the numbers of work-days per year, X_L^m and X_L^f, and the daily wage rates, P_L^m and P_L^f, the cost of labor was obtained as $P_L X_L = P_L^m X_L^m + P_L^f X_L^f$. This and the following factor costs are expressed in billion yen per year. Next, the quantity and price indices of labor input (X_L and P_L) were computed by the Törnqvist approximation method using the quantity and price data of male and female labor, X_L^m and X_L^f, and P_L^m and P_L^f.

The cost of intermediate inputs ($P_I X_I$) was obtained by adding up the expenditures on seed, fertilizer, feed, agri-chemicals, fuels and electricity, other intermediate inputs, and agricultural services. The Törnqvist quantity and price indices of intermediate inputs (X_I and P_I) were obtained using the set of data on the expenditures and price indices of the above seven items of intermediate inputs. The sources of data are the same as in the case of the quantity and price indices of total output.

In order to obtain the quantity and price indices of machinery inputs, the Jorgenson (1974) service price model was applied. Machinery inputs in this paper consist of farm machinery and farm automobiles. According to Jorgenson, the service price of each component of this category of capital assets (P_t) is yielded by

$$P_t = q_t(r_t + \delta_t). \tag{A.1}$$

where q_t, r_t and δ_t are the asset price, interest rate, and depreciation rate at time t. Here, capital gain was ignored as being unimportant, since a farm machine, once it is bought by a farmer, is usually used for a specific purpose of agricultural production with little or no aim at obtaining capital gain.

The rate of depreciation is computed from the following identity:

$$K_t = K_{t-1} + I_t - \delta_t K_{t-1} \tag{A.2}$$

where K_{t-1} is capital stock at the end of period $t-1$ and I_t is gross investment at time period t. Using the interest rate r_t and the rate of depreciation δ_t together with the asset price index q_t, the service price of this component of machinery capital assets can now be obtained by $(A.1)$.

The flow of services for each capital component is assumed to be proportional to the stock K_t,

$$V_t = P_t K_{t-1} \tag{A.3}$$

where V_t is the value of service flow at t.

Using this formula, the cost of machinery ($P_M X_M$) was obtained by adding the values of service flows of farm machinery and farm automobiles. Next, using the series of computed service prices and values of service flows of these capital assets, the Törnqvist quantity and price indices of machinery input (X_M and P_M) were computed.

The same procedure was applied in order to obtain the cost ($P_O X_O$) and the quantity and price indices (X_O and P_O) of other inputs. The other inputs are composed of large plants, animals, and farm buildings and structures.

The following procedures were applied to obtain the capital stocks and gross investments for the 1960-90 period. The capital stock of farm machinery was obtained by the perpetual inventory method. Those of farm automobiles, plants, and animals were computed by the physical stock valuation method. For the capital stocks of farm buildings and structures, the benchmark year method was applied.

The major sources of data for these computations are the **Statistical Yearbook of Farm Machinery, Agricultural Survey, Statistics of Farm Products**, and **Statistics of Livestock Products** published annually by the MAFF.[7] The amounts of the gross investments of these capital items were directly obtained from the **NAAF**.

The sources of data for farm machinery, farm automobiles, plants, animals, and farm buildings and structures are as follows. The basic data of capital stocks and gross investments for these capital assets for the 1960-79 period are from Izumida (1987). The data for the period 1980-90 were obtained following the Izumida's procedures based on the same set of the original data sources used by Izumida. However, the data of farm automobiles for the 1960-66 period could not be obtained for lack of data.

The asset price indices were obtained from the NAAS, the 1963 and 1992 issues. The market interest rate used here is the rate for loan trust taken from **Japan Statistical Yearbook** published annually by the Bureau of Statistics, Office of the Prime Minister, various issues.

The quantity and price indices of land input are obtained in the following manner. The planted areas of paddy and upland fields were multiplied by the respective prices per unit of land to obtain the total values of paddy and upland fields. In order to obtain the values of the service flows of paddy and upland fields, these total land values were multiplied by the same market interest rate (r_t) as used in obtaining the service flows of the capital assets.

[7]The detail of the sources of data and the computational procedures are given in Izumida(1987).

The cost of land (P_BX_B) was obtained by summing up these service flows.

Using the prices of paddy and upland fields and the respective values of the service flows, the Törnqvist quantity and price indices of land input (X_B and P_B) were computed.

The source of data for the planted areas of paddy and upland fields is the SY, various issues. The prices of land were taken from **Survey Report on Prices and Rents of Paddy and Upland Fields** published annually by the Japan Real Estate Institute. These prices are for medium-quality paddy and upland fields which are for farming purposes and are in general located in farming areas. Since they are expressed in yen per unit of land (say, hectare), they were transformed into indices by setting the 1985 value to 1.0.

The total cost (C) was calculated as

$$C = P_LX_L + P_MX_M + P_IX_I + P_BX_B + P_OX_O. \tag{A.4}$$

The revenue share and the cost share of each component were then obtained by

$$S_Q = PQ/C \tag{A.5}$$

and

$$S_i = P_iX_i/C \tag{A.6}$$

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

Finally, the Törnqvist index of total input (F) was computed using the Törnqvist price and quantity indices, P_L, P_M, P_I, P_B, and P_O, and X_L, X_M, X_I, X_B, and X_O. Using the Törnqvist quantity indices of total output (Q) and total input (F), the Törnqvist quantity index of total factor productivity (TFP) was computed as Q/F.

As for the stock of technological knowledge, the present study employed the estimating procedure and the basic data for public research and extension activities used in Ito (1992). These basic data are already deflated by an appropriate deflator 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 structure and the speed (or rate) of obsolescence of the stock of technological knowledge.

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 six years for these three years. As for the rate of obsolescence of the stock of technological knowledge, Ito assumed 10 percent per year following Goto et al. (1986).

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.

$$R_t = G_{t-6} + (1 - \delta_R)R_{t-1} \tag{A.7}$$

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.7) 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 1960) R_s can be expressed as

$$R_s = G_{s-5}/(\delta_R + g) \tag{A.8}$$

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

Using (A.7) and (A.8), Ito estimated the stock of technological knowledge for the 1960-87 period. Using the same procedure, this study extended the estimates up to 1990. Furthermore, for a sensitivity analysis, this study obtained two more series of stocks of technological knowledge for the 1960-90 period assuming 8- and 10-year lags, since there were still five to ten research topics with 8- to 10-year development lags for the above-mentioned three years, 1967, 1977, and 1987. In these cases, however, the same rates, 10 percent each, were also assumed for 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 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 a maximum for extension activities for a particular innovation.[8] In addition, for a sensitivity analysis purpose, it also assumes three years, too. Using a similar procedure as 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, 10 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 10 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.

As Ito did, this study assumes that the stocks of technological knowledge

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

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 1960-90 period. Since there are three series of stocks for technological knowledge and two series of stocks for extension expenditures, respectively, there are altogether six different combinations. These six combinations of the R&E capital stocks were used for the sensitivity analysis based on the estimating equation system composed of equations (5), (6), and (7). The estimated results for these six options of the R&E capital stocks were in general very similar. However, the combination of 10-year lag for research and 5-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 used for the variable R in the present study.

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Table 1: Parameter Estimates of the Translog Cost Function for the Japanese Agricultural Sector, 1960-90

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	12.025	1072.7	γ_{MI}	-0.064	-2.7
α_Q	0.856	67.9	γ_{MB}	0.005	0.3
α_L	0.295	47.5	γ_{MO}	0.020	0.9
α_M	0.092	25.2	γ_{IB}	-0.033	-1.6
α_I	0.305	75.1	γ_{IO}	-0.104	-3.8
α_B	0.187	57.4	γ_{BO}	0.115	5.8
α_O	0.121	21.3	δ_{QL}	-0.013	-0.3
β_R	-0.112	-2.6	δ_{QM}	0.111	2.8
γ_{QQ}	0.642	4.4	δ_{QI}	0.071	1.5
γ_{LL}	0.080	4.2	δ_{QB}	-0.033	-0.8
γ_{MM}	0.015	0.7	δ_{QO}	-0.137	-2.6
γ_{II}	0.133	3.1	μ_{QR}	0.039	1.2
γ_{BB}	0.025	1.2	μ_{LR}	-0.033	-2.1
γ_{OO}	0.029	0.8	μ_{MR}	0.029	2.5
γ_{LM}	0.024	1.8	μ_{IR}	-0.019	-1.4
γ_{LI}	0.068	4.2	μ_{BR}	0.045	3.8
γ_{LB}	-0.111	-9.1	μ_{OR}	-0.023	-1.4
γ_{LO}	-0.061	-3.2	β_{RR}	0.091	2.4

Estimating Equations	$\bar{R}^2$
Cost function	0.931
Labor share equation	0.672
Machinery share equation	0.966
Intermediate inputs share equation	0.938
Land share equation	0.926
Revenue share equation	0.456

Table 2: The Negative of the Cost-R&E Elasticity ($-\varepsilon_{CR}$) and the Ratio of the R&E Stock to the Total Cost (R/C), 1960-90

Year	Negative of Cost-R&E Elasticity	Ratio of R&E Stock to Total Cost
1960	0.194	1.72
1961	0.197	1.68
1962	0.201	1.77
1963	0.204	1.92
1964	0.203	1.94
1965	0.205	2.05
1966	0.204	2.11
1967	0.199	2.14
1968	0.199	2.00
1969	0.199	2.06
1970	0.200	1.97
1971	0.201	2.06
1972	0.195	2.22
1973	0.190	2.39
1974	0.189	2.37
1975	0.182	2.53
1976	0.177	2.84
1977	0.169	2.97
1978	0.161	3.33
1979	0.155	3.48
1980	0.151	3.37
1981	0.143	3.73
1982	0.135	3.92
1983	0.130	4.27
1984	0.118	4.80
1985	0.112	5.07
1986	0.110	5.26
1987	0.109	5.62
1988	0.109	6.09
1989	0.110	6.26
1990	0.110	6.32

Notes:
1. The negative of the cost-R&E elasticity was estimated using equation (8).
2. The R/C ratio is expressed in percent.

Table 3: Annual Expenditures on Research and Extension (R&E) Activities and the Accumulated Capital Stock of R&E Expenditures,1960-90

Year	Research Expenditures	Extension Expenditures	Total Expenditures	Capital Stock of R&E Expenditures
1960	21.2	15.5	36.7	250.9
1961	24.5	16.8	41.3	254.7
1962	28.3	18.9	47.2	263.9
1963	35.7	16.9	52.6	276.7
1964	38.1	17.2	55.3	283.8
1965	37.9	17.8	55.6	287.1
1966	42.7	20.4	63.1	288.3
1967	46.2	21.3	67.5	293.2
1968	50.7	22.3	73.0	297.1
1969	58.7	25.3	84.0	302.5
1970	63.4	28.2	91.6	311.2
1971	71.1	29.9	101.0	325.1
1972	74.2	31.1	105.3	342.2
1973	76.1	29.8	105.9	366.0
1974	74.7	30.4	105.1	392.7
1975	78.4	34.6	113.0	419.5
1976	77.5	34.9	112.5	450.1
1977	80.1	36.3	116.4	582.4
1978	77.2	38.2	115.4	514.7
1979	79.8	36.1	115.9	552.3
1980	81.3	35.5	116.8	595.2
1981	82.0	35.5	117.5	641.7
1982	79.0	37.4	116.4	688.0
1983	78.7	35.5	114.2	733.5
1984	76.8	34.3	111.1	814.6
1985	77.8	34.2	111.9	847.0
1986	78.0	34.2	112.3	865.3
1987	88.5	34.2	122.7	896.3
1988	N/A	N/A	N/A	919.4
1989	N/A	N/A	N/A	941.7
1990	N/A	N/A	N/A	962.9

Notes:
1. Data for research and extension expenditures are from Ito (1992). They are already deflated by an appropriate price index for agricultural research and extension expenditures by Ito and expressed in ten billion yen. Ito has not updated the expenditure data since 1988. N/A designates "not available."
2. The procedure for estimating the accumulated capital stock of research and extension expenditures is fully explained in the Appendix.

Table 4: Bias Effects of Technological Change Due to R&E

Factor input	B_i	B_i^Q	B_i^e
Labor	-0.112	-0.005	-0.117
	(-2.1)	(-0.3)	(-2.1)
	[95.9]	[4.1]	[100.0]
Machinery	0.313	0.135	0.448
	(2.5)	(2.8)	(3.1)
	[69.8]	[30.2]	[100.0]
Intermediate	-0.061	0.026	-0.035
inputs	(-1.4)	(1.5)	(-1.7)
	[174.4]	[-74.4]	[100.0]
Land	0.243	-0.020	0.223
	(3.8)	(-0.8)	(3.0)
	[108.8]	[-8.8]	[100.0]
Other inputs	-0.188	-0.128	-0.316
	(-1.4)	(-2.6)	(-2.1)
	[59.4]	[40.6]	[100.0]

Notes:
1. The biases were estimated at the approximation point using equations (10) and (11).
2. B_i is the pure bias effect (μ_{iR}/S_i), $B_i^Q$is the scale effect $((\delta_{Qi}/S_i)(-\varepsilon_{CR}/\varepsilon_{CQ}))$, 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.