[*Jpn. J. Rural Econ.* Vol. 5, pp. 12-34, 2003]

Impacts of Set-Aside and R&E Policies on Agricultural Productivity in Japan, 1965-97

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This paper estimates "input-saving" and "output-augmenting" productivity (*PGX* and *PGY*) with respect to the stock of technological knowledge resulting from public R&E investments as well as returns to scale (*RTS*) at farm level in Japanese agriculture for the period 1965-97. It also investigates the impacts of set-aside and public R&E policies on *PGX, PGY,* and *RTS.* In attaining objectives, a multi-product translog variable cost function is estimated using farm management data for Japanese agriculture excluding the Hokkaido district. Empirical results show that both *PGX* and *PGY* have experienced decreasing trends, while returns to scale have shown increasing trends since 1972. Additionally, the set-aside programs seemed to have the effect of discouraging larger-scale farming. Meanwhile, public R&E activities have encouraged larger-scale farming but have had negative effects on *PGX* and *PGY.* The negative effects may have been caused mainly by declining effciency in the utilization of research outputs on the part of farmers probably because of dampened incentives due partly to the set-aside programs.

Key words: set-aside programs, R&E investments, "input-saving" and "output-augmenting" productivities, returns to scale, multi-product translog variable cost function.

1. Introduction

Total factor productivity (TFP) has been considered as a main source of growth of production in agriculture. Figure 1 shows changes in TFP of different farm size classes for the period 1957-97 in Japan excluding Hokkaido.[1]

At least two important observations can be gathered from Fig. 1. First, farms in all size classes experienced fairly rapid increases in TFP from 1957 to 1975, in particular, for the period 1971-75 during which a "larger-scale mechanization" became popular, but after 1975 until recently, they faced rather stagnant TFP. However, we can observe some slight differences among different size classes in the movements of TFP. Second, it seems that the larger the size classes, the greater the TFP index for the entire observation period.[2]

What are the causes for this stagnation in the TFP growth since the mid-1970s? Kuroda [35] examined the impacts of public R&D and extension (R&E in short hereafter) investments on changes in TFP based on the estimates of the translog cost function using the aggregate agricultural sectoral data for 1960-90. He found that a major reason for the decline in the growth rates of TFP may have been the decline in the cost reduction effect of R&E.

Similar to Kuroda [35], this study will investigate the impacts of public R&E activities on agricultural productivity. Unlike Kuroda [35], however, the investigation will be carried out

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We acknowledge useful comments by Anit N. Mukherjee, Romeo G. Teruel, and Radha Balkaransingh. We also thank Sumio Hamagata for his able computations. This work was partially funded by a Grant-in-Aid for Scientific Research (C) No. 12660197 from the Ministry of Education, Science, Sports and Culture of Japan (MESSC), the Nomura Foundation for Social Sciences, the Japan Securities Scholarship Foundation, the Murata Science Foundation, and the Statistical Data Bank Project of the MESSC. However, the opinions expressed are those of the authors alone.

for farms with different size classes based on farm management data. This method will therefore enable us to evaluate the impacts of public R&E activities on agricultural productivity among different size classes.

In addition, this study will examine the impacts of set-aside programs on agricultural productivity. A set-aside program for rice production was introduced for the first time, in the history of Japanese agriculture, in 1969 because of surplus rice which manifested itself since 1965. Since then, the set-aside area has an increasing trend, though there were fluctuations over time as shown in Fig. 2. It is therefore not only in economic sense meaningful but also academically intriguing to find out what effects the set-aside programs have on productivity of farms with different land scales.

Several studies have been conducted to examine the impacts of set-aside programs in Japanese agriculture. Hasebe [16] investigated the impacts of set-aside programs on land movements. Kusakari [36] found that the "given-up income" due to set-aside programs was greater on larger farms than on smaller farms. Ito [19] examined the impacts of rice set-aside programs on rice income and demand for rented land. Kondo [31, 32] investigated the impacts of set-aside programs on rice income and land rent. In fact, there are many papers in this field written on foreign agriculture like Arnade [2], Gisser [13], Fraser [10, 11], Bourgeon, Jayet, and Picard [4], Rygnestad and Fraser [40], to name only a few. But, none of them attempted to examine the impacts of set-aside programs on agricultural productivity. In this sense, this is a first ever study attempting to examine quantitatively the impacts of set-aside programs on agricultural productivity.

Furthermore, this paper will estimate returns to scale,[3] which will offer very important policy information when it comes to transforming the present structure of small-scale farming to larger-scale farming. In addition, as in the case of agricultural productivity, we will estimate the impacts of set-aside and public R&E policies on returns to scale. Again, this study can be considered as pioneering in evaluating quantitatively the impacts of set-aside programs on returns to scale.

In order to achieve these objectives, this study employs the framework of a multi-product variable (or restricted) translog cost function which consists of two outputs (crop and livestock products), three variable inputs (machinery, intermediate input, and other input), and three exogenous variables (labor and land as fixed inputs and the stock of technological knowledge based on public R&E investments). Note that this study employs explicitly a stock of technological knowledge as a proxy for technological change instead of the usual time trend. Thus, the productivity to be estimated in this study will be the productivity with respect to the stock of technological knowledge at the farm level.

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

2. Analytical Framework

Consider the following variable cost function

$$C=G(Q, P, Z) \qquad (1)$$

where Q is a vector of outputs, P denotes a vector of variable input prices, and Z is a vector of exogenous variables. In this model, Q is disaggregated into crop (Q_G) and livestock products (Q_A); P consists of the prices of machinery (P_M), intermediate input (P_I), and other input (P_O); Z consists of labor (Z_L) and land (Z_B) as fixed inputs and a stock of technological knowledge (Z_R) which can be regarded as a productivity parameter external to all of the farms. Dummy variables are distinguished for period (D_p), farm sizes (D_s), and weather conditions (D_w). Several comments may be necessary here for the specification of the variables in this cost function.

First, the major reason for introducing a multi-product cost function is that we want to explicitly test whether or not Japanese agricultural production is characterized by weak separability in outputs and input nonjointness. If these hypotheses are rejected, employing a single output cost function may lead to a biased result. In addition, when it comes to evaluating the effects of set-aside programs on agricultural productivity and returns to scale, we have to note that the set-aside programs are a part of production adjustment measures which have encouraged farmers to switch rice to other crops. In this sense, it is expected that we can capture in a more comprehensive manner the impacts of set-aside programs on agricultural productivity and returns to scale than in the case of focusing only on rice production.

Second, to make it not only possible but also convenient to estimate the impacts of changes in planted area on various indicators such as productivity and scale economies, we treat land as a fixed input in this paper. In this manner, we may evaluate the impacts of the set-aside programs, at least indirectly, on productivity and scale economies. In addition, the price of land (or rent) during the postwar years was set at a certain low level by the government and therefore did not reflect the market price until at the latest 1975. Using these land prices may result in biases in the estimated results since this covers almost one third of all samples in the study period, 1965-97. Judging from this, it may be more realistic to treat land as a fixed input rather than a variable input. Instead, it may be interesting and informative to estimate the shadow price of land based on the parameter estimates of the variable cost function.[4)]

Third, it seems to be conceptually natural to treat labor as a variable input since farmers can vary their labor input during the period of production, i.e., one year. On the other hand, however, it may be more realistic and appropriate to regard agricultural labor market as imperfect considering the fact that almost 97% of labor input is family labor. Although it is still possible to utilize farm wage rate of temporary-hired labor to evaluate family labor,[5)] such method may cause biases in the estimated results. Instead, by treating labor as a fixed input, one may estimate the shadow price of family labor using the estimated parameters of the variable cost function, which may give an intriguing picture of the implicit price of family labor for different size classes. We thus treat labor as a fixed input in the present study.[6)]

Fourth, machinery, intermediate input, and other input are defined as variable inputs. There would not be any objections to treat intermediate input as a variable input. What about machinery? Conceptually, this is usually treated as a fixed input. However, mechanical custom jobs have been getting more and more popular among farms in Japan. This may indicate that adjustments for machinery stock have become much easier, suggesting that we may treat machinery input as a variable rather than fixed input. Next, other input consists of animals, plants, and farm buildings and structures. Although this input appears to be more like a fixed input than machinery, this study simply assumed that it is a variable input.[7)]

Finally, since a stock of technological knowledge has the characteristics of a public good, all farms can, through non-excludability of utilization, have access to all technological information. Therefore, we define in the cost function the total stock of technological knowledge at the national aggregate level rather than at the per-farm basis. Note here that this study employs explicitly the stock of technological knowledge as a proxy for technological change instead of a time trend.[8)]

The productivity to be estimated in this study will therefore be the productivity with respect to the stock of technological knowledge at farm level.

Now, for econometric analysis the following translog cost function is utilized.

$$\begin{aligned}\ln C = {} & \alpha_0 + \sum_{i=1}^{2}\alpha_i \ln Q_i + \sum_{k=1}^{3}\beta_k \ln P_k + \sum_{l=1}^{3}\beta_l \ln Z_l \\ & + \sigma_p D_p + \sum_{s=2}^{4}\sigma_s D_s + \sigma_w D_w \\ & + \frac{1}{2}\sum_{i=1}^{2}\sum_{j=1}^{2}\gamma_{ij} \ln Q_i \ln Q_j + \frac{1}{2}\sum_{k=1}^{3}\sum_{n=1}^{3}\delta_{kn} \ln P_k \ln P_n \\ & + \frac{1}{2}\sum_{l=1}^{3}\sum_{h=1}^{3}\theta_{lh} \ln Z_l \ln Z_h + \sum_{i=1}^{2}\sum_{k=1}^{3}\phi_{ik} \ln Q_i \ln P_k \\ & + \sum_{i=1}^{2}\sum_{l=1}^{3}\mu_{il} \ln Q_i \ln Z_l + \sum_{k=1}^{3}\sum_{l=1}^{3}\nu_{kl} \ln P_k \ln Z_l \end{aligned} \tag{2}$$

where i, j are outputs (G, A); k, n denote variable inputs for machinery (M), intermediate input (I), and other input (O); l, h are for labor (L), land (B), and the stock of technological knowledge (R); s denotes farm size dummies (2, 3, and 4 for 0.5-1.0, 1.0-1.5, and 2.0 hectares and over, respectively); p and w denote period and weather dummies, respectively, and ln indicates the natural logarithm. Applying Shephard's [41] lemma to the translog cost function (2), we obtain factor demand functions. Assuming that farm firms take factor prices as given, the following cost share equations are derived:

$$S_k=\frac{\partial C}{\partial P_k}\frac{P_k}{C}=\frac{\partial \ln C}{\partial \ln P_k}$$
$$=\beta_k+\sum_{n=1}^{3}\delta_{kn}\ln P_n+\sum_{i=1}^{2}\phi_{ik}\ln Q_i+\sum_{l=1}^{3}\nu_{kl}\ln Z_l \quad (3)$$

$$i=j=G,\ A$$
$$k=n=M,\ I,\ O$$
$$l=L,\ B,\ R.$$

The translog cost function can be used along with the profit-maximizing condition to derive additional equations representing the optimal choice of the endogenous outputs (Q_G and Q_A) (Fuss and Waverman [12, pp. 288-289]).

$$R_i=\frac{\partial C}{\partial Q_i}\frac{Q_i}{C}=\frac{\partial \ln C}{\partial \ln Q_i}$$
$$=\alpha_i+\sum_{k=1}^{3}\phi_{ik}\ln P_k+\sum_{j=1}^{2}\gamma_{ij}\ln Q_j+\sum_{l=1}^{3}\mu_{il}\ln Z_l \quad (4)$$
$$i=j=G,\ A$$
$$k=n=M,\ I,\ O$$
$$l=L,\ B,\ R.$$

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

Introducing the revenue share (R_i) equations into the estimation of the system of equations will in general lead to a more efficient estimation of the coefficients of, in particular, the output-associated variables due to the additional information provided by the revenue shares.[9]

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (2) this requires that $\Sigma_{k=1}^{3}\beta_k=1$, $\Sigma_{n=1}^{3}\delta_{kn}=0$, $\Sigma_{k=1}^{3}\phi_{ik}=0$, and $\Sigma_{l=1}^{3}\nu_{kl}=0$ ($i=G,\ A;\ k=n=M,\ I,\ O;\ l=L,\ B,\ R$). The translog cost function (2) has a general form in the sense that the restrictions of input-output separability and neutrality with respect to Z_R are not imposed a priori. Instead, these restrictions will be statistically tested via the estimation process of this function.

1) Technological progress due to R&E

Based on the estimated results of the variable translog cost function, we can compute the magnitude of technological progress due to an increase in the stock of technological knowledge, Z_R, and the degree of economies of scale. Modifying slightly the procedure developed by Caves, Christensen, and Swanson (CCS) [6],[10] we will compute two indicators of technological progress in terms of elasticities. They are (1) the elasticity of "input-saving" technological progress with respect to Z_R with outputs held fixed (PGX); and (2) the elasticity of "output-augmenting" technological progress with respect to Z_R with inputs held fixed (PGY). According to CCS, $PGY=RTS\cdot PGX$ where RTS denotes returns to scale.

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

$$PGX=\frac{\partial \ln C/\partial \ln Z_R}{1-\partial \ln C/\partial \ln Z_B}=-\frac{\varepsilon_{CZR}}{1-\varepsilon_{CZB}} \quad (5)$$

Second, the PGY is given by

$$PGY=-\frac{\partial \ln C/\partial \ln Z_R}{\Sigma_{i=1}^{2}\partial \ln C/\partial \ln Q_i}=-\frac{\varepsilon_{CZR}}{\Sigma_{i=1}^{2}\varepsilon_{CQ_i}}$$
$$=RTS\cdot PGX \quad (6)$$

where

$$=\varepsilon_{CZR}=\frac{\partial \ln C}{\partial \ln Z_R}$$
$$=\beta_R+\sum_{k=1}^{3}\nu_{kR}\ln P_k+\sum_{i=1}^{2}\mu_{iR}\ln Q_i+\sum_{h=1}^{3}\theta_{hR}\ln Z_h \quad (7)$$

$$\varepsilon_{CZB}=\frac{\partial \ln C}{\partial \ln Z_B}$$
$$=\beta_B+\sum_{k=1}^{3}\nu_{kB}\ln P_k+\sum_{i=1}^{2}\mu_{iB}\ln Q_i+\sum_{h=1}^{3}\theta_{hR}\ln Z_h \quad (8)$$

$$\varepsilon_{CQ_i}=\frac{\partial \ln C}{\partial \ln Q_i}$$
$$=\alpha_i+\sum_{k=1}^{3}\phi_{ik}\ln P_k+\sum_{j=1}^{2}\gamma_{ij}\ln Q_j+\sum_{l=1}^{3}\mu_{il}\ln Z_l \quad (9)$$

and

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

As defined earlier, $i=j=G,\ A,\ k=n=M,\ I,\ O,$ and $h=l=L,\ B,\ R,$ in equations (5) through (10).

2) Impacts on *PGX*, *PGY*, and *RTS*

Needless to say, one can compute the impacts of all the exogenous variables ($Q,\ P,\ Z$) on PGX, PGY, and RTS. However, in order to evaluate the effects of the set-aside programs and public R&E programs on productivity and scale economies, this paper will concentrate on evaluating the impacts of land (Z_B) and the stock of technological knowledge (Z_R) on *PGX, PGY,* and *RTS.* Furthermore, the impacts are expressed in terms of elasticities in order to easily capture the relative importance of the effects.

First, using the parameters of the translog cost function, the impacts of Z_B and Z_R on *PGX* are given by the following equations:

$$\frac{\partial \ln PGX}{\partial \ln Z_B}=\frac{\partial PGX}{\partial Z_B}\frac{Z_B}{PGX}=-\left[\frac{\theta_{BR}}{\varepsilon_{CZR}}-\frac{\theta_{BB}}{1-\varepsilon_{CZB}}\right] \tag{11}$$

$$\frac{\partial \ln PGX}{\partial \ln Z_R}=\frac{\partial PGX}{\partial Z_R}\frac{Z_R}{PGX}=-\left[\frac{\theta_{RR}}{\varepsilon_{CZR}}-\frac{\theta_{BR}}{1-\varepsilon_{CZB}}\right] \tag{12}$$

Second, the impacts of Z_B and Z_R on *PGY* are given by the following equations:

$$\frac{\partial \ln PGY}{\partial \ln Z_B}=\frac{\partial PGY}{\partial Z_B}\frac{Z_B}{PGY}=-\left[\frac{\theta_{BR}}{\varepsilon_{CZR}}+\frac{\mu_{GB}+\mu_{AB}}{\varepsilon_{CQ_G}+\varepsilon_{CQ_A}}\right] \tag{13}$$

$$\frac{\partial \ln PGY}{\partial \ln Z_R}=\frac{\partial PGY}{\partial Z_R}\frac{Z_R}{PGY}=-\left[\frac{\theta_{RR}}{\varepsilon_{CZR}}+\frac{\mu_{GR}+\mu_{AR}}{\varepsilon_{CQ_G}+\varepsilon_{CQ_A}}\right] \tag{14}$$

Finally, the impacts of Z_B and Z_R on *RTS* are given by the following equations:

$$\frac{\partial \ln RTS}{\partial \ln Z_B}=\frac{\partial RTS}{\partial Z_B}\frac{Z_B}{RTS}=-\left[\frac{\theta_{BB}}{1-\varepsilon_{CZB}}+\frac{\mu_{GB}+\mu_{AB}}{\varepsilon_{CQ_G}+\varepsilon_{CQ_A}}\right] \tag{15}$$

$$\frac{\partial \ln RTS}{\partial \ln Z_R}=\frac{\partial RTS}{\partial Z_R}\frac{Z_R}{RTS}=-\left[\frac{\theta_{BR}}{1-\varepsilon_{CZB}}+\frac{\mu_{GR}+\mu_{AR}}{\varepsilon_{CQ_G}+\varepsilon_{CQ_A}}\right] \tag{16}$$

3) Tests for the structure of production

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

(1) No technological change

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

$$H_0:\beta_R=\theta_{lR}=\mu_{iR}=\nu_{kR}=0 \tag{17}$$
$$i=G,\ A,\quad k=M,\ I,\ O,\quad l=L,\ B,\ R$$

(2) Weak separability of outputs

According to Hall [15], a technology is weakly separable in outputs if and only if the cost function can be written as

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

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

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

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

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

for $k=M,\ I,\ O$.

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

$$\phi_{Gk}\alpha_A=\phi_{Ak}\alpha_G \tag{18}$$

simultaneously for $k=M,\ I,\ O$.

(3) Input nonjointness

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

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

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

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

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

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

holds or not.

(4) Constant returns to scale

Constant returns to scale (CRTS) can be tested in the variable cost function framework. The test of the CRTS hypothesis can be executed by testing $RTS=1$ in equation (10). This implies testing the following joint null hypothesis using parameters of the translog variable cost function (2).

$$\begin{aligned}
&\alpha_G+\alpha_A+\beta_L+\beta_B=1\\
&\gamma_{GG}+\gamma_{GA}+\mu_{GL}+\mu_{GB}=0\\
&\gamma_{GA}+\gamma_{AA}+\mu_{AL}+\mu_{AB}=0\\
&\phi_{GM}+\phi_{AM}+\nu_{ML}+\nu_{MB}=0\\
&\phi_{GI}+\phi_{AI}+\nu_{IL}+\nu_{IB}=0\\
&\mu_{GR}+\mu_{AR}+\theta_{LR}+\theta_{BR}=0 \qquad (20)
\end{aligned}$$

3. The Data and Estimation Procedure

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

For statistical estimation, since the quantities of outputs (Q_G and Q_A) on the right hand side of the variable cost function (1) are in general endogenously determined, a simultaneous procedure should be employed for the estimation of the system of equations. This system of equations consists of the variable translog cost function (2), three of the cost share equations (3), and two revenue share equations (4). Note here that the estimation model is complete in the sense that it has as many (six) equations as endogenous variables (six). Therefore, the full information likelihood (FIML) method is chosen. In this process, the restrictions due to symmetry and linear homogeneity in prices are imposed. Due to the linear-homogeneity-in-prices property of the cost function, one cost share equation can be omitted from the simultaneous equation system. In this study the other input share equation is omitted. The coefficients of the omitted other input cost share equation can easily be obtained after the system is estimated using the imposed linear homogeneity restrictions.

4. Empirical Results

The estimated parameters of the system and the associated asymptotic t-values are reported in Table 1.[11] Goodness-of-fit statistics are given in Table 2 which indicate a fairly good fit for the model.

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

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

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

Finally, the null hypothesis of constant returns to scale is rejected both at the 1% and at the 5% significance levels. This implies that there exist increasing returns to scale judging from the estimated magnitude of returns to scale at the means of the variables, 1.188.

In addition, based on the parameter estimates in Table 1, the monotonicity and concavity and convexity conditions with respect to variable input prices and fixed input quantities, respectively, are checked at each observation. Since all the estimated cost shares for both outputs and inputs are positive, the production technology satisfies the monotonicity condition. The concavity and convexity conditions with respect to factor prices and fixed input quantities, respectively, are satisfied at each observation.[12] Thus, we may say that the estimated cost function represents a second order approximation to the *true* data generating cost function which satisfies the curvature conditions. The estimated parameters given in Table 1 are utilized for further analysis.

1) *PGX* and *PGY* with respect to R&E stock and returns to scale

Using equations (5) and (6), *PGX* and *PGY* were estimated for all observations of the four size classes for the entire study period 1965-97. As explained earlier, *PGX* gives the elasticity of input-saving technological progress with respect to Z_R with outputs held fixed and *PGY* the elasticity of output-augmenting technological progress with respect to Z_R with inputs held fixed. They are shown in Figs. 3 and 4, respectively.

First, both *PGX* and *PGY* show clear differences of magnitude in technological progress resulted from public R&E investments among the four size classes. That is, the larger the size of the farm, the greater the speed of the technological progress. Furthermore, the differences of the speed of technological progress increased among the different size classes as time went on, in particular, since 1972.[13] The speeds themselves however decreased in all the four size classes.

Second, the movements of *PGX* and *PGY* are very similar in all four size classes, although the magnitudes of elasticities of *PGX* were consistently smaller than those of *PGY* by around 0.05. Both *PGX* and *PGY* increased from 1965 to 1968, then decreased slightly until 1971. However, they again increased slightly in 1972, but since then consistently decreased until 1997. While the movements are very similar among the smaller size classes 1, 2, and 3, the largest size class 4 showed movement a little different from that of the other three size classes, in particular, after 1981. In this class both *PGX* and *PGY* were almost constant for the 1982-94 period with 1993 being the exception where they registered around 0.22 and 0.25, respectively. Although both *PGX* and *PGY* dropped a little in 1995, they seem to have shown an increasing trend since then.

The decreases in the magnitudes of the technological progress due to the stock of technological knowledge may have been a major cause for the stagnant or slower increases in TFP since 1975 as observed in Fig. 1. In other words, farmers in all size classes may be said to have become less responsive to technological opportunities resulting from public R&E activities.

Next, as shown earlier, $PGY = RTS \cdot PGX$. That is, the magnitude of *PGY* is different from that of *PGX* by the degree of returns to scale. The movements of returns to scale of the four different size classes over the 1965-97 period which were estimated using equation (10) are presented in Fig. 5.

As shown in the figure, the returns to scale ranged from around 1.14 (for size class 4) to 1.26 (for size class 1) for the study period. This implies that a 10% increase in aggregate output will reduce the variable cost by 1.4 to 2.6 % at the margin. Furthermore, we may observe two distinct features about the movements of the magnitude of scale economies.

First, scale economies decreased from 1965 to 1972 and then had increasing trends until 1993 in the smaller three size classes. But, after 1993, although the smaller three classes showed some different movements, they all experienced decreases in scale economies in 1997. On the other hand, the largest size class showed a little different movement in the scale economies. Scale economies in this class decreased from 1965 to 1975, then increased until 1981, slightly decreased in 1982, became stagnant from 1982 to 1993, and started decreasing after that.

The decreases in scale economies from 1965 to the early 1970s in all the size classes may imply that scale economies caused by smaller-scale mechanization during the 1950s and 1960s decreased as farms in all the size classes extensively utilized the production technology based on this type of mechanization. In contrast, the increase in scale economies since the early 1970s must have been strongly related to the stronger indivisibility of machinery inputs caused by the rapid expansion of larger-scale mechanization such as rice transplanters, harvesters, and so on.

Second, it is very clear from Fig. 5 that the smaller the farm size, the greater the degrees of scale economies especially after the early 1970s. This finding supports similar findings by Kako [30] and Chino [8]. This may imply that larger size farms took an initiative in introducing larger-scale machinery and exploiting the improved technology based on larger-scale machinery much faster than smaller-scale farms. This finding further implies that while smaller-scale farms are operating at a point along the average cost curve which is closer to the vertical axis (less output), larger-scale farms are operating at a point along the same average cost curve which is farther from the vertical axis (more output).

2) Impacts of changes in planted area on *PGX, PGY,* and *RTS*

Next, in order to investigate the impacts of set-aside programs, the effects of changes in planted area on *PGX, PGY,* and *RTS* were estimated using equations (11), (13), and (15), respectively. The estimates expressed in terms of elasticity are exhibited in Figs. 6, 7, and 8, respectively. Several features are summarized in the following paragraphs.

First, the impacts of changes in planted area both on *PGX* and on *PGY* were negative in all the four size classes for the entire 1965-97 period. Furthermore, the negative effects consistently became stronger over time in all the four size classes; the elasticity ranged from -0.18 to -0.36 for *PGX* and -0.16 to -0.32 for *PGY*. In addition, as can be clearly observed from the figure, the smaller the farm size, the stronger the negative effects.

These findings imply that an increase in planted area reduces the productivity due to the stock of technological knowledge. Conversely, this may imply that decreases in planted area due to the set-aside programs had an effect of raising the productivity caused by public R&E investments and such effects increased in all the four size classes over time.[14] This may in turn be interpreted as follows. In order to meet the requirements of the set-aside programs, farmers may have utilized more intensively higher yielding varieties and/or better quality lands by giving up lower quality lands. As such, smaller size farms have shown stronger responses in this process.[15]

Second, it is found in Fig. 8 that changes in planted area had a positive effect on returns to scale in all the size classes: the elasticity ranged from 0.026 to 0.054. The impacts had increasing trends in all the size classes until 1974. Since then, however, different size classes showed different movements in the impacts over time. Size classes 1 and 2 roughly had decreasing trends for the whole 1974-1997 period though there were fluctuations. Size class 3 showed a very similar trend to these two smaller size classes until 1993. But it experienced a sharp increase and then decrease for the 1994-96 period. The largest size class had different movements from the smaller three size classes especially after 1981. The impacts increased in 1982, became stagnant until 1988, and started increasing again though with some drops in 1991 and 1993.

The finding that increases in planted area have positive impacts on returns to scale conversely implies that decreases in planted area will reduce the degree of returns to scale. This in turn may imply that the set-aside programs introduced since 1969 had negative effects on economies of scale in all the size classes. In the largest size class, in particular, the negative effect was the strongest. This finding corresponds fairly well to the movements of returns to scale of size class 4 in Fig. 5. We may conclude here that the land set-aside programs have had negative effects on larger-scale farming since such programs had the effect of reducing the degree of economies of scale, in particular, of larger scale farms.

3) Impacts of changes in the stock of technological knowledge on *PGX, PGY,* and *RTS*

The impacts of changes in Z_R on *PGX, PGY,* and *RTS* were estimated in terms of elasticity using equations (12), (14), and (16), respectively. To allow for convenient evaluation, the order of the graphical presentations of equations (12), (14), and (16) have been reversed. Thus, the impacts of changes in Z_R on *RTS, PGX,* and *PGY* are reported in Figs. 9, 10, and 11, respectively. Several findings are evaluated in the following paragraphs.

According to Fig. 9, increases in the stock of technological knowledge had a positive effect on returns to scale in all the size classes for the entire 1965-97 period: the elasticity ranged from 0.079 to 0.132. The smallest size class had the largest impact almost for the entire period except for the last three years; the elasticity increased sharply from 1965 to 1974 but since 1975 the rate of increase dropped substantially. The other three classes increased the elasticities sharply from 1965 to around 1977 and then the rates of increase became much smaller for the 1978-97 period. These movements appear to be consistent with changes in the patterns of mechanization in postwar Japanese agriculture; from small-scale mechanization for the period the late-1950s through the early-1970s to larger-scale mechanization since the early-1970s. This in turn may indicate that public R&E activities have had effects of encouraging larger-scale farming by changing the attitude toward farm mechanization from smaller- to larger-scale mechanization during the last four decades.

Next, it is obvious in Figs. 10 and 11 that the effects of changes in R_Z on agricultural productivity growth, *PGX* and *PGY*, were negative over the entire 1965-97 period; the elasticity of *PGX* with respect to Z_R ranged from -0.24 to -0.65 while the elasticity of *PGY* with respect to Z_R ranged from -0.17 to -0.53. Furthermore, it can be observed in Figs. 10 and 11 that, in absolute terms, the smaller the size classes, the greater the elasticities.

These findings may imply that an additional increase in the stock of technological knowledge will have a fairly strong negative effect on the growth of agricultural productivity resulting from increases in the stock of technological knowledge, and that the negative effects have become stronger over time in all the four size classes. In particular, the smallest size class has experienced the strongest negative effect for the entire 1965-97 period.

What then was the mechanism behind the negative effects of the stock of technological knowledge on *PGX* and *PGY*? To answer this question, it may be convenient to go back to equations (12) and (14). To begin with, the first term of equation (12) can be termed the "technological progress effect" and the second term the "fixed input effect" of Z_R on *PGX*.[16] We found that the technological progress effect was negative and the fixed input effect was positive for all the size classes.[17] This finding indicates that the negative technological progress effect surpassed the positive fixed input effect so that the total effect of Z_R on *PGX* became negative in all four size classes.

Next, the first term of equation (14) can be said to represent the "technological progress effect" and the second term the "scale effect" of Z_R on *PGY*.[18] We found that both effects were negative for all four size classes.[19] In short, we may say that the negative technological progress effects played an important role in causing the negative effects of the stock of technological knowledge on *PGX* and *PGY*.

The "technological progress effect" can further be decomposed into three effects. Rewrite the negative of the cost-R&E elasticity given in equation (7) as $-\varepsilon_{CZR} = -\partial \ln C / \partial \ln Z_R = (-\partial C/\partial Z_R)(Z_R/C) = (-\partial C/\partial \phi)(\partial \phi / \partial Z_R)(Z_R/C)$. The last expression has been derived based on the cost function (1). That is, the cost reducing effect of the stock of technological knowledge can be decomposed into (a) the shadow value or the efficiency of utilization of research "outputs" in agricultural production $(-\partial C/\partial \phi)$, (b) the shadow value or the efficiency of the stock of technological knowledge in the "research production function" $(TK = \phi(Z_R))$,[20] and (c) the ratio of the stock of technological knowledge to the variable cost of agricultural production (Z_R/C). Let us then evaluate these factors one at a time.

Although the Z_R/C ratio decreased consistently over the whole 1965-97 period as shown in Fig. 12, the ratio itself was positive.

Next, what about the efficiency of research output production $(\partial \phi / \partial Z_R)$? According to Anderson [1], the research production function can be written as $TK_t = \phi(Z_{Rt})$ where $Z_{Rt} = \sum_{i=0}^{T} \omega_{t-i} E_{t-i}$, TK_t is the stock of technological knowledge in period t, E_t is R&E investments in period t, and ω is the weight. As is clear in the latter equation, an increase in current and past investments in public R&E activities will increase research achievements *TK*. Figures 13 and 14 present the annual expenditures on and the accumulated capital stock of R&E investments, respectively. They are deflated by the research expenditure deflater and expressed in 1985 prices. According to Fig. 14, the stock of R&E increased fairly sharply from the early-1970s through the late-1980s, and then the rate of increase started declining. These movements reflect the rather sharp increase in research expenditures in the 1960s and the stagnation in both research and extension expenditures since the early 1970s up to the late-1980s. It may be inferred from this observation that the efficiency of research output production was high during the early-1970s through the late-1980s and then started declining. It is very likely that this efficiency would be very small and would reach zero or even negative levels in the late-1990s and early-2000s if the trend in investments on R&E activities continues to stagnate. At any rate, however, the efficiency of research output production can be considered to have been positive for the whole 1965-97 period.[21]

These observations indicate that the decrease in the efficiency of utilization of research outputs ($-\partial C/\partial\phi$) more than offset the positive effects due to the positive Z_R/C ratio and the positive efficiency of research production function ($\partial\phi/\partial Z_R$) during the 1965-97 period.

It is very likely that the decline in the efficiency of utilization of research outputs may have been caused by dampened incentives for farmers to utilize newly developed technologies due to the set-aside programs for rice production since 1969.[22]

4) Impacts of changes in the other exogenous variables on *PGX, PGY,* and *RTS*

Let us here briefly evaluate the impacts of the other exogenous variables (Q_G, Q_A, P_M, P_I, P_O, and Z_L) on *PGX, PGY,* and *RTS*. This may enable us to interpret the trends of *PGX, PGY,* and *RTS* over time as observed in Figs. 3, 4, and 5, respectively. To do this, we will evaluate the estimated elasticities of *PGX, PGY,* and *RTS* with respect to the other exogenous variables in accordance with the actual movements of these variables. In reality, for the entire 1965-97 period, both crop and livestock products (Q_G and Q_A) increased, the prices of machinery and intermediate inputs relative to the aggregate output price (P_M and P_I) decreased steadily, the price of other input relative to the aggregate output price (P_O) increased slightly, and the quantity of labor input (Z_L) decreased consistently. Tables or figures of the estimated elasticities are not shown here to save space.[23]

First, let us take a look at the effects of the other exogenous variables on *PGX* and *PGY*. Increases both in crop and livestock outputs (Q_G and Q_A) had positive impacts on both *PGX* and *PGY* in all four size classes for the entire 1965-97 period: on the average, the elasticities were 0.374 and 0.046 for *PGX* and 0.279 and 0.008 for *PGY*, respectively. By the same token, decreases in the prices of machinery and intermediate input (P_M, P_I), and increase in other input (P_O) relative to the aggregate output price had respectively negative, positive, and positive effects on *PGX* and *PGY* in all the size classes for the same period: on the average, the elasticities were -0.04, 0.127, and 0.087 for *PGX* and -0.059, 0.150, and 0.092 for *PGY*, respectively. A decrease in the quantity of labor input (Z_L) had negative effect on *PGX* and *PGY* in all the size classes for the same period: on the average, the elasticities were -0.135 for *PGX* and -0.254 for *PGY*, respectively.

Based on these results together with the above results with respect to Z_B and Z_R, we may interpret the decreasing trends of *PGX* and *PGY* as observed in Figs. 3 and 4 as follows. The negative effects on *PGX* and *PGY* caused by (1) decreases in the relative price of machinery (P_M), (2) decreases in the quantity of labor input (Z_L), and (3) increases in the stock of technological knowledge (Z_R) overshadowed the positive effects due to (1) increases in the quantities of both crop and livestock outputs (Q_G and Q_A), (2) decreases in the relative price of intermediate input (P_I), (3) increases in the relative price of other input (P_O), and (4) decreases in planted area (Z_B). This was true in all four size classes, in particular, during the 1972-97 period. Of course, we are aware of the fact that the relative magnitudes of the effects were different among the different size classes, and as a result the movements of *PGX* and *PGY* were different among the different size classes as seen in Figs. 3 and 4.

Next, increases in both crop and livestock production (Q_G and Q_A), decreases in the relative prices of machinery (P_M), and decreases in the quantity of labor input (Z_L) had negative effects on *RTS* in all four size classes for the 1965-97 period: on the average, the elasticities were respectively -0.095, -0.054, -0.019, and -0.120. On the other hand, decreases in the relative price of intermediate input (P_I) and increases in the relative price of other input (P_O) had positive effects on returns to scale in all four size classes for the same period: on the average, the elasticities were 0.022 and 0.005, respectively.

Now, let us put all the effects together with the effects with respect to changes in Z_B and Z_R in order to interpret the trends of *RTS* as observed in Fig. 5. The negative effects on *RTS* due to (1) increases in crop and livestock outputs (Q_G and Q_A), (2) decreases in the relative price of machinery (P_M), and (3) decreases in planted area (Z_B) overshadowed the positive effects due to (1) decreases in the relative price of intermediate input (P_I), (2) increases in the relative price of other input (P_O), and (3) increases in the stock of technological knowledge (Z_R) from 1965 to the early 1970s. Then, the positive effects surpassed the negative effects roughly until 1993, and, again, the negative effects seem to have become stronger than the positive effects since then. Again, we have to note here that the relative magnitudes of the effects were different among the different size classes, and as a result the movements of the degrees of scale economies were different among the different size classes as seen in Fig. 5.

5. Summary and Concluding Remarks

This study has estimated the "input-saving" and "output-augmenting" technological progress (*PGX* and *PGY*) with respect to the stock of technological knowledge resulted from public R&E investments as well as economies of scale (*RTS*) for the period 1965-97 based on the parameter estimates of the multiple-output variable cost function. It then investigated quantitatively the impacts of the set-aside programs and R&E activities on these indicators. These estimations were carried out for four different size classes of Japanese agriculture except for the Hokkaido district. The major findings of the study are as follows.

First, the rejection of both hypotheses of weak separability of outputs and input nonjointness implies that the multiproduct function approach is preferable when it comes to analyzing the agricultural technology of postwar Japan.

Second, although there were fluctuations in the movements of *PGX* and *PGY* until 1972, they consistently decreased after that until 1997. It was found that, in spite of the decreasing trends, the larger the size class, the greater the magnitudes of *PGX* and *PGY*. The decrease in the magnitudes of *PGX* and *PGY* with respect to the stock of technological knowledge may have been a major cause for the stagnant or slower increases in TFP since 1975 observed in Fig. 1. In other words, farmers in all the size classes may have become less responsive to technological opportunities resulting from public R&E activities.

Third, scale economies were found in all the size classes for the whole 1965-97 period. However, the magnitude of scale economies decreased from 1965 to around 1972, and since then increased in all the size classes but with a little different pattern in the largest class. The increase in scale economies since 1972 must have been related to the stronger indivisibility due to larger-scale mechanization occurring since the early 1970s.

Fourth, changes in planted area had negative impacts on *PGX* and *PGY* in all the size classes, indicating that the set-aside programs introduced since 1969 had positive effects on productivity resulting from public R&E activities. This may in turn imply that, in order to meet the requirements of the set-aside programs, farmers may have utilized more intensively higher yielding varieties and/or higher quality land by giving up lower quality land. Furthermore, changes in planted area had a positive effect on returns to scale in all the size classes. In particular, this effect was the greatest on the largest size class. This may indicate that the set-aside programs had negative effects on scale economies, implying that the set-aside programs have had an effect of discouraging larger-scale farming, especially on larger-scale farms, during the last three decades.

Fifth, increases in the stock of technological knowledge had a positive impact on scale economies in all four size classes for the entire study period 1965-97, indicating that public R&E activities have encouraged larger-scale farming based on larger-scale mechanization. In addition, it was found that increases in the stock of technological knowledge had a fairly strong negative effect on the growth of agricultural productivity and the negative effect became stronger over time. The major reason for this negative effect may have been rapid decreases in the efficiency of utilization of research outputs on the side of farmers. It is very likely that the decreases in the efficiency of utilization of research outputs may have been caused by dampened incentives for farmers to utilize newly developed technologies due to the set-aside programs for rice production since 1969. Another reason for this is that substitutions of domestic farm products for imported farm products, either crop products or livestock products, may have limited the chances of realization of newly developed technologies.

We may conclude from these findings that, in order to drastically change the existing structure of small-scale farming to that of much larger-scale farming, the set-aside programs have to be remodeled so as to give stronger incentives to larger-scale farms. Such changes in the set-aside programs would in turn increase the efficiency of utilization of research outputs on those farms. In addition, in order to increase research outputs through the public research production function, the government has to increase R&E investment.

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

Appendix A: Tables for Empirical Results

Table 1. Parameter estimates of the multiple-output translog cost function for the Japanese agricultural sector, 1965-97

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	0.036	0.3	θ_{LB}	0.071	0.1
α_G	1.730	63.5	θ_{LR}	−0.399	−0.7
α_A	0.442	42.0	θ_{BR}	0.029	1.6
β_M	0.343	53.9	θ_{RR}	0.117	1.8
β_I	0.467	70.5	ϕ_{GM}	0.227	2.5
β_O	0.190	107.2	ϕ_{GI}	−0.239	−3.0
β_L	−1.272	−6.1	ϕ_{GO}	0.011	0.3
β_B	−0.308	−1.4	ϕ_{AM}	−0.090	−5.6
β_R	−0.528	−4.7	ϕ_{AI}	0.067	4.4
σ_P	−0.059	−1.7	ϕ_{AO}	0.022	3.0
σ_2	−0.022	−0.3	μ_{GL}	0.522	1.4
σ_3	−0.030	1.3	μ_{GB}	0.395	2.6
σ_4	−0.037	−0.2	μ_{GR}	−0.010	−0.8
σ_w	0.029	2.2	μ_{AL}	0.567	5.3
γ_{GG}	0.063	0.2	μ_{AB}	−0.019	−3.5
γ_{GA}	−0.628	−10.9	μ_{AR}	0.088	1.9
γ_{AA}	0.284	12.0	ν_{ML}	−0.237	−1.9
δ_{MM}	0.018	0.2	ν_{MB}	0.026	0.5
δ_{II}	0.158	2.9	ν_{MR}	−0.064	−1.0
δ_{OO}	0.037	1.2	ν_{IL}	0.297	2.6
δ_{MI}	−0.069	−1.1	ν_{IB}	−0.033	−0.7
δ_{MO}	0.051	1.2	ν_{IR}	0.121	2.0
δ_{IO}	−0.089	−3.6	ν_{OL}	−0.056	−2.8
θ_{LL}	−1.673	−1.3	ν_{OB}	0.008	0.3
θ_{BB}	−0.609	−3.1	ν_{OR}	−0.056	−2.8

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

Table 2. Goodness-of-fit measures

Estimating equations	R-squared	S.E.R.
Cost function	0.950	0.111
Machinery share equation	0.644	0.032
Intermediate inputs share equation	0.696	0.034
Crop revenue share equation	0.803	0.132
Livestock revenue share equation	0.824	0.052

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

Table 3. Tests of the production structure

Hypothesis	Wald test statistic	Degrees of freedom	Critical value	
			0.05	0.01
No technological change	59.1	8	15.51	20.09
Weak separability	46.3	2	5.99	9.21
Input nonjointness	22.1	1	3.84	6.63
Constant returns to scale	38.6	6	12.59	16.81

Appendix B: Figures

First of all, the procedure of estimating the TFP indexes for the four size classes in Fig. 1 is explained in Appendix C. In addition, the estimating procedure for the elasticities in Figs. 3 to 11 are explained in texts. Finally, the data sources for Figs. 2 and 13 are given in the respective figures. The data sources for Figs. 12 and 14 are the same as for Fig. 12 and the estimation procedures are presented in Appendix C.

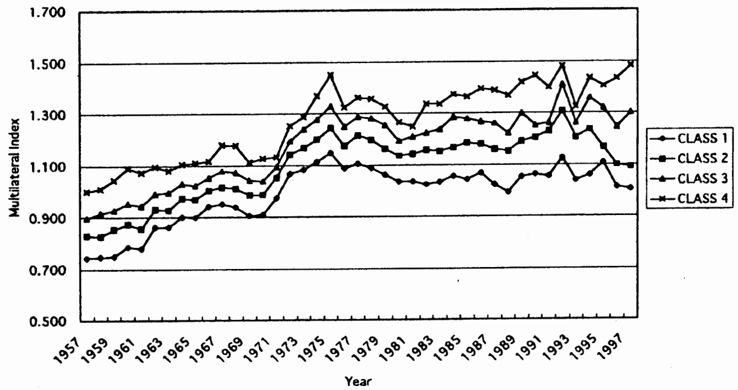

Figure 1. TFP for 1957–97: tofuken

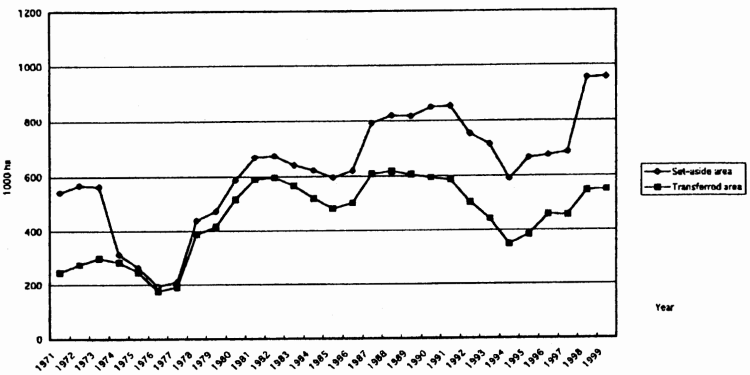

Figure 2. Set-aside and transferred areas, 1971–99: all Japan
Source: Japan, Ministry of Agricultures, Forestry and Fisheries. *Pokketo Beibaku Deta Bukku (Pocket Databook on Rice and Wheat)*. Food Agency, Tokyo, various issues.

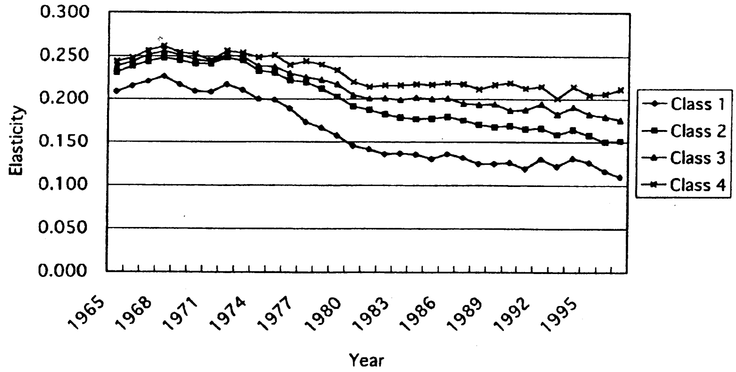

Figure 3. ***PGX*** **for 1965-97: tofuken**

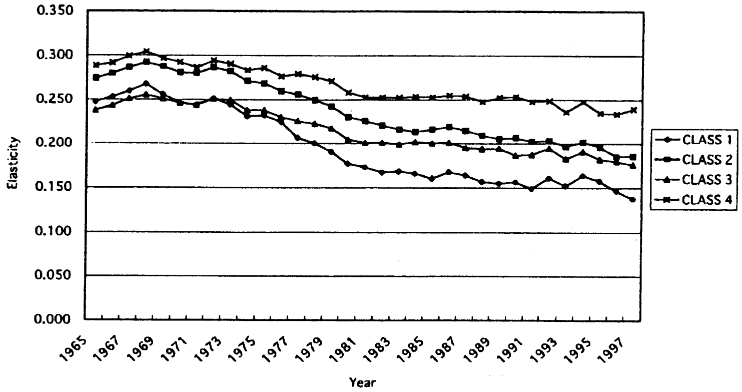

Figure 4. ***PGY*** **for 1965-97: tofuken**

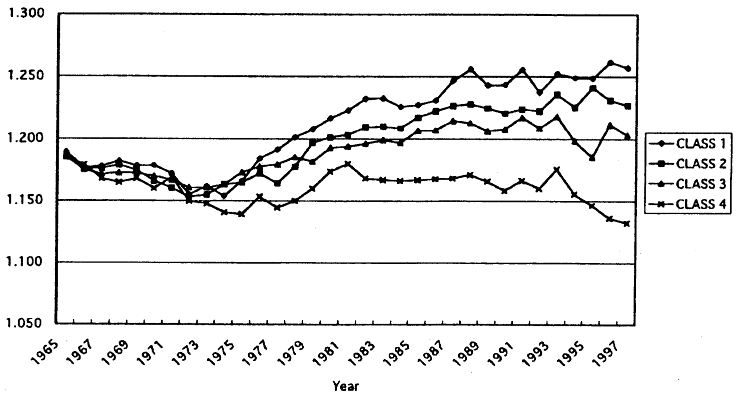

Figure 5. Economics of scale for 1965-97: tofuken

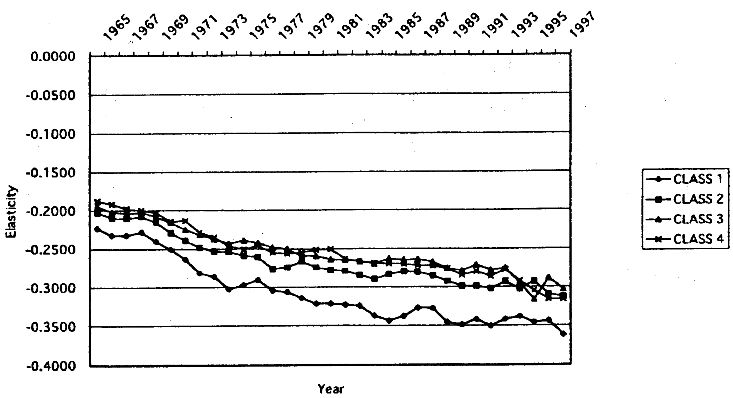

Figure 6. Impacts of changes in planted area on *PGX*, 1965-97: tofuken

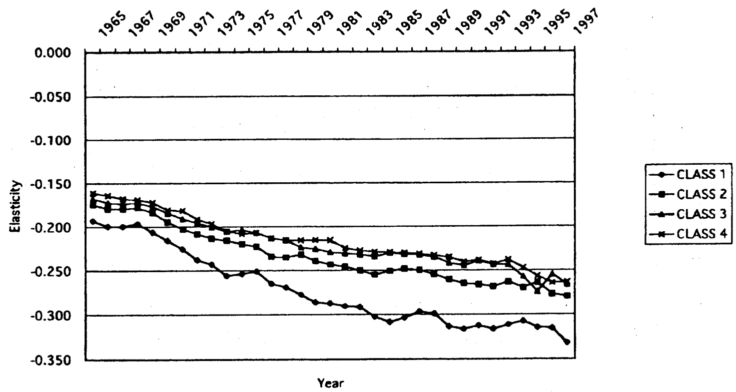

Figure 7. Impacts of changes in planted area on *PGY*, 1965-97: tofuken

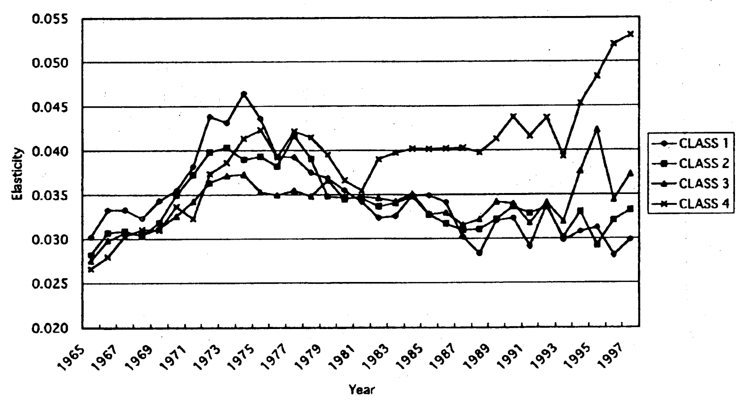

Figure 8. Impacts of changes in planted area on economics of scale, 1965-97: tofuken

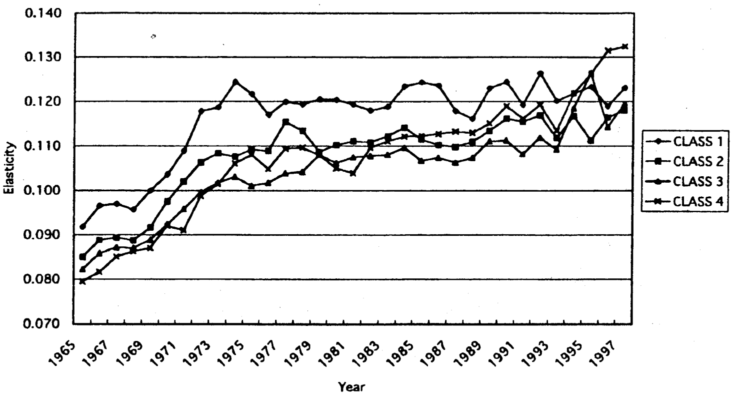

Figure 9. Impacts of changes in the stock of technological knowledge on economics of scale, 1965-97: tofuken

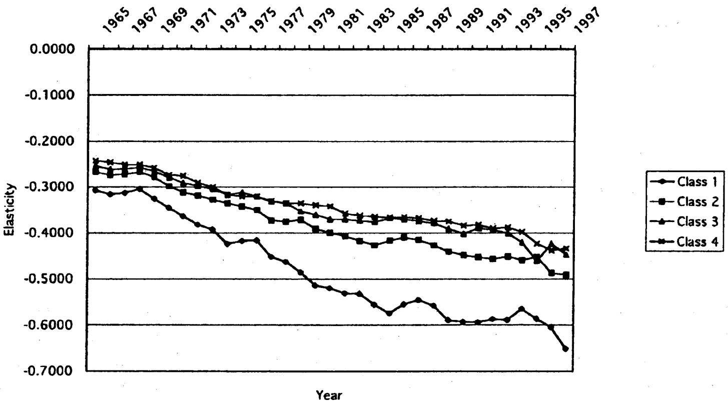

Figure 10. Impacts of changes in the stock of technological knowledge on *PGX*, 1965-97: tofuken

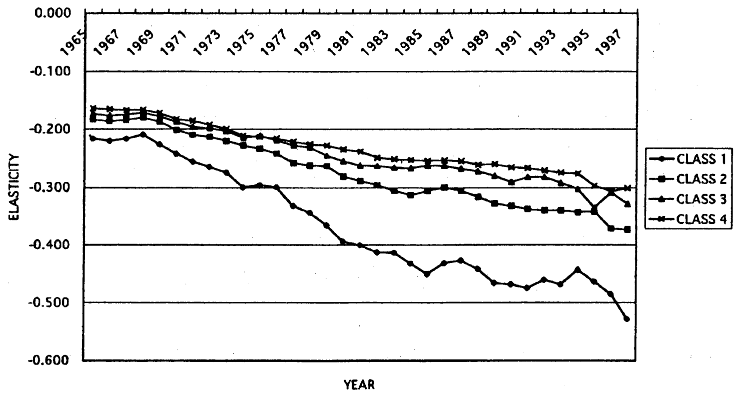

Figure 11. Impacts of changes in the stock of technological knowledge on *PGY*, 1965-97: tofuken

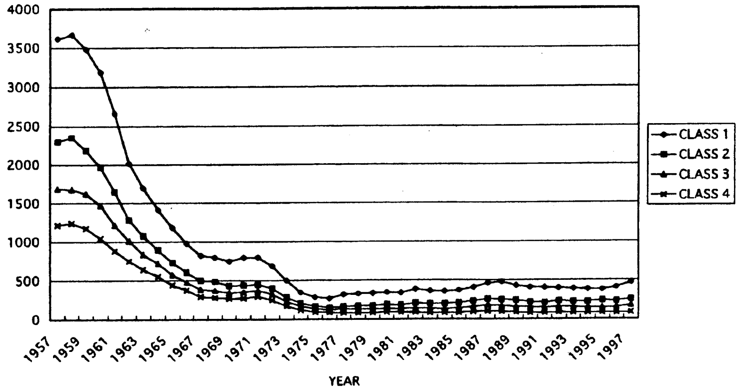

Figure 12. R&E/total revenue ratio for 1957-97: all classes

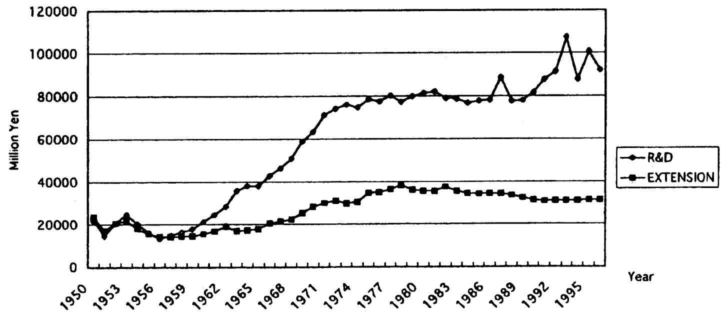

Figure 13. Public real R&D and extension expenditures, 1950-96 (in 1985 prices)

Sources: Japan, Ministry of Agricultures, Forestry and Fisheries. *Norinsuisan Shiken-Kenkyu Nenpo (Yearbook of Experiment and Reseearch on Agriculture, Forestry, and Fisheries)* and *Norinsuisan Kankei Shiken Kenkyu Yoran (Abstract Yearbook of Experiment and Research on Agriculture, Forestry, and Fisheries)*, various issues.

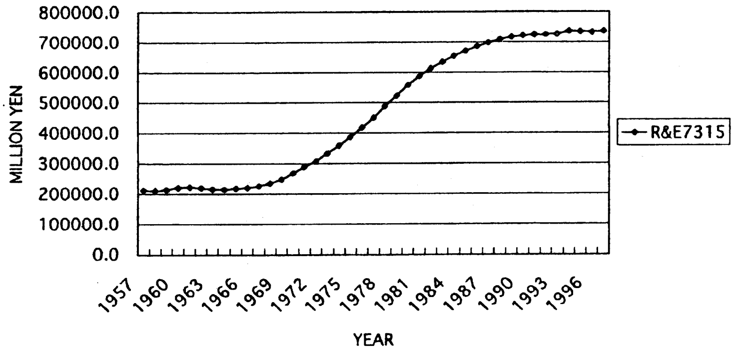

Figure 14. Stock of public technological knowledge, 1957-97 (in 1985 prices)

Appendix C: Variable Definitions

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

In each year of the 1965-97 period, one average farm was taken from each of the four size classes, 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0 hectares (ha in short) or over, from all Japan excluding Hokkaido district because of the different size classification. Thus, the sample size is $33 \times 4 = 132$. Unfortunately, we could not directly obtain the data for the average farm in the smallest size class, 0.5 ha or less, because of changes in the size classification during the sample period. It should be noted that exclusion of farms in this size class may cause some bias in the estimated parameters since the share of the number of farms of this size class in the total number of farms has been fairly high.

The Törnqvist indexes of the quantity and price indexes of crop products (Q_G and P_G) were computed by the Caves-Christensen-Diewert's (CCD) [6] multilateral index method. The CCD method is most relevant for the estimation of the Törnqvist index for a pooled cross-section of time-series data set. In the following paragraphs, wherever possible all indexes were obtained based on this method.

For the quantity and price indexes of crop products (Q_G and Q_A), ten categories of crop products were distinguished with price indexes for these categories taken from the FHE and PWRV. The quantity index of livestock products (Q_A) was obtained by dividing the market sales of livestock products by the price index of livestock products (P_A) taken from PWRV. It is noted here that the base year for the price indexes is 1985.

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

The variable cost (C) was defined as the sum of the expenditures on these four categories of factor inputs, i.e., $C = \sum_{i=1}^{3} P_i X_i (i = M, I, O)$. The cost share ($S_i$) was obtained by dividing the expenditure on each category of factor inputs ($P_i X_i$) by the variable cost (C).

The period dummy (D_p) is defined as 1 for 1965-74, i.e., before the "oil crisis", and 0 for 1975-97, i.e., after the "oil crisis". The size dummies (D_s) are for size II (1.0-1.5), III(1.5-2.0), and IV(2.0 ha or over). Weather dummy (D_w) is defined as 1 for bad harvest years and 0 for normal harvest years. The data was obtained from MAFF *Sakumotsu Tokei* (*Crop Statistics*).

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

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

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

The stock of technological knowledge (Z_R) was estimated by the perpetual inventory method. The data used for this estimation was public research and extension expenditures. The source of data is the *Norinsuisan Kankei Shiken Kenkyu Yoran* (*Abstract Yearbook of Research and Experiment on Agriculture, Forestry, and Fisheries*) (AYRE) published annually by the MAFF. The estimation procedures are basically the same as in Ito [18].

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

The *Norinsuisan Shiken-Kenkyu Nenpo* (*Yearbook of Research and Experiments of*

Agriculture, Forestry, and Fisheries) (YRE) by MAFF reports research 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 [18] regarded this research period as the development lag of each research topic, and obtained the number of research topics for each development lag for 1967, 1977, and 1987. He then computed the weighted average year of research lag period with the numbers of research topics as weights for each of these three years and obtained roughly 6 years for these three years. As for the rate of obsolescence of the stock of technological knowledge, we assumed 10% per year following Goto et al. [14].

Now, the stock of technological knowledge was estimated as follows. Suppose that R_t is the stock of technological knowledge at the end of year t. Then, the following equation can be obtained:

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

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

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

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

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

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

Next, Ito [18] 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 realized in real agricultural production. This study assumes 5 years as the maximum for extension activities for a particular innovation. This assumption is based on personal discussions with workers who are engaged in extension programs. Using a procedure similar to that used for the stock of technological knowledge, i.e. the benchmark year method, the capital stock of extension activities was estimated for a 5-year lag. In this case, 10% was assumed for the rate of growth of the capital stocks based on the growth rate of extension expenditures (investment) for the 1955-59 period which was very close to 10%. However, since there is no reliable information for the rate of obsolescence of the capital stock of extension activities, this study assumes simply 10% as in the case of the stock of technological knowledge.

This study assumes that the two different stocks of technological knowledge based on R&E and extension activities combined 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 1957-97 period.

For a sensitivity analysis, this study assumes 5, 10, and 15 percent for the rate of obsolescence both for the stock of technological knowledge and for the capital stock of extension investments; 5, 6, 7, 8, 9, 10, and 11 years for research development lag; and 3, 4, and 5 years for extension lag. Thus, there are altogether $(3\times7)\times(3\times3)=189$ different combinations. These 189 combinations of the R&E capital stocks were used for the sensitivity analysis based on the estimating equation system composed of equations (2), (3), and (4).

As a result, the combination of 15% for the rate of obsolescence both for the stock of technological knowledge and for the capital stock of extension investments, a 7-year lag of research development, and a 3-year lag for extension activities gave the best results in terms of the R^2s and the asymptotic t-statistics of the coefficients as well as monotonicity and concavity conditions. Thus, this option was used for the variable Z_R in the present study.[24)]

Total Output (*TO*), *Total Input* (*TI*), *and Total Factor Productivity* (*TFP*)

In order to estimate TFP, we need to first estimate TO and TI. To begin with, we estimated TO using the CCD [6] multilateral index by aggregating ten categories of crop products and one category of livestock products as classified in the FHE for the period 1957-97.

Next, for the estimation of the index of TI, we need the total costs on machinery, intermediate, and other inputs as well as labor and land inputs. That is, we have to treat the fixed inputs (land and labor) in the variable cost function framework in the present paper as variable inputs. We have already estimated C_M, C_I, and C_O for the former three variable inputs, respectively.

As for labor and land costs (C_L and C_B), we estimated them as follows. First, the price of labor (P_L) was obtained by dividing the wage bill for temporary hired labor by the number of male-equivalent labor hours of temporary hired labor. The labor cost ($C_L = P_L Z_L$) was then obtained as the sum of the labor cost for operator, family, and exchange workers imputed by P_L and the wage bill for hired labor.

Next, in order to estimate land cost, the land price P_B was first obtained by dividing land rent by the rented land area (1,000 yen per 10 ares). This price was then used to impute the land cost of owned arable land area. Finally, the land cost ($P_B Z_B$) was defined as the sum of total rent for owned and rented arable land and expenditures on land improvements and water use.

Now, the total cost was defined as $TC = C_M + C_I + C_O + C_L + C_B$. Based on the dataset of the prices, quantities, and costs for factor inputs, the CCD [6] multilateral index was estimated for TI for the 1957-97 period.

Finally, we estimated TFP by dividing TO by TI. In order to systematically see the differences in the TFP index among the different size classes, the 1957 value of size class four was set at unity.

1) The procedure employed to estimate TFP is multilateral index method as proposed by Caves, Christensen, and Diewert (CCD) [6], which is explained in detail in Appendix B. The four size classes are I (0.5-1.0), II (1.0-1.5), III (1.5-2.0), and IV (2.0 hectares and over). In order to ease the comparison of the magnitudes of the TFP indexes among different size classes, the value of the multilateral TFP index of size class four in 1957 was set at 1.0.

2) This finding is totally opposite to those obtained by Kuroda [34] and Hu [17] where the conventional Törnqvist approximation method instead of the multilateral CCD [6] method was used to estimate the indexes of total output, total input, and total factor productivity for each size class separately. Since the multilateral index satisfies the circularity condition, it has more desirable characteristic as an index than the Törnqvist approximation index especially in the case of pooled time-series of cross section data as used in the present paper. Therefore, we may claim that our finding here is pointing towards a better direction.

3) The terms returns to scale, economies of scale, and scale economies are used interchangeably in this paper.

4) We have estimated the shadow prices of land as well as labor. However, they are not presented in this paper. The estimation and evaluation of the shadow prices of land and labor will be treated elsewhere in a different paper.

5) This procedure has been used by many researchers in estimating cost and profit functions. For example, Kako [29], Chino [8], Kuroda [33], Ito [18, 19] to name only a few.

6) One troublesome problem occurring from the assumption that the agricultural labor market is not perfect is that the optimal solutions of the production decision (profit maximization) and the consumption decision (utility maximization) of the agricultural household have to be made simultaneously rather than recursively (Maruyama [37], Jorgenson and Lau [28] among others). This implies that we could not treat the profit maximization of the agricultural household as a producer independently from the consumption side behavior. This in turn indicates that the estimation of the cost function itself and hence the shadow prices of labor and land may be influenced by factors related basically to the consumption decision of the agricultural household. But, we ignore this problem in the present paper simply because the model implementation will be too much complicated. Kusakari [36] takes the same stand.

7) Needless to say, the cost functions where other input is treated as a fixed input have been estimated. But, the results were not satisfactory at all. Treating it as a variable input has given much more satisfactory results.

8) We specified the variable cost function by adding a time trend in order to capture the effects of autonomous technological change which occurs independently from public R&E activities. However, the estimation was not satisfactory because of the multicolinearity between the time trend variable and the stock of technological knowledge Z_R.

9) For a detailed discussion on the inclusion of the revenue share equations in the system of regression equations, see Ray [39] and Capalbo [5].

10) Ohta [38] develops in much more comprehen-

sive manner the rates and biases of technological progress and returns to scale in a multi-product multi-input production.

11) We tested for the cointegration relationship for each of the cost function, three cost share equations, and two revenue share equations. For the details of the test for panel data as in the present study, see Banerjee [3]. The residuals from each regression are used in an augmented Dicky-Fuller [9] test. The result implies that there exists cointegration for each equation, indicating that the long-run relationship is economically meaningful for each equation.

12) All the eigenvalues of the Hessian matrix were negative for the former condition and positive for the latter.

13) Ito [20, p. 182] obtained a similar result based on the estimated result of the translog cost function for the 1960-87 period.

14) Here, we are implicitly assuming that the reduction in planted area has been mainly caused by the set-aside programs, although the farmland area abandoned for planting has been increasing. In this sense, some qualification is needed for the interpretation of the quantitative findings. In order to obtain more direct effects of the set-aside programs, one may have to devise a model where the set-aside land area is explicitly introduced.

15) It should be noted here that the government has paid bonuses in order to encourage farmers to transfer the set-aside rice fields to other crops based on the production adjustment programs. Such bonuses may have negative effects on farmers to increase production efficiency. Thus, in order to analyze more explicitly farmers' incentives related to the production adjustment programs, it is strongly recommended that a model which can treat farmers' effort level and gains including bonuses be introduced. Ito [19] has shown intriguing and promising research in this direction.

16) It may be easier to understand these effects by looking at equation (5). The numerator corresponds to the "technological progress effect" and the denominator to the "fixed input effect".

17) Both technological progress and fixed input effects were estimated separately before adding them up to yield the total effect of Z_R on PGX and PGY. However, they are not reported here to save space.

18) Again, it may be easier to understand these effects by looking at equation (6). The nominator corresponds to the "technological progress effect" and the denominator to the "scale effect".

19) Again, both effects were estimated separately, but they are not reported here to save space. However, it should be noted here that the scale effect defined here is different from the effect of Z_R on scale economies given in equation (16).

20) We implicitly assume the production function as $Q=F(X_M, X_I, X_O; Z_L, Z_B, TK)$ where $TK=\phi(Z_R)$ before deriving the cost function given in equation (1).

21) The causes for the decreased efficiency of research output production should be examined very carefully. However, it is our conjecture that the stagnant investment on R&E activities from the early 1970s up to the late-1980s may have resulted in unfavorable effects on research and extension activities of agricultural researchers and extension people, causing less active research production.

22) In order to show the mechanism of how the set-aside programs cause the decline in farmers' production incentives, Ito [19] showed rigorously that set-aside programs in rice production have effects which distract farmers from choosing the optimum technology.

23) The complete results will be offered to readers who are interested in them on request.

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

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

and

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

where weights are normalized to sum to one as, for example, for $m=7$, $w_{t-1}=w_{t-7}=0.05$, $w_{t-2}=w_{t-6}=0.1$, $w_{t-3}=w_{t-5}=0.2$, and $w_{t-4}=0.3$. For a sensitivity analysis, we assumed again 5, 6, 7, 8, 9, 10, and 11 years for research lag years and 3, 4, and 5 years for extension lag years as in the case of the benchmark year method. Thus, we tried $6\times3=18$ different combinations of the stocks of technological knowledge for the sensitivity analysis of the estimation of the system of the variable translog cost function and the factor share and revenue share equations. However, for none of them was the concavity condition with respect to the stock of technological knowledge satisfied.

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(Received May 2, 2002; accepted February 10, 2003)