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

by

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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 effectiveness of R&E measured in terms of the cost-R&E elasticity had on average an increasing trend for the entire study period. The major cause for the decline or stagnation in agricultural productivity since the late 1960s was found to be the decline and/or stagnation in the investment in R&E activities since the late 1960s. The bias of R&E was found to be toward labor and land saving, and machinery and intermediate inputs using, which is 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

The growth of total factor productivity (TFP) has played an important role in increasing the growth of total output of postwar Japanese agriculture (Hayami; Van Der Meer and Yamada; Kuroda 1994). However, as shown in Figure 1, 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 per annum 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). Using this procedure, Kuroda (1994) 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 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 agriculture (Hayami and Ruttan).

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 and intermediate inputs using) is consistent with the Hicksian induced innovation hypothesis (Kawagoe, Ohtsuka, and Hayami; Kako; Kuroda 1988; Kuroda 1994). However, this result is based on the models where time is used as an index of technological change. Instead, the present study employs more direct proxy variable for the index of technological change, i.e., R&E rather than time. Thus, the second ob-

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. As noted by Huffman and Evenson, this area of investigation is still relatively new. Indeed, this study is a first investigation of the bias effects of R&E for Japanese agriculture, 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.

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).

It is assumed that the agricultural sector has a production function which satisfies the neoclassical regularity conditions. It is further assumed that the farm-firm 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 technology index is represented by R&E. Then, there exists a cost function which is a dual of the production function (Diewert).

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

where Q is the quantity of output, 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 the accumulated capital stock of R&E expenditures.

It may be relevant here to point out three important qualifications on the use of the variable R. First, R is a simple sum of the expenditures on research and extension activities. Measuring the impacts of extension expenditures on agricultural productivity separate from research expenditures has been difficult. If extension's role is distinct from that of research, a separate extension variable should be used in the production and hence cost functions. However, 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 contribution of research and extension. The latter case is assumed to be the appropriate situation in the present study. Therefore, research and extension expenditures are combined. Second, the accumulated capital stock of R&E expenditures is defined for R, because it is considered that the stock of R&E expenditures instead of the annual flow of them produce technological knowledge through the research production function (Anderson). 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 R&E expenditures on productivity and factor biases would tend to be overestimated.

In order to obtain these effects quantitatively, the following translog form is specified for the cost function (1).

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

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

$$\begin{aligned}
S_i &= \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \frac{\partial \ln C}{\partial \ln P_i} \\
&= \alpha_i + \sum_{i=1}^{5} \gamma_{ij} \ln P_i + \delta_{Qi} \ln Q + \mu_{iR} \ln R \qquad (3)
\end{aligned}$$

$$\begin{aligned}
S_Q &= \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{\partial \ln C}{\partial \ln Q} \\
&= \alpha_Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \mu_{QR} \ln R \qquad (4)
\end{aligned}$$

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

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (2) 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 (2) 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, test of homotheticity implies that changes in output level do not have any effect on the cost shares. This implies that the following set of restrictions on the translog cost function (2); $\delta_{Qi} = 0$ $(i = L, M, I, B, O)$.

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 $C(Q, P, R) = Q \cdot H(P, R)$. This implies the following set of parameter restrictions on the translog cost function; $\alpha_Q = 1$, $\gamma_{QQ} = \delta_{Qi} = \mu_{QR} = 0$ $(i = L, M, I, B, O)$.

Furthermore, the test of neutrality with respect to R&E implies that the cost shares are not influenced by changes in R&E. This implies $\mu_{iR} = 0$ $(i = L, M, I, B, O)$ in the translog cost function (2).

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

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

As an approximation, if the negative of the cost-R&E elasticity $(-\varepsilon_{CR})$ is multiplied by the actual rate of change in R&E capital stock $(\Delta \ln R)$, then one can obtain the negative of the rate of cost reduction due to changes in

R&E $(-\Delta \ln C)$. This rate can be considered as an approximated dual rate of technological change, λ. That is,

$$\lambda = -\Delta \ln C = -\varepsilon_{CR} \cdot \Delta \ln R \tag{6}$$

or

$$\lambda = -\frac{\Delta C}{C} = -\varepsilon_{CR}\frac{\Delta R}{R} \tag{6'}$$

According to Ohta, the primal rate of shift, i.e., the rate of technological change, μ, can be obtained by dividing the dual rate of cost reduction (λ) by the scale elasticity (ε_{CQ}). That is,

$$\mu = \frac{\lambda}{\varepsilon_{CQ}} = -(\frac{\varepsilon_{CR}}{\varepsilon_{CQ}})\frac{\Delta R}{R} \tag{7}$$

where scale elasticity (ε_{CQ}) is estimated through the translog cost function (2) by

$$\varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \sum_{i=1}^{5} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \mu_{QR} \ln R \qquad i = L, M, I, B, O. \tag{8}$$

Equation (7) indicates that technological change is affected by the cost-R&E elasticity, the scale elasticity, and the rate of change in R&E capital stock.

Another (but, conventional) method to evaluate the effect of R&E on agricultural productivity is to investigate the efficiency of investment in R&E activities by estimating the marginal productivity (MP) of (or marginal rate of return to) R&E capital stock. Furthermore, based on the estimates of MP, the internal rate of returns (IRR) to R&E can be estimated.

The MP of R&E can be obtained, in the translog cost function framework of this study, by[1]

$$MP = (-\frac{\partial C}{\partial R})/\frac{\partial C}{\partial Q} = (-\frac{\partial \ln C}{\partial \ln R}/\frac{\partial \ln C}{\partial \ln Q})\frac{Q}{R} = (-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}})\frac{Q}{R} \tag{9}$$

Equation (9) indicates that the MP of R&E can be obtained by multiplying the negative of the cost-R&E elasticity ($-\varepsilon_{CR}$) normalized by the scale elasticity (ε_{CQ}) by the average productivity of R&E (Q/R).

The IRR (r) for the discrete time period can be obtained by

$$(1+r)^{\theta} = \sum_{t=0}^{T} \frac{MP_t}{(1+r)^t} \tag{10}$$

where θ is the lag of diffusion of developed technology. Following Fujita and Ito, five years are assumed to be the maximum.

Next, the bias effects of R&E, if any, can be captured by non-neutral changes in factor shares due to changes in R&E capital stock. This study defines the bias effects as

$$\frac{\partial S_i}{\partial \ln R} = \mu_{iR}, i = L, M, I, B, O. \tag{11}$$

If $\mu_{iR} > 0$ (< 0), then technological change caused by R&E is said to be biased toward using (saving) the i-th factor. If $\mu_{iR} = 0$, then technological change is said to be the i-th factor neutral. Based on the estimated results of the μ_{iR}, one can examine whether or not the direction of the measured factor biases is consistent with the Hicksian induced innovation hypothesis.

Furthermore, changes in output scale may also cause biases in technological change. Such bias effects can be measured, in the translog cost function

[1]Ito presents a compact mathematical derivation of the marginal productivity of R&E capital stock in the cost function framework (pp.245-246).

framework of this study, by non-neutral changes in the factor shares due to changes in the level of output as[2]

$$\frac{\partial S_i}{\partial \ln Q} = \delta_{iQ}, i = L, M, I, B, O. \tag{12}$$

If $\delta_{iQ} > 0$ (< 0), then technological change due to changes in output scale is said to be the i-th factor using (saving). If $\delta_{iQ} = 0$, then the i-th factor neutral.

Note that R&E plays an important role in increasing the level of output by shifting the production (cost) function upward (downward). In this sense, it can be said that R&E exerts at least partly indirect impacts on factor biases via changes in output scale.

For statistical estimation, since the right-hand-side variable Q in the cost function (2) 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 variables definitions for estimating the system of the translog cost function and the cost and revenue share equations are described in the Appendix.

[2]Antle and Capalbo define the nonhomotheticity effect due to changes in output as $\partial \ln S_i / \partial \ln Q$ (pp.40-41).

Empirical Results

In the process of estimation of the system of the cost function and the factor and revenue share equations, the three hypotheses, i.e., homotheticity, constant returns to scale, and 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 48.0, 214.2, and 312.8 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 linear homogeneity restrictions. The results are presented in Table 1. As shown in Table 1, the adjusted R^2s were rather high for all equations except for the revenue share equation. Though a little low, the adjusted R^2 for the revenue share equation, 0.537, is not that bad. Thus, the fit of the model as a whole may be said to be good. In addition, monotonicity and concavity of the cost function were checked and satisfied for the approximation point. This set of estimates is referred to as the final specification of the model and will be used for further analyses.

Cost Reduction Effects of R&E

To begin with, let us examine the impacts of R&E on agricultural productivity by looking into the estimate of the negative of the cost-R&E elasticity ($-\varepsilon_{CR}$) which is presented in Figure 2. This figure shows that this elasticity had a clear increasing trend during the 1960-73 period (0.103 in 1960 to 0.162 in 1973), then it became stagnant until 1985, although the magnitude of the elasticity was fairly large (around 0.154 on average). However, it started increasing again since 1986 and reached the maximum (0.177) in 1988 and began to decrease after that. However, it is difficult to judge at this point of time due to lack of data whether or not it has a decreasing trend after 1989.

This finding indicates that the cost reducing effects of R&E increased for the period 1960-73, faced a stagnation for the period 1974-85, and again increaed for the period 1986-90. To put it another way, R&E activities in Japanese agriculture increased the effectiveness in advancing technological progress for the period 1960-73, maintained that level of the effectiveness for the period 1974-85, and increased again the level of the effectiveness for the period1986-90. In sum, R&E activities for the entire 1960-90 period were in general rather effective in advancing agricultural productivity.[3]

What were then the cause for the decrease in the growth rate of TFP after 1968 as seen in Figure 1? To answer this question, the approximate primal rate of technological change was estimated for each year of the 1960-90 period using equation (7). Based on this estimate, the accumulated technological change index was obtained setting the 1960 value at 1.0. This index is presented in Figure 3 together with the TFP index given in Figure 1. Although the parametrically estimated rate of technological change has a smooth curve, the basic characteristics of the two indices are in general very similar. That is, the rate of growth of productivity were highest for the 1960-68 period, and then decreased for the following 1969-90 period. This indicates that the cause for the decrease in agricultural productivity in terms of the TFP index

[3] This result contradicts with that obtained by Ito. His result shows consistent decreases in the negative of the cost-R&E elasticity after 1973. He obtained this result by estimating a variable cost function with land being a quasi-fixed input using the data of average farm for each of five size classes. It is likely that Ito might have failed to capture amply the spillover effect of R&E due to the usage of micro-level data rather than the aggregate macro data for the agricultural sector.

may now be discussed in terms of the parametrically measured technological change.

Since, as shown in equation (7), the primal rate of technological change is a product of the negative of the cost-R&E elasticity normalized by the scale elasticity $(-\varepsilon_{CR}/\varepsilon_{CQ})$ and the rate of change in R&E capital stock $(\Delta R/R)$, it is necessary to examine the movements of these two indicators over the 1960-90 period. First, the mean value and the standard deviation of the scale elasticity for this entire 30-year period was 1.18 and 0.02, respectively, indicating that this elasticity was considerably stable for this period. Thus, as shown in Figure 2, the negative of the cost-R&E elasticity deflated by the scale elasticity varied almost parallel to the negative of the cost-R&E elasticity. This implies that changes in scale economies explain little the declines in productivity during the 1960-90 period. However, as shown earlier, the cost-R&E elasticity in general had an increasing trend, indicating that R&E activities have been increasing the effectiveness in advancing technological progress. Thus, the negative of the cost-R&E elasticity deflated by the scale elasticity was not responsible for the decline in productivity since the late 1960s. The factor responsible for the decline must have then been the rate of change in R&E capital stock.

In order to confirm this inference, the rate of increase in R&E capital stock was obtained for each year of the 1960-90 period and is shown in Figure 4. According to this figure, the rate of increase in R&E had an increasing trend until 1968, though it decreased for the 1960-62 period. However, after 1968 it had a decreasing trend, although there was an increase in this rate for the 1972-77 period. This movement of the rate of increase in R&E appears to be consistent with that of the index of technological change as shown in Figure 3. In sum, it may be said that the major cause for the decline in the growth rate of agricultural productivity after 1968 was the decrease in the growth rate of R&E capital stock.

The Efficiency of R&E

Next, the marginal productivity of R&E (MP) was estimated for each year of the 1960-90 period using equation (9) and is presented in Figure 5. It is shown that the MP was very large for each year of the 1960-68 period, more than 13 yen per 1 yen increase in R&E capital stock. However, after that period it decreased consistently, though the MP itself was still as large as around 5 yen during the 1980s.

It may be worth explaining at this juncture about the divisions into several sub-periods of the 1960-90 period. To begin with, the entire period was divided into two sub-periods, 1960-68 and 1969-90. The year 1969 was chosen as a benchmark year for this subdivision because this was the year where an acreage restriction program was ever introduced into the Japanese rice, a crop that is widely considered as the most important product of the Japanese agriculture. Note that the 1960-68 period corresponds to the period of rapid growth of the Japanese economy as a whole which ended in 1972. In this period, the average annual compound rate of growth was 11.0 percent.

During the 1969-90 period, while the government consistently strengthened the acreage restriction programs, it launched an important program of reorganizing paddy utilization for rice production in 1978. The program has been aimed at encouraging movements of paddy fields in order for large scale farms to exploit scale economies. Thus, choosing 1978 as another benchmark year, the 1969-90 period was further divided into two sub-periods, 1969-77 and 1978-90. Although for the first several years of the 1969-77 period, the growth rate of the Japanese economy as a whole was still high, it became much moderate after 1973 when the "oil crisis" occurred. This moderate economic growth continued also for the 1978-90 period; the average annual compound growth rate for the 1973-90 period was 4.1 percent.

Now, based on the estimates of the MP, the IRR of R&E was estimated for the three sub-periods 1960-68, 1969-77, and 1978-90. This estimation was executed for three hypothetical lag periods of diffusion of developed technology, 3, 4, and 5 years, and $T = \infty$ was assumed. In this estimation, the simple average MPs for the three sub-periods were used in order to simplify the computation: 14.6, 8.8, and 4.3 yen, respectively, in 1985 price. The results are presented in Table 2. This table shows that the IRR was still larger than 45 percent in any case, it decreased consistently over time. In other words, although the efficiency of investment in R&E activities was still high, it declined considerably over time during the 1960-90 period.[4]

It is clear from the formula of estimation of the IRR given in equation (10) that the major reason for this decline in the IRR over the study period was the reduction in the MP of R&E. What was then the cause for the reduction in the MP?

As shown in equation (9), the MP can be obtained as a product of the negative of the cost-R&E elasticity deflated by the scale elasticity $(-\varepsilon_{CR}/\varepsilon_{CQ})$ and the average productivity of R&E (Q/R). It was already observed in Figure 2 that, roughly speaking, the former had an increasing trend for the 1960-90 period. On the other hand, the average productivity of R&E declined consistently over the 1960-90 period as seen in Figure 6. This was mainly because output grew with a low rate and became stagnant after 1968; the annual growth rates of total output were 0.70 and -0.16 percent for the 1969-77 and 1978-90 period, respectively. In sum, it may safely be said that the

[4]Ito obtained similar results. However, his estimates of the IRR for the 1980-87 period were extremely low, around 2.2 to 2.3 percent, compared with 45.4 to 62.2 percent for the 1970-90 period in the present study.

major cause for the decline in the efficiency of R&E has been the stagnation of the output growth.

The Bias Effects of R&E

The direction of the factor biases due to changes in R&E can be evaluated by equation (11), i.e., the estimates of the coefficients μ_{iR} $(i = L, M, I, B, O)$ of the translog cost function. The estimates of the μ_{iR} are all significant at the conventional five percent significance level. They show that changes in R&E had bias effects toward machinery and intermediate inputs using, and labor, land, and other inputs saving during the study period.

As argued in section two, changes in R&E may have also bias effects via changes in the level of output scale. In this paper, therefore, part of non-homotheticity effects is regarded as estimating the indirect effects of factor biases. The direction of the factor biases due to changes in output scale can be evaluated by the estimates of the δ_{Qi} $(i = L, M, I, B, O)$ of the translog cost function presented in Table 1. These estimates indicate that changes in the output scale had bias effects toward machinery and intermediate inputs using, and labor, land, and other inputs saving, although the estimates of δ_{QM} and δ_{QO} are statistically significant at only 20 percent level. Thus, the direction of the factor biases was found to be exactly the same as that with respect to changes in R&E.

In sum, it can be said that changes in R&E had not only the direct but also the indirect bias effects toward machinery and intermediate inputs using, and labor, land, and other inputs saving for the study period.

The direction of the factor biases is associated, respectively, with the rising trends of the prices of labor and land and with the declines in the prices of machinery and intermediate inputs relative to the output price. In this sense, the direction of the biases with respect to changes in R&E is consistent with Hicksian induced innovation hypothesis. This implies that the public research sector has been sensitive to changes in factor prices in executing R&E activities.

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 effectiveness of R&E in advancing technological progress increased and remained at fairly high level during the study period. Thus, the major reason for the declines in the growth rates of TFP (or technological change) was the decrease in the growth rate of R&E capital stock after 1968. (2) The efficiency of investment in R&E activities measured in terms of the marginal productivity (MP) of and the internal rate of return (IRR) to R&E (estimated based on the MP) decreased consistently over the 1960-90 period, although both the MP and IRR remained rather high. The major reason for this decline was found to be the stagnation of the growth of output after 1968. (3) The direction of the factor biases due to R&E was toward machinery and intermediate inputs using, and labor, land, and other inputs saving. This was consistent with the Hicksian induced innovation hypothesis. This implies that the public research activities have been sensitive to the movements in the factor markets and hence the conditions of factor endowments.

In one word, given the factor markets, the public R&E activities in Japanese agriculture have been effective in advancing the productivity and efficient in utilizing the factor inputs. However, in order to raise or at least maintain the existing effectiveness and efficiency of R&E activities, it is necessary to raise the growth rate of total output of the agricultural sector. Along this line of thought, there is a conjecture that the everlasting acreage restriction programs for rice production since 1969 may have had an effect of reducing farmers' incentives in management. Furthermore, although the degrees of supports were substantially reduced, the persistent government price support programs for agricultural products, especially for rice, impeded competition. This in turn may have caused what Leibenstein calls a "slack" or "X-inefficiency" in farm management.

Thus, for increased growth of agricultural output, regulations such as acreage restrictions and restrictions on farmland utilization and transactions as well as price supports have to be relaxed or withdrawn to a large extent.

Appendix

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 for the latter. After that, those for 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 ($QandP$) 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 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. 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 Tönqvist 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 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

$$P_t = q_t(r_t + \delta_t). \qquad (A.1)$$

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:

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

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,

$$V_t = P_t K_{t-1} \qquad (A.3)$$

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 obtainn 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 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. The data for the period 1980-90 were obtained following 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. The cost of land ($P_B X_B$) 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

$$C = P_L X_L + P_M X_M + P_I X_I + P_B X_B + P_O X_O. \qquad (A.4)$$

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

$$S_Q = PQ/C \qquad (A.5)$$

and

$$S_i = P_i X_i / C \qquad (A.6)$$

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

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 was computed as Q/F.

As for the capital stock.of R&E, the present study employed the estimate of Ito. He obtained this estimate as follows. To begin with, the capital stock of the benchmark year (R_s) was obtained by

$$R_s = E_{s-5}/(\delta_R + g) \tag{A.7}$$

where E is public research expenditures, δ_R is the rate of obsolescence of the stock of technological knowledge, and g is the annual growth rate of the capital stock of research expenditures. In deriving (A.7), Ito assumed that the amounts of investment in research activities are added to the capita stock of research expenditures with a six-year lag of development. In addition, he assumed 10 percent for both δ_R and g to obtain R_s. Finally, Ito re-defines the capital stock of research expenditures by adding extension expenditures to R_s. This R_s was deflated by the price index of research expenditures (1985=1.0) and expressed in 10 billion yen.

References

Anderson, J. R. "Agricultural Research in a Variable and Unpredictable World," in P. G. Pardey, J. Roseboom and J.R. Anderson (eds.). **Agricultural Research Policy: International Quantitative Perspective.** Cambridge: Cambridge University Press 1991.

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

Christensen, L. R. and W. H. Greene. "Economies of Scale in U.S. Electric Power Generation." **J. Polit. Econ.** 84 (1976):655-676.

Denny, M., M. Fuss, and L. Waverman. "The Measurement and Interpretation of Total Factor Productivity in Regulated Industries," in T. G. Cowing and R. E. Stevenson (eds.). **Productivity Measurement in Regulated Industries.** New York: Academic Press 1981.

Diewert, W. E. "Applications of Duality Theory," in M. D. Intriligator and D. A. Kendrick (eds.). **Frontiers of Quantitative Economics.** Amsterdam: North Holland Publishing Co. 1974.

Fujita, Y. **Agricultural Extension and Technological Innovations**(in Japanese). Tokyo: Nosan Gyoson Bunka Kyokai 1987.

Hayami, Y. **A Century of Agricultural Growth in Japan.** Tokyo: University of Tokyo Press 1975.

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

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

Huffman, W. E. and R. E. Evenson. "Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other

Policies." **Amer. J. Agr. Econ.** 71 (August 1989): 761-773.

Ito, J. "An Economic Analysis of Investment in Agricultural Research and Extension Activities in Japan." **Keizai Kenkyu** (in Japanese). 43 (July 1992): 237-247.

Izumida, Y. **Theoretical and Empirical Study on the Rates of Return to Capital and Investment in Postwar Japanese Agriculture**(in Japanese). Special Bulletin No. 44. College of Agriculture, Utsunomiya University, Utsunomiya, Japan 1987.

Japan, Ministry of Agriculture, Forestry, and Fisheries. **National Accounts of Agriculture and Food-Related Industries**(in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries various issues.

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

Japan, Ministry of Agriculture, Forestry, and Fisheries. **Statistical Yearbook of the Ministry of Agriculture, Forestry, and Fisheries**(in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries various issues.

Japan, Ministry of Agriculture, Forestry, and Fisheries. **Survey Report on Farm Household Economy**(in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries various issues.

Japan, Office of the Prime Minister. **Japan Statistical Yearbook**(in Japanese). Tokyo: Bureau of Statistics, Office of the Prime Minister various issues.

Japan Real Estate Institute. **Survey Report on Prices and Rents of Paddy and Upland Fields**(in Japanese). Tokyo various issues.

Jorgenson, D. W. "The Economic Theory of Replacement and Depreciation," in W. Sellekaerts (ed.). **Econometrics and Economic Theory.** London: Macmillan 1974.

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

Kawagoe, T., K. Ohtsuka, and Y. Hayami. "Induced Bias of Technical Change in Agriculture: The United States and Japan, 1880-1980." **J. Polit. Econ.** 94 (1986): 523-544.

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

Kuroda, Y. "Productivity Measurement in Japanese Agriculture, 1956-90." Discussion Paper Series No. 556. Institute of Socio-Economic Planning, University of Tsukuba, Tsukuba, Ibaraki 305, Japan.

Leibenstein, H. **Beyond Economic Man: A New Foundation for Microeconomics.** Cambridge, MA: Harvard University Press 1976.

Ohta, M. "A Note on the Duality between Production and Cost Functions: Rate of Returns to Scale and Rate of Technical Progress." **Economic Studies Quarterly** 25 (December 1974): 63-65.

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

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

Van Der Meer, C. L. J. and S. Yamada. **Japanese Agriculture: A Comparative Economic Analysis.** London and New York: Routledge 1990.

Yamada, S. "The Secular Trends in Input-Output Relations of Agricultural Production in Japan, 1878-1978," in C. M. Hou and T. S. Yu (eds.). **Agricultural Development in China, Japan, and Korea.** Taipei: Academia Sinica 1982.

Yamada, S. "Country Study on Agricultural Productivity Measurement and Analysis, 1945-1980: Japan." SYP/VII/84. Institute of Oriental Culture, University of Tokyo, Japan 1984.

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	12.039	1281.2	γ_{MI}	-0.009	-1.1
α_Q	0.846	60.1	γ_{MB}	-0.004	-0.7
α_L	0.291	93.1	γ_{MO}	-0.010	-1.9
α_M	0.091	127.6	γ_{IB}	-0.086	-4.0
α_I	0.317	107.5	γ_{IO}	-0.052	-4.6
α_B	0.179	42.6	γ_{BO}	0.043	6.0
α_O	0.122	118.7	δ_{QL}	-0.092	-2.9
β_R	-0.154	-7.1	δ_{QM}	0.012	1.2
γ_{QQ}	0.549	4.4	δ_{QI}	0.255	6.6
γ_{LL}	0.145	12.8	δ_{QB}	-0.160	-3.6
γ_{MM}	0.032	3.8	δ_{QO}	-0.015	-1.1
γ_{II}	0.157	5.5	μ_{QR}	0.092	4.1
γ_{BB}	0.109	4.3	μ_{LR}	-0.087	-12.5
γ_{OO}	0.083	10.9	μ_{MR}	0.058	12.9
γ_{LM}	-0.009	-2.7	μ_{IR}	0.059	5.4
γ_{LI}	-0.010	-0.8	μ_{BR}	-0.021	-2.0
γ_{LB}	-0.062	-4.8	μ_{OR}	-0.009	-2.0
γ_{LO}	-0.064	-13.9	β_{RR}	0.054	2.2

Estimating Equation	$\bar{R}^2$
Cost function	0.994
Labor share equation	0.976
Machinery share equation	0.995
Intermediate inputs share equation	0.939
Land share equation	0.943
Revenue share equation	0.537

Table 2: Internal Rate of Return to R&E Capital Stock (%)

Diffusion lag (Years)	1960-68	1969-77	1978-90
3	97.0	81.4	62.2
4	79.1	67.2	52.4
5	67.1	57.5	45.4

Figure 1. Index of Total Factor Productivity of the Agricultural Sector for 1960-90

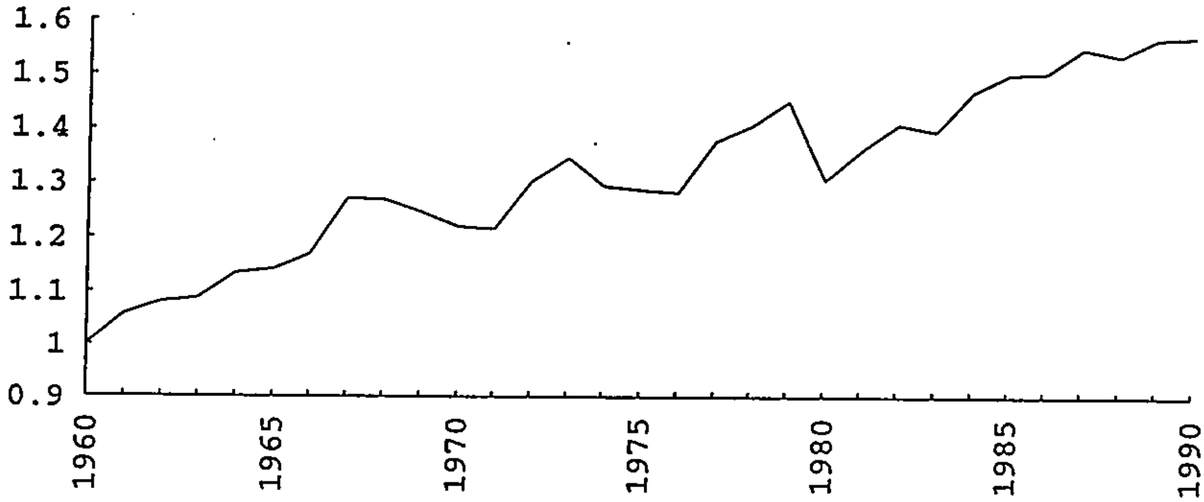

Figure 2. The Negative of The Cost-R&E Elasticity and The Negative of The Cost-R&E Elasticity Deflated by the Scale Elasticity for 1960-90

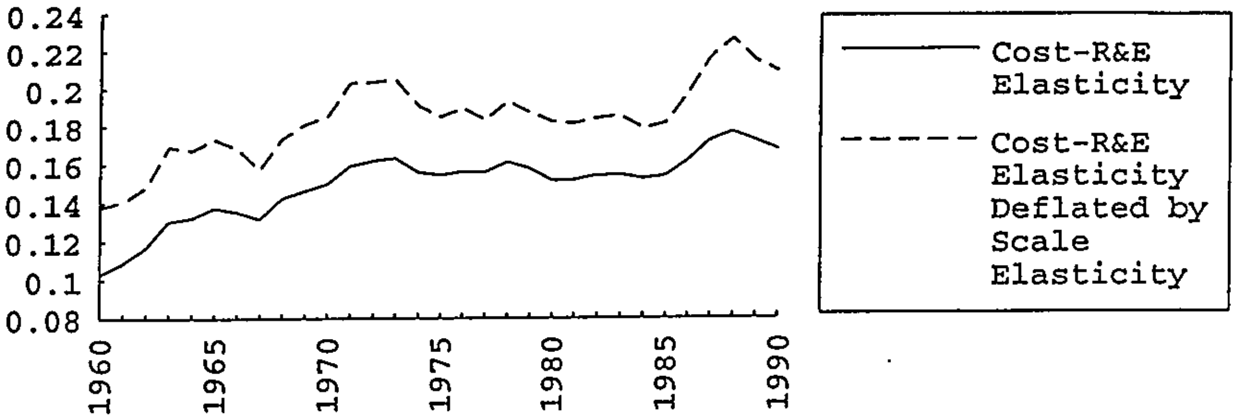

Figure 3. Indices of TFP and Parametrically Estimated Technological Change for 1960-90

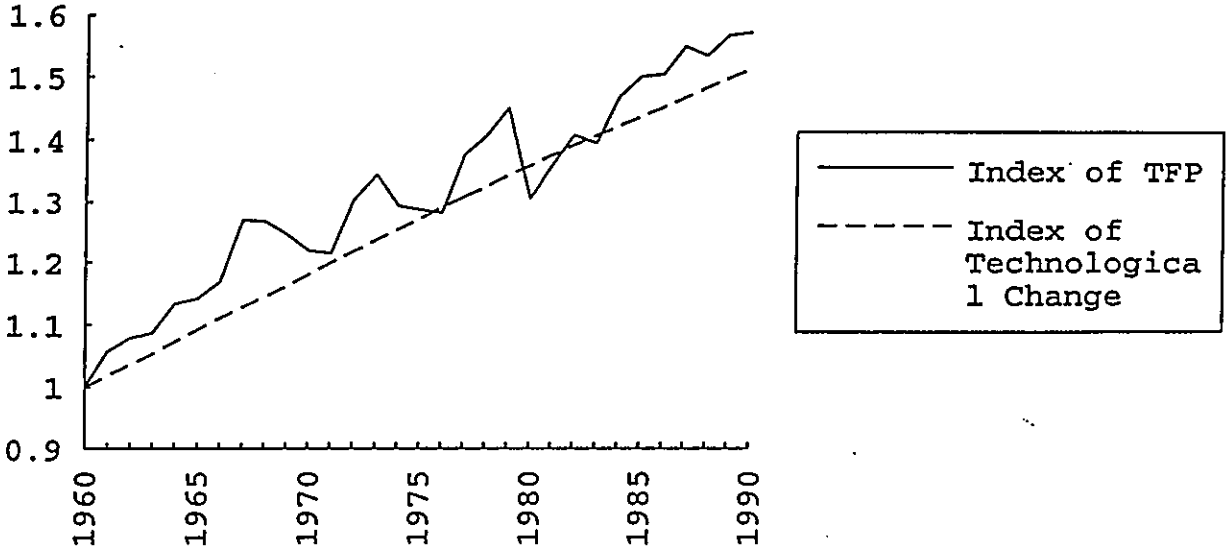

Figure 4. Annual Rate of Increase in R&E Capital Stock for 1960-90

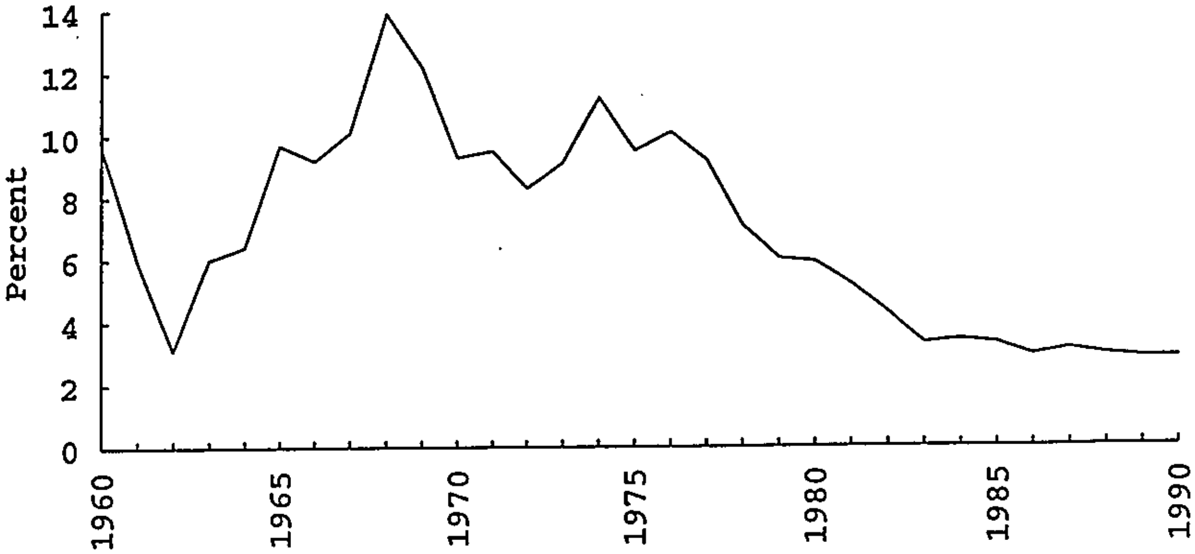

Figure 5. Marginal Productivity of E&E Capital Stock for 1960-90 (in 1985 Prices)

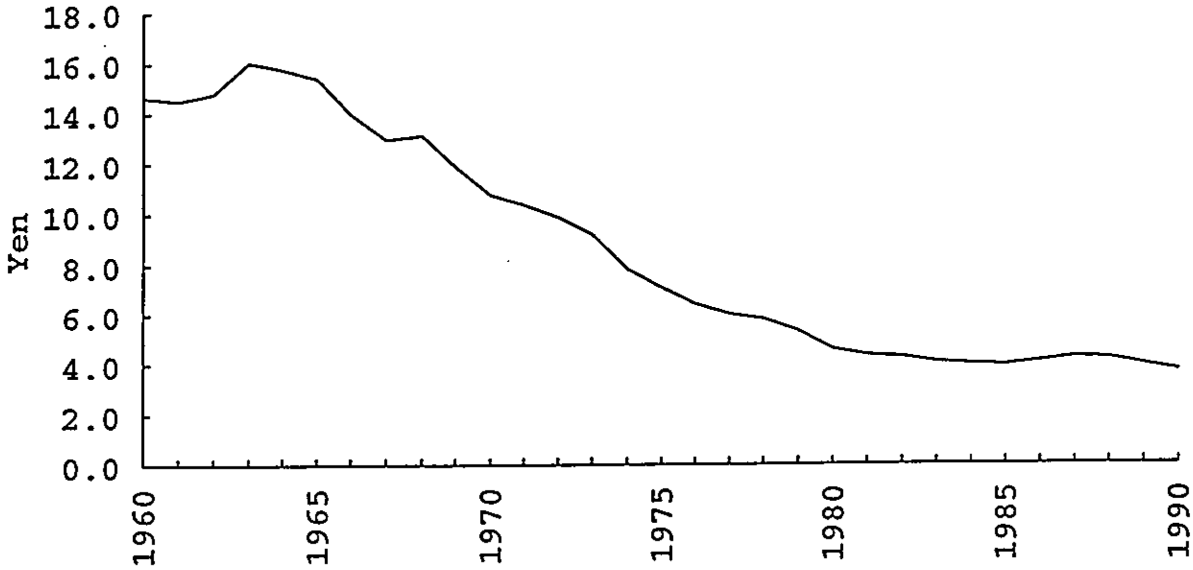

Figure 6. Average Productivity of R&E Capital Stock for 1960-90 (in 1985 Prices)