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Impacts of Economies of Scale and Technological Change on Agricultural Productivity in Japan

by

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1. Introduction

As is well known, the Japanese economy as a whole experienced rapid growth from the mid-1950s through the early 1970s, with the annual growth rate for this period averaging more than 10 percent. However, after this period of dramatic growth, it entered upon a stage of moderate growth with a much lower average annual rate of around 4 percent. How has the agricultural sector faced through such a drastic change in the overall economic environment? What has been the connection between agricultural production and the Japanese economy as a whole during the periods of rapid and slow or steady growth? In particular, it is of great interest and critical importance to analyze changes in total factor productivity (TFP), since it is a major contributing factor to growth in agricultural production. Accordingly, the objective of this study is to measure and analyze total factor productivity in agricultural production during the period 1958-84.

A number of studies in this area of research have been published in Japan mainly by Yamada and Hayami. However, these studies are in principle only for describing how Japanese agriculture grew before and after World War II by estimating the indexes of total output, total input, and total factor productivity. This study, however, attempts to analyze the underlying economic structure that led to changes in total factor productivity in postwar Japanese agriculture. More specifically, the point of departure of this study lies in the following two distinctive features.

First, the method used by Yamada and Hayami to measure the index of total factor productivity is conventional in a double sense. To begin with, they applied the Laspeyres indexing procedure to measure the indexes of total output, total input, and total factor productivity. This suggests that they implicitly assume that the underlying agricultural production function is linear and hence all factor inputs in the production process are perfectly substitutable (Christensen). However, recent studies (for example, Kako 1978, Nghiep, Chino, Kuroda 1987) on the production structure of Japanese agriculture offer empirical evidence that not all factor inputs are perfect substitutes. This means that the Laspeyres method may not be appropriate in measuring total factor productivity. Christensen in this context recommends using the Törnqvist approximation method of the Divisia indexing procedure. Here the underlying production function is of flexible form so that the elasticities of substitution between any pairs of factor inputs can take any values.

Furthermore, Yamada and Hayami measured total factor productivity based on the assumption that the underlying production function is characterized by constant returns to scale. Needless to say, however, the same assumption is also made in the case of applying the Törnqvist approximation method. As is well known, under the assumtion of constant returns to scale, the rate of growth of total factor productivity is equal to the rate of technological change. However, if scale economies exist, estimates of the growth rate of total factor productivity include the effect of scale economies and therefore overestimate the effect of technological change. Recent empirical studies give evidence that scale economies have existed in postwar Japanese agriculture, e.g., Kako (1979) and Chino.

Although this study follows the conventional Törnqvist procedure in order to measure the indexes of total output, total input, and total factor productivity, it also goes one step further attempting to disentangle and measure the contributions of scale economies (if any) and technological change to the growth of total factor productivity in postwar Japanese agriculture. For this objective, the production structure of postwar Japanese agriculture will be empirically investigated. In particular, the existence of scale economies will be statistically examined in the process of empirical estimation. Thus, the first feature of this study which departs from previous studies is the attempt to link the measured growth of total factor productivity to the economic theory of production.

Next, the studies by Yamada and Hayami are based on national aggregate data of the agricultural sector, and are convenient for investigating at macro level changes and/or differences in the growth rates of total factor productivity between pre- and post-war years; between agriculture and nonagriculture; or between countries.

However, such macro level studies do not offer any information on changes and/or differences in the patterns of growth of total factor productivity among farm-firms with different scales of operation. It may be very interesting to investigate such differences at the farm level, because such information will offer an important clue to the question of who can produce agricultural commodities most efficiently. Thus, the measurement and decomposition of the rate of growth of total factor productivity in this paper will be carried out based on the farm level aggregate data for the 1958-84 period. This is the second feature of this study.

This study is organized as follows. In section two, the indexes of total output, total input, and total factor productivity are measured for the 1958-84 period through the conventional Törnqvist approximation procedure. In section three, the measured rate of growth of total factor productivity is linked to the theory of production. Section four discusses the specification of the translog cost function and the statistical procedure. The data used for empirical estimation is explained in section five, and empirical results are analyzed in section six. Finally, some concluding remarks are offered in section seven.

2. Total Output, Total Input, and Total Factor Productivity

This section investigates movements in total output, total input, and total factor productivity (TFP) for average farms of four size classes, 0.5-1.0 (I), 1.0-1.5 (II), 1.5-2.0 (III), and 2.0 hectares and over (IV), for the 1958-84 period. The basic sources of data were taken from the Survey Report on Farm Household Economy (FHE) and the Survey Report on Prices and Wages in Rural Villages (PWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries, Government of Japan.

For the measurement of the indexes of total output, total input, and total factor productivity, the conventional Divisia aggregation procedure is employed.[1/] The Divisia indexes for aggregate output (Q) and input (F) are defined in terms of proportional rates of growth ($\dot{Q}$ and $\dot{F}$) as follows:

$$(1) \qquad \dot{Q} = \sum_j \frac{q_j Q_j}{R} \dot{Q}_j ,$$

$$(2) \qquad \dot{F} = \sum_i \frac{P_i X_i}{C} \dot{X}_i ,$$

where q_j and Q_j are respectively the price and quantity of output j; P_i and X_i are respectively the price and quantity of input i; $R = \sum_j q_j Q_j$, the total revenue, $C = \sum_i P_i X_i$, the total cost; and $\dot{Q}_j$ and $\dot{X}_i$ the proportional rates of growth of output j and input i, respectively.

Since TFP = Q/F, the proportional rate of growth of total factor productivity ($\dot{TFP}$) is defined by

$$(3) \qquad \dot{TFP} = \dot{Q} - \dot{F} .$$

The formulas (1)-(3) are however in terms of instantaneous changes. The data to be used in this study are available at yearly intervals. The Tӧrnqvist discrete approximation procedure is then introduced to the formulas (1) and (2): [1]

$$\Delta \ell n\ Q = \ell n \left(\frac{Q_t}{Q_{t-1}}\right) = \frac{1}{2} \sum_j (r_{jt}+r_{jt-1})\ \ell n \left(\frac{Q_{jt}}{Q_{jt-1}}\right) \tag{4}$$

$$\Delta \ell n\ F = \ell n \left(\frac{F_t}{F_{t-1}}\right) = \frac{1}{2} \sum_i (s_{it}+s_{it-1})\ \ell n \left(\frac{X_{it}}{X_{it-1}}\right) , \tag{5}$$

where $r_j = q_j Q_j / R$, the revenue share of output j; $s_i = P_i X_i / C$, the cost share of input i; and t denotes time period. The corresponding discrete approximation to formula (3) is given by

$$\Delta TFP = \Delta \ell n\ Q - \Delta \ell n\ F . \tag{6}$$

Making use of equations (4), (5), and (6), the indexes of total output, total input, and total factor productivity were measured for the average farm in each size class for the 1958-84 period. In these measurements, eleven different items of outputs were classified into five categories, i.e., rice, vegetables, fruits, livestock, and others, while inputs were classified into labor, machinery, intermediate inputs, land, and other inputs.[2] The details of these categorizations are provided in section five. The base year was set at 1958. The estimates of the indexes of total output, total input, and total factor productivity are presented in graphic form in Figures 1, 2, and 3, respectively.

According to Figure 1, average farms in all size classes increased total output fairly rapidly for the period 1958-75, although the rates of growth are apparently different among classes. After 1975, however, a clear distinction may be recognized in the growth patterns of total output among different size classes. Total output of average farms in smaller classes (I and II) declined fairly rapidly in the late 1970s, though growing again after 1980. Total output of average farms in larger scale farms (classes III and IV) continued to increase even after 1975. In particular, the growth of total output of class IV farms for the 1975-84 period was remarkable compared with those of the other classes.

In order to investigate these differences in the growth patterns of total output among size classes in more detail, the growth rates of total output and the revenue-share weighted growth rates of the five categories of outputs were computed for each size class for the two subperiod 1958-75 and 1975-84. The results are presented in Table 1. Several findings emerge from this table.

First, as expected from Figure 1, the growth rates of total output were fairly high ranging from 3.9 to 4.8 percent per year in all size classes for the 1958-75 period, which is remarkable for agricultural production, although low compared with the growth rates of nonagricultural sectors for the same period. During the 1975-84 period, the annual growth rates of total output in classes I and II became negative, i.e., -1.8 and -1.6 percent, respectively, whereas those in classes III and IV were still fairly high, 1.7 and 3.4 percent, respectively.

Second, for the 1958-75 period, the revenue-share weighted growth rate of rice production was very low in all size classes. On the other hand, the growth of production of vegetables, fruits, and livestock contributed substantially to the growth of total output in all size classes during this period. This seems to have been caused mainy by the increased demand for these products due to a sharp increase in per capita income, and further effected by the "Selective Expansion Policy" of agricultural commodities such as livestock, vegetables, and fruits by the Ministry of Agriculture, Forestry, and Fisheries on the supply side.

Third, during the 1975-84 period, it turned out that rice production contributed negatively to the growth of total output in each size class. This seems to have been due mainly to declining rice demand along with the Government's policies for paddy field retirement and diversion to other agricultural commodities.

Finally, during this period, production of vegetables, fruits, and livestock also contributed negatively to the growth of total output in classes I and II. In contrast, production of these agricultural commodities in classes III and IV contributed significantly to the growth of total output. This must have been due to the fact that larger-scale specialized producers became dominant during this period, most markedly in livestock.

Next, movements of total input are investigated in Figure 2. Here we can see the period 1968-1970 as a turning point in the growth of total input. Before this turning point, the patterns of growth in total input were very similar among all size classes. After this period, however, the patterns of growth of total input seem to have been widely different among different size classes. However, these patterns may be categorized roughly into two groups. One is for classes I and II whose total input showed cyclical movements during the 1970-84 period but never reached the level attained in the period 1968-70. In contrast, average farms in classes III and IV increased their levels of total input during the 1970-84 period. In particular, the increase in total input in class IV was quite substantial as in the case of total output.

As in the case of total output, in order to examine in more detail differences in the patterns of growth in total input among different size classes and periods, the growth rates of total input and the cost-share weighted growth rates of the five categories of inputs were computed. In this computation, however, the overall 26-year period was subdivided into the 1958-75 and 1975-84 periods in order to make the discussion consistent with the analysis of total output. The results are reported in Table 2. Several points are noteworthy in this table.

First, during the 1958-75 period, the rates of growth in total input were fairly high in all size classes. The contribution of labor input to this growth was strongly negative in all size classes. The relative decline in the labor component is not as marked as farm size increases. On the other hand, machinery and intermediate inputs contributed significantly to the growth of total input in all size classes. The cost-share weighted growth rates of these inputs were more-or-less equal among all size classes. These movements in the relative contributions seem to reflect both the rapid migration of labor and farm mechanization as well as increased utilization of fertilizer, agri-chemicals, and feed during the period underquestion.

Second, as observed in Figure 2, the growth of total input in classes I and II became stagnant or negative during the 1975-84 period, while that of classes III and IV was fairly rapid — the growth rates were 1.9 and 3.3 percent per year, respectively. Also during this period, labor input contributed negatively to the growth of total input in all size classes, and cost-share weighted growth rates shrank in all size classes except for class II compared with the previous period. This may be largely because during this period the pace of labor migration from the agricultural to the nonagricultural sectors slowed down due mainly to decreased labor demand in the nonagricultural sectors.

On the other hand, the contribution of machinery input to the growth of total input even increased during this period compared with the previous period in all size classes. This seems to reflect the fact of mechanization through larger-scale machinery (e.g., riding-type tractors, combines, rice-transplanters, etc.) which was promoted during this period.

Furthermore, the contribution of intermediate inputs to the growth of total input became negative in classes I and II in the 1975-84 period, while that in classes III and IV was still positive, although the degree of contribution was smaller than the previous period. This is mainly because smaller-scale farms decreased their usage of fertilizer, agri-chemicals, and feed during this period, while larger-scale farms, especially specialized larger-scale livestock farms, continued to increase the utilization level of feed.

In addition, the increasing tendency to operate larger-scale specialized farmings in the production of vegetables, fruits, and livestock during this period promoted an increased investment in farm buildings and structures, plants, and animals. This in turn raised the level of other inputs, contributing to the growth of total input in classes III and IV.

Finally, let us investigate movements of total factor productivity in Figure 3. Two points are worth mentioning.

First, the patterns of the growth of TFP are surprisingly similar among all size classes during the 1958-75 period. It is however noteworthy that TFP in smaller size classes apparently grew faster than that in larger size classes. However, during the

1975-84 period, movements of the indexes of TFP show different patterns among different size classes. In classes I and II, TFP had a declining trend, although it seems to have started increasing again from 1981 or 1982. In class III, it declined until 1980, but after that it shows an increasing trend. TFP in class IV shows a cyclical movement from 1975 to 1981. It seems to have an increasing trend after 1981, although it declined slightly from 1983 to 1984.

Second, two jumps can be recognized in the growth of TFP in all size classes during the 1958-75 period. The first jump occurred during the late 1950s through the early 1960s. The second one occurred during the early 1970s. And the latter jump was much larger than the first one. These two jumps in the growth of TFP seem to be consistent with the two time periods of rapid-pace promotion of different types of farm mechanization. The first type of mechanization is characterized by a rapid increase in small-scale machinery such as hand-driven cultivators, while the second type is characterized by the increased use of larger-scale machinery such as riding-type tractors, combines, and rice-transplanters.

It may be relevant at this point to summarize the above findings on the movements of total output, total input, and total factor productivity. For this purpose, Table 3 may be useful where the growth rate of total output in each size class was decomposed into the growth rates of total input and total factor productivity for the two sub-periods 1958-75 and 1975-84 as well as the whole period. Several points are worth mentioning.

First, as expected from Figure 3, the average annual growth rates of TFP in classes I and II (2.2 and 2.4 percent, respectively) were greater than those in classes III and IV (1.9 and 1.8 percent, respectively) during the 1958-75 period. During the 1975-84 periods, however, they drastically declined in all size classes, although the rates of decrease in larger classes were much smaller than those in smaller classes. In particular, farms in classes I and II experienced strongly negative growth rates of TFP, i.e., -1.9 and -1.6 percent per year, respectively.

Second, although the rates of growth of TFP were fairly large in all size classes during the 1958-75 period, the degrees of relative contributions to the growth rates of total output were different among different size classes. They were 56.2, 50.2, 49.6, and 40.6 percent for classes I, II, III, and IV, respectively. There seems a decreasing trend in these degrees of contribution as the farm size increases. Conversely, an increasing trend was found in the degrees of contribution of the growth rates of total input to those of total output as the farm size increases. This may imply that of farms seeking growth in total output, smaller farms depended relatively more on increasing the growth rate of TFP, whereas larger farms sought to increase growth rate through total input changes.

Third, the above finding for the 1958-75 period seems to have been exaggerated in the 1975-84 period. The negative growth rate of total output in class I (-1.84 percent) can be explained by the negative growth rate of TFP which measured -1.91 percent. Almost the same phenomenon can be observed in class II. On the other hand, in classes III and IV, the growth rates of total output (1.86 and 3.28 percent, respectively) are explained almost completely by the growth rate of total input.

What were, then, the determinants of the drastic changes and differences in the growth rates of TFP during the period under question and among different size classes? Conventionally measured TFP indexes as such cannot provide any answer to such a question. It is possible to approach this problem only when the measured growth rate of total factor productivity is linked with the theory of production.

3. Total Factor Productivity and the Theory of Production

In order to link the measured rate of TFP growth to the theory of production, the neoclassical cost function approach is employed in this stury.[3] The reason for this is that as the results of a number of studies (for example, Christensen and Greene, Berndt and Khaled, and Nadiri and Schankerman) have shown, it is much more convenient in estimating various parameters for the characteristics of technology than direct estimation of the production function.

It is assumed that farms have a production function which satisfies the usual regularity conditions. Assuming further that factor input prices are determined exogenously and farms employ the cost-minimizing input-mix for any level of output, then there exists a cost function that is dual to the production function (Diewert).

$$C = G(Q, P, t) \tag{7}$$

where Q is output; P is a vector of prices of the corresponding vector of factor inputs (X); C $(= \sum_{i=1}^{m} P_i X_i)$ is the minimized total cost; and t is an index of time.

Totally differentiating the cost function (7) with respect to time yields

$$\frac{dC}{dt} = \frac{\partial G}{\partial Q}\frac{\partial Q}{\partial t} + \sum_i \frac{\partial G}{\partial P_i}\frac{\partial P_i}{\partial t} + \frac{\partial G}{\partial t} \quad . \tag{8}$$

Dividing both sides of equation (8) by C, using Shephard's (1953) lemma $(\partial G/\partial P_i = X_i)$, and expressing the proportional rates of growth of relevant variables through the use of a dot superscript, we obtain,

$$\dot{C} = \frac{\partial G}{\partial Q}\frac{Q}{C}\dot{Q} + \sum_i \frac{P_i X_i}{C}\dot{P}_i + \frac{1}{C}\frac{\partial G}{\partial t} \quad , \tag{9}$$

Define the elasticity of cost with respect to output as

$$\varepsilon_{CQ} = \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{\partial G}{\partial Q}\frac{Q}{C} \quad . \tag{10}$$

Following Christensen and Green, scale economies are defined as $SCE = 1 - \varepsilon_{CQ}$. Depending on SCE > 0, SCE = 0, or SCE < 0, there exist increasing, constant, or decreasing returns to scale. Define also the proportional rate of shift in the cost function (or the rate of cost diminution) as

$$(11) \qquad \lambda = \frac{1}{C}\frac{\partial C}{\partial t} = \frac{1}{C}\frac{\partial G}{\partial t} \quad .$$

Then, equation (9) becomes

$$(12) \qquad \dot{C} = \varepsilon_{CQ}\,\dot{Q} + \sum_i \frac{P_i X_i}{C}\,\dot{P}_i + \lambda \; .$$

The proportional growth rate of the total cost is the sum of the scale effect ($\varepsilon_{CQ}\dot{Q}$), the change in aggregate factor input prices ($\sum_i (P_i X_i/C)\dot{P}_i$), and the rate of cost diminution (λ). We define here λ as the technological change effect resulted from shifts in the cost curve.

Next, totally differentiating $C = \sum_i P_i X_i$ with respect to time, we obtain

$$(13) \qquad \sum_i \frac{P_i X_i}{C}\,\dot{P}_i = \dot{C} - \sum_i \frac{P_i X_i}{C}\,\dot{X}_i = \dot{C} - \dot{F} \quad .$$

Substituting equation (13) into (12) yields

$$(14) \qquad -\lambda = \varepsilon_{CQ}\dot{Q} - \dot{F} \quad .$$

Using the definition $\dot{TFP} = \dot{Q} - \dot{F}$, equation (14) becomes

$$(15) \qquad \dot{TFP} = (1 - \varepsilon_{CQ})Q - \lambda \quad .$$

If constant returns to scale exist, then $1 - \varepsilon_{CQ} = 0$, implying $\dot{TFP} = -\lambda$. That is, the conventionally measured $\dot{TFP}$ is tantamount to the negative of the rate of cost diminution. According to Ohta, the primal rate of shift in the production function is related to the rate of shift in the cost function by $-\lambda = \varepsilon_{CQ}\mu$ where μ is the primal rate of shift in the production function. Therefore, under constant returns to scale (i.e., $\varepsilon_{CQ}=1$), we obtain $\dot{TFP} = \mu = -\lambda$. That is, the rate of growth of TFP is composed of only technological change effect.

If, however, scale effects are present (i.e., $\varepsilon_{CQ}\neq 1$), then it turns out that conventionally measured estimates of the growth rate of total factor productivity include both scale effects and technological change effects. However, if the cost elasticity (ε_{CQ}) is known, then the measured rate of growth of TFP can be decomposed into scale effects and technological change effects by equation (15). Such a decomposition analysis will provide important information on the relative importance of these effects on changes in the rate of TFP growth and hence changes in the rate of growth of total output.

The next step is then to estimate the cost elasticity (ε_{CQ}). As mentioned earlier, it is most convenient to estimate the appropriately specified cost function in order to do so.

4. Specification of the Cost Function and Statistical Procedure

Following Stevenson and Greene, the following translog form of the cost function is specified with a slight modification for econometric estimation.

$$(16)\qquad \ln C^* = \alpha^t + \alpha_Q^t \ln Q + \sum_{i=1}^{5} \alpha_i^t \ln P_i + \frac{1}{2}\gamma_{QQ}^t (\ln Q)^2$$

$$+ \frac{1}{2}\sum_{i=1}^{5}\sum_{j=1}^{5}\gamma_{ij}^t \ln P_i \ln P_j + \sum_{i=1}^{5}\delta_{Qi}^t \ln Q \ln P_i$$

$$i = j = L, M, I, T, O$$

where all the parameters are assumed to vary log-linearly with time according to

$$\alpha^t = \alpha + \alpha' \ln t$$

$$\alpha_Q^t = \alpha_Q + \alpha_Q' \ln t$$

$$(17)\qquad \alpha_i^t = \alpha_i + \alpha_i' \ln t$$

$$\gamma_{ij}^t = \gamma_{ij} + \gamma_{ij}' \ln t$$

$$\gamma_{Qi}^t = \gamma_{Qi} + \gamma_{Qi}' \ln t$$

$$i = L, M, T, I, O,$$

and subscripts L, M, T, I, and O designate labor, machinery, intermediate inputs, land, and other inputs. This specification allows a non-neutral effect of time on all of the coefficients of the translog cost function and hence all the characteristics of the production structure are assumed to vary with time. Stevenson and Greene originally assumed that the parameters vary linearly with time. This linear assumption may not be appropriate for fitting the model to long time-series data, since, in such a case, the non-neutral time effect becomes unusually large for later points of time. This is why the log-linear time effect is assumed in the present study.

The above-specified translog cost function is assumed to be twice-differentiable, so that the Hessian of this function with respect to the factor input prices is symmetric. This implies the symmetry restrictions: $\gamma_{ij} = \gamma_{ji}$ and $\gamma'_{ij} = \gamma'_{ji}$ for $i \neq j$ (i, j = L, M, I, T, O).

Making use of the Shephard's duality theorem, the cost share equations can be derived as:

$$(18)\qquad s_i = \alpha_i + \sum_{j=1}^{5} \gamma_{ij}\, \ell n\, P_j + \delta_{Qi}\, \ell n\, Q + \alpha'_i\, \ell n\, t + \sum_{j=1}^{5} \gamma'_{ij}\, \ell n\, t\, \ell n\, P_j + \delta'_{Qi}\, \ell n\, t\, \ell n\, Q$$

where $s_i = \frac{\partial C^*}{\partial P_i}\frac{P_i}{C^*} = \frac{\partial\, \ell n\, C^*}{\partial\, \ell n\, P_i}$, $\quad i = j = L, M, I, T, O.$

Any sensible cost function must be homogenous of degree one in factor input prices. This requires the following restrictions on parameters of the translog cost function (16).

$$(19)\qquad \sum_{i=1}^{5} \alpha_i = 1 \qquad\qquad \sum_{i=1}^{5} \alpha'_i = 0$$

$$\sum_{i=1}^{5} \gamma_{ij} = \sum_{j=1}^{5} \gamma_{ij} = 0 \qquad\qquad \sum_{i=1}^{5} \gamma'_{ij} = \sum_{j=1}^{5} \gamma'_{ij} = 0$$

$$\sum_{i=1}^{5} \gamma_{Qi} = 0 \qquad\qquad \sum_{i=1}^{5} \gamma'_{Qi} = 0$$

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

Essentially, th same set of restrictions follows from the adding-up requirement of the factor cost shares.

The cost elasticity is given by

$$\varepsilon_{CQ} = \frac{\partial \ \ell n \ C^*}{\partial \ \ell n \ Q} = \alpha_Q^t + \gamma_{QQ}^t \ \ell n \ Q + \sum_{i=1}^{5} \delta_{Qi}^t \ \ell n \ P_i \tag{20}$$

which offers information on returns to scale. As mentioned earlier, when $\varepsilon_{CQ} = 1$, then there exist constant returns to scale. In equation (20), if $\alpha_Q = 1$, $\alpha'_Q = 0$, $\gamma_{QQ} = \gamma'_{QQ} = 0$, and $\delta_{Qi} = \delta'_{Qi} = 0$ ($i = L, M, I, T, O$), then $\varepsilon_{CQ} = 1$. Thus, the hypothesis of constant returns to scale can be tested in the process of econometric estimation of the translog cost function.

For statistical specification we assume an additive error with zero expectations and finite variance for each of the six equations of the model given in equations (16) and (18). The covariance of the errors of any two equations is permitted to be nonzero for the same farm. However, the covariances of the errors of any two equations corresponding to different farms are assumed to be identically zero. Given this specification of errors, Zellner's method provides asymptotically efficient estimators. Moreover, the efficiency of estimation can be increased by imposing known restrictions on the coefficients in the equations.

We impose a priori the equality restrictions[4/] and the linear homogeneity (equivalently the adding-up) restrictions given in (19) on the translog cost function (16) and on the cost share equations. This allows us to exclude arbitrarily any one equation from the five cost share equations. The cost share equation of other inputs was then omitted. The estimates of the coefficients of this equation can easily be obtained by making use of the parameter relationships of the linear homogeneity restrictions after the system is estimated.

The set of final estimating equations are as follows.

$$(21)\quad \ell n\ C^* = \alpha_0^t + \alpha_Q^t\ \ell n\ Q + \sum_{i=1}^{4} \alpha_i^t\ \ell n\ P_i/P_0 + \frac{1}{2}\gamma_{QQ}^t(\ell n\ Q)^2$$

$$+ \frac{1}{2}\sum_{i=1}^{4}\sum_{j=1}^{4}\gamma_{ij}^t\ \ell n\ P_i/P_0\ \ell n\ P_j/P_0 + \sum_{i=1}^{4}\delta_{Qi}^t\ \ell n\ Q\ \ell n\ P_i/P_0 + u_C$$

$$(22)\quad s_i = \alpha_i^t + \delta_{Qi}^t\ \ell n\ Q + \sum_{i=1}^{4}\gamma_{ij}^t\ \ell n\ P_i/P_0\ \ell n\ P_j/P_0 + u_i$$

$$i = j = L,\ M,\ I,\ T$$

where u_C and u_i (i = L, M, I, T) are random disturbance terms with zero means. These five equations will be estimated jointly by the Iterative Seemingly Unrelated Regression (ISUR) method. This method is an improved version of Zellner's efficient estimation procedure by which, unless the procedure is iterated, the estimates are sensisitve to which share equation is excluded (Oberhofer and Kmenta).

5. Data

The data required for the estimation of the model is the total cost, the quantity of output, and the prices and cost shares of the five factor inputs: labor, machinery, intermediate inputs, land, and other inputs. The major sources of data used to process these variables were the Survey Report on Farm Household Economy (FHE) and the Survey Report on Prices and Wages in Rural Villages (PWRV) published annually by the Government of Japan, Ministry of Agriculture, Forestry, and Fisheries. In each year of the 1958-84 period one average farm was taken from each of the four size classes, 0.5-1.0 (I), 1.0-1.5 (II), 1.5-2.0 (III), and 2.0 hectares and over (IV), from all Japan (excluding Hokkaido district because of the different size classification). Thus, the sample size is 27 × 4 = 108.

The quantity and price indexes of output (Q and P_A) were computed by the Törnqvist approximation method of the Divisia index. For this computation eleven different categories of farm products were distinguished for crop and livestock products. The base of these (and the following) indexes is set at 1958 values from class I.[5/]

The quantity and price indexes of machinery (X_M and P_M),[6/] intermediate inputs (X_I and P_I), and other inputs (X_O and P_O) were also constructed by the Törnqvist method. In these computations, the cost of machinery ($P_M X_M$) was defined as the sum of the costs for machinery, energy, and rentals; the cost of intermediate inputs ($P_I X_I$) as the sum of the expenditures on fertilizer, feed, agri-chemicals, materials, clothes, and others; and the cost of other inputs (P_0X_0) as the sum of the expenditures on animals, plants, and farm buildings and structures. The necessary data were taken from the FHE. In addition, the price data necessary for computing the Törnqvist indexes were obtained from the PWRV.

The quantity of labor (X_L) was defined as the total number of male-equivalent labor hours of operators, family, and hired workers. The number of male-equivalent labor hours by female workers was estimated by multiplying the number of female labor hours by the ratio of female daily wage rate to male wage rate which can be obtained annually from the PWRV. The price of labor (P_L) was obtained by dividing the wage bill for temporary hired labor by the number of male-equivalent labor hours of temporary hired labor. The labor cost (P_LX_L) was defined as the sum of the labor cost for operator and family workers imputed by P_L and the wage bill for hired labor.

The quantity of land (X_T) was defined as the total area of arable land. The price of land (P_T) was obtained by dividing the cost for rented land by the rented land area. The land cost (P_TX_T) was estimated by multiplying P_T by X_T.

Finally, the total cost (C) was defined as the sum of the expenditures on these five categories of factor inputs, i.e., $C = \sum_{i=1}^{5} P_iX_i$ (i = L, M, I, T, O). The cost share (s_i) was obtained by dividing the expenditure on each category of factor inputs (P_iX_i) by the total cost (C).

6. Empirical Results

The translog cost function (21) and the four cost share equation in (22) were estimated first by ordinary least squares method in order to check the goodness of fit. The R^2's adjusted for degrees of freedom were 0.997 for the cost function, and 0.952, 0.869, 0.584, and 0.923 for the labor, machinery, intermediate inputs, and land cost share equations, respectively, indicating a fairly good fit for the model.

Next, in the process of the estimation by the ISUR method, several hypotheses concerning the characteristics of the production technology were statistically tested. They are (1) homotheticity (H_0: $\delta_{Qi} = \delta'_{Qi} = 0, \forall_i$), (2) constant returns to scale (H_0: $\alpha_Q = 1$, $\alpha'_Q = 0$, $\gamma_{QQ} = \gamma'_{QQ} = 0$, $\delta_{Qi} = \delta'_{Qi} = 0, \forall_i$), and Hicks neutrality (H_0: $\alpha'_Q = \alpha'_i = 0$, $\gamma'_{QQ} = \gamma'_{ij} = 0$, $\delta'_{Qi} = 0, \forall_{i,j}$). These hypotheses were tested conditionally on the maintained hypothesis of cost minimization, i.e., under the imposition of equality restrictions on the system of equations.[7] An F-test was applied to all the tests. As a result, all the null hypotheses were strongly rejected at the conventional five percent level of statistical significance. These results imply that changes in output affect factor cost shares; that the cost elasticity does not take the value of unity, indicating the existence of scale economies (or diseconomies) in agricultural production; and that technological change is not neutral in the Hicksian sense. This suggests that technological change biases existed in agricultural production during the 1958-84 period.[8]

Thus, no restrictions other than the equality and linear homogeneity were imposed in estimating the system of the five equations. The coefficients of the cost share equation of other inputs were obtained based on the parameter relations of linear homogeneity restrictions. The result is presented in Table 4.[9] This set of estimates is referred to as the final specification of the model and will be used for further analyses.[10]

Decomposition of Total Factor Productivity

To begin with, let us investigate returns to scale in agricultural production during the 1958-84 period. As mentioned earlier, the rejection of the hypothesis of constant returns to scale indicated that there existed increasing (or decreasing) returns to scale in agricultural production. Scale economies (SCE $= 1 - \varepsilon_{CQ}$) were then computed by making use of equation (20) for each size class.[11] The results are shown in Figure 4.

Figure 4 indicates that there existed increasing returns to scale in agricultural production in all size classes during the 1958-84 period. This finding supports the results by Kako (1979) and Chino, who showed that increasing returns to scale existed in rice production during the periods 1973-75 and 1961-79, respetively. The existence of scale economies seems to have been due largely to the increased indivisibility of capital assets as a result of rapid mechanization and increased investment in farm buildings and structures during the period under question.

However, the degrees and patterns of changes in scale economies over time look apparently different among different size classes. Larger size classes (III and IV) enjoyed substantially large economies of scale during the 1960s. Although the degrees of economies of scale declined in the 1970s and 1980s, they remained consistently larger than those of smaller scale farms (size classes I and II). However, it must be noted that the differentials in the degrees of economies of scale among the four size classes became smaller and smaller as time passed. This seems to have been due largely to the rapid dissemination of farm mechanization not only to larger scale farms but even for smaller scale farms during the period under question.

Next, using the estimates of scale economies, the conventionally measured growth rate of total factor productivity ($\dot{TFP}$) was decomposed into the scale effect and technological change effect by making use of equation (15) for each size class for the two subperiods 1958-75 and 1975-84 and also for the overall period 1958-84. In this computation, the technological change effect was obtained as a residual[12/] by subtracting the scale effect from the conventionally measured TFP growth rate presented in Table 3. The results are provided in Table 5.

It is clearly observed in this table that the scale effect becomes larger in both periods as the farm size increases. However, this effect drastically decreases in all size classes from the first period to the second. It even became negative in size classes I and II. These negative scale effects in classes I and II were due to the negative growth rates of total output as shown in Table 1.

On the other hand, the technological change effect was found to vary inversely with farm size during the 1958-75 period. During the 1975-84 period, however, it turned out to be negative in all size classes, implying an upward shift of the cost curve. The estimates of the technological change effect in Table 5 indicate that the upward shifts of the cost curves in smaller size classes (I and II) were much greater than those in larger size classes (III and IV).[13/] Thus, it may be said that the drastic decrease in the growth rate of total factor productivity, as discussed in section two, was caused mainly by substantial decline in the technological change effect during the 1975-84 period.

Let us next look into the relative contributions of these effects to the growth rate of total factor productivity. It is clearly observed that, during both the 1958-75 and 1975-84 periods, the major determinant of the TFP growth rates in smaller size classes, positive or negative, was the technological change effect, whereas the scale effect played a most important role in determining the TFP growth rates in larger scale farms, most markedly for the largest size class. The relatively greater contribution of the scale effect to the growth rate of total factor productivity, especially in the case of the largest size class, must have been strongly associated with the relatively larger scale economies which in turn must have resulted from the quite rapid increase in factor inputs such as machinery and farm buildings and structures as observed in Table 2.

In summary, the smaller scale farms achieved a greater efficiency gain defined in terms of the TFP growth rate than the larger scale farms during the 1958-75 period through their faster technological progress. This may have been attained by catching up with technologies previously used solely by larger scale farms such as mechanized farming. However, after this period, smaller scale farms could not compare in efficiency with larger scale farms whose efficiency of production has been achieved mainly by the scale effect during the whole period 1958-84.

We have thus far seen that increasing returns to scale played an important role in determining the efficiency level of agricultural production. However, the relative contributions of the scale effect to the TFP growth were substantially different between the two sub-periods and among different size classes. What were the factors or conditions responsible for such changes in the scale effect over time and between size classis?

As seen in equation (20), scale economies are a function of the output level (Q), the factor input prices (P_i), and technological change (t). In order to provide an answer for the above question, the impacts of changes in the output quantity, factor input prices, and technological change on scale economies ($SCE = 1 - \varepsilon_{CQ}$) will be examined in the following subsections.

Impacts of Changes in Output and Factor Input Prices on Scale Economies

To begin with, the impact of a change in output on scale economies can be calculated as

$$(23) \qquad \frac{\partial \; SCE}{\partial \; \ell n \; Q} = \frac{\partial}{\partial \; \ell n \; Q} (1 - \varepsilon_{CQ}) = - \frac{\partial \; \varepsilon_{CQ}}{\partial \; \ell n \; Q} = - \gamma^{t}_{QQ} \quad .$$

If $\gamma^{t}_{QQ} < 0$, then expansion of output increases the degree of scale economies. If $\gamma^{t}_{QQ} > 0$, then it decreases the degree of scale economies.

Next, the impact of a change in the price of the i-th factor input on scale economies may be given by

$$(24) \qquad \frac{\partial \; SCE}{\partial \; \ell n \; P_i} = - \frac{\partial \; \varepsilon_{CQ}}{\partial \; \ell n \; P_i} = - \delta^{t}_{Qi} \quad , \quad i = L, M, I, T, O.$$

If $\delta^{t}_{Qi} < 0$, then an increase in the price of factor input i will result in an increase in the degree of scale economies. If, on the other hand, $\delta^{t}_{Qi} > 0$, then the degree of scale economies will be reduced. Using equations (23) and (24), the impacts of changes in output and factor input prices were computed for the two sub-periods 1958-75 and 1975-84 as well as for the whole period. The estimates are presented in Table 6. Note however that γ^{t}_{QQ} and δ^{t}_{Qi} are the coefficients of the translog cost function (16) and hence these effects are common to all size classes.[14]

As shown in Table 6, $\partial SCE/\partial \ell n\ Q$ came out to be positive, implying that farmers can enjoy a higher-level of scale economies by increasing the output level. This effect was most remarkable in the 1958-75 period. However, during the 1975-84 period, it became much smaller compared with the previous period.

The impact of change in the price of labor was positive and fairly constant for the whole period. On the other hand, changes in the prices of machinery, land, and intermediate inputs had negative impacts on scale economies for the whole period. The actual movements of the relative prices of these factor inputs during this period were in that the prices of labor and land increased sharply, while those of machinery and intermediate inputs consistently decreased. The estimates in Table 6 thus indicate that the relative increase in the price of labor and the relative decreases in the prices of machinery and intermediate inputs caused an increase in the extent of scale economies mainly through factor substitutions. On the other hand, the sharp increase in the land price had the effect of lowering the degree of scale economies, since it apparently acted as a strong constraint on the enlarged scale of farm land.

Impacts of Technological Change on Scale Economies

The impact of technological change on scale economies may be computed by the derivative of SCE with respect to time as

$$(25) \qquad \frac{\partial\ SCE}{\partial T} = -\frac{\partial\ \varepsilon_{CQ}}{\partial T} = -\ (\alpha'_{Q} + \gamma'_{QQ}\ \ell n\ Q + \sum_{i}\delta'_{Qi}\ \ell n\ p_{i}),$$

$$i = L,\ M,\ I,\ T,\ O.$$

If $\partial SCE/\partial T > 0$ (< 0), then technological change will increase (decrease) the degree of scale economies.

The economic implications of technological change on scale economies may be more clearly interpreted by making use of a diagram. In Figure 5, average and marginal cost curves are drawn. Using these cost curves, scale elasticity (ε_{CQ}) and hence scale economies ($1 - \varepsilon_{CQ}$) can be defined as follows. Rearranging the definition of scale elasticity yields

$$\varepsilon_{CQ} = \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{\partial C}{\partial Q}/\frac{C}{Q} = \frac{MC}{AC}$$

where AC and MC designate the average and marginal costs of producing Q. The ratio of MC to AC may be given in Figure 5 by $\overline{MQ}/\overline{AQ}$. Thus, the definition of scale economies is given by $SCE = 1 - \varepsilon_{CQ} = (1 - \overline{MQ}/\overline{AQ}) = \overline{AM}/\overline{AQ}$. Therefore, the impacts of technological change on scale economies ($\partial SCE/\partial T$) can be determined by a change in the ratio $\overline{AM}/\overline{AQ}$ when technological change occurred.

Suppose there was positive technological progress from time t to t+1. This may imply a shift of the average cost curve downwards and to the right as shown in Figure 5.[15] That the impacts of technological change on scale economies measures positive (i.e., $\partial SCE/\partial T > 0$) means that the ratio $\overline{AM}/\overline{AQ}$ increases due to technological change. This, in turn, implies that the production recedes the minimum efficient scale (MES) region which was shifted by technological progress. In other words, it may be said that technological change has increased the degree of scale economies to be exploited. Conversely, if $\partial SCE/\partial t < 0$, it may imply that technological change has promoted farmers to exploit the benefits of scale economies and the production is accomplished in a region closer to the MES than before.[16] Thus, the magnitude of $\partial SCE/\partial t$ in absolute values may be used as a measure of the speed of enlargement (if it is positive) or exploitation (if it is negative) of scale economies when technological changes occur.

Now, the estimates of $\partial SCE/\partial T$ are shown in Figure 6. According to this figure, the impacts of technological change on scale economies were negative in all size classes for the whole period except for the first few years in class I, implying that technological change reduced the degrees of scale economies in all size classes. During the 1960s in particular, the speed of exploitation of scale economies in larger size classes was much greater than that in smaller size classes. Even after the 1960s, the speed of exploitation of scale economies in larger size farms were still greater than that in smaller scale farms. This was rather expected, since, as observed earlier in this section, larger scale farms had more room in scale economies for exploitation than smaller scale farms throughout the whole 1958-84 period.

At this point, resorting to the diagram in Figure 5, let us try to interpret the relationship between the estimates of the rates of technological change reported in Table 5 and those of the estimates of the impacts of technological change on scale economies given in Figure 6.

During the 1958-75 period, the rates of the shifts of the average cost curves downwards and to the right in the smaller size classes were much greater than those in the larger size classes (Table 5). On the other hand, although, as observed earlier, technological change stimulated the exploitation of scale economies in all size classes, the absolute values of $\partial SCE/\partial t$ in the larger scale farms were greater than those in the smaller scale farms (Figure 6). These results may imply that technological improvements and diffusion during this period not only shifted the average cost curves downwards and to the right, but also helped farmers in all size classes exploit scale economies, so that production came out to be carried out in regions closer to the minimum efficient scales of both smaller and larger scale farms. However, the speed of exploitation of scale economies due to technological change was much faster in larger scale farms than in smaller scale farms.

One could not however judge from the value of $\partial SCE/\partial t$ how close to the MES farmers operate their production. Such a judgement must be done by the value of SCE itself as clearly understood by the diagram in Figure 5. Thus, the earlier finding that larger scale farms enjoyed greater degrees of scale economies than smaller scale farms indicate that the former continued carrying out production in regions further away from the minimum efficient scales than the latter did.

During the 1975-84 period, smaller scale farms experienced substantial technological retrogression, while larger scale farms also experienced lesser degrees of negative technological changes than smaller scale farms. This may imply that the average cost curves of smaller size classes shifted substantially upwards and to the left, while those of larger size classes also shifted in the same direction but to much lesser extents. These shifts of the average cost curves indicate that the minimum efficient scales decreased in all size classes.

On the other hand, Figure 6 shows that the speed of exploitation of scale economies became much slower in all size classes compared with the previous period.

As observed in Table 3, the negative annual growth rates of total output in size classes I and II can be largely explained by negative technological progress. Thus, the above results indicate that smaller scale farms continued to exploit scale economies, though at a slower pace compared with their previous period and with the pace of larger scale farms, in the process of the negative growth of total output due to technological retrogression during the 1975-84 period. This may in turn imply that production in smaller scale farms has moved towards contracted equilibria.

On the other hand, although technological retrogression also suppressed the growth of total output in larger size classes during this period, total output of these classes still grew due mainly to the increases in total input and the scale effect (Tables 3 and 5). The above results may be interpreted as follows: In the process of the upwards-left shifts of the average cost curves, larger scale farms continued to exploit scale economies faster than smaller scale farms, though much more slowly than during the previous period. It should be noted however that production of larger-scale farms has also moved towards contracted equilibria due to technological retrogression, although the total outputs have grown.

7. Summary and Conclusions

This study has investigated the determinants of changes in the growth of total factor productivity in Japanese agriculture for the period 1958-84. This investigation was carried out for different size classes of farms. For this objective, the growth rate of conventionally measured total factor productivity was decomposed into the scale effect and technological change effect. The findings may be summarized as follows:

Substantial differences were found in the growth rates of total output, total input, and total factor productivity among different size classes, especially between smaller scale farms and larger scale farms. In particular, larger scale farms increased total output at fairly high growth rates not only during the 1958-75 period but even during the 1975-84 period when the whole Japanese economy entered upon a stage of low growth. This was achieved mainly by increased total input and efficiency gains due largely to increasing returns to scale.

On the other hand, although efficiency gains due to technological change were positive in all size classes during the 1958-75 period, they became negative in all size classes during the 1975-84 period. In particular, the negative technological change effects explained almost completely the negative growth rates of total output in smaller size classes during the latter period. Furthermore, technological change effected scale economies in a manner such that farmers came to operate production in the regions closer to the minimum efficient scales in all size classes during the whole 1958-84 period. Quite large scale economies remained in all size classes even in the early 1980s in spite of the exploitation of scale economies due to technological change. However, technological change during the 1975-84 period shifted the average cost curves in all size classes upwards and to the left, indicating that the minimum efficient scales declined. In particular, the upwards-left shifts of the average cost curves were substantial in smaller size classes.

Finally, let us say a word as a conclusion on a policy implication of this study. It is now an urgent issue in Japanese agriculture that production must be done more efficiently and at much lower costs so that prices of agricultural commodities can be substantially lowered. The findings of this study suggest in this context that larger scale farming should be strongly promoted. This must be carried out in such a manner to stimulate technological progress so that the minimum efficient scale can be enlarged significantly. For this, however, the government must lessen the many institutional constraints which have led to increasing land prices, and encourage freer mobility of lands, so that the number of large scale farmers with entrepreneurial spirit will increase.

Figure 1. Index of Total Output(1958-84)

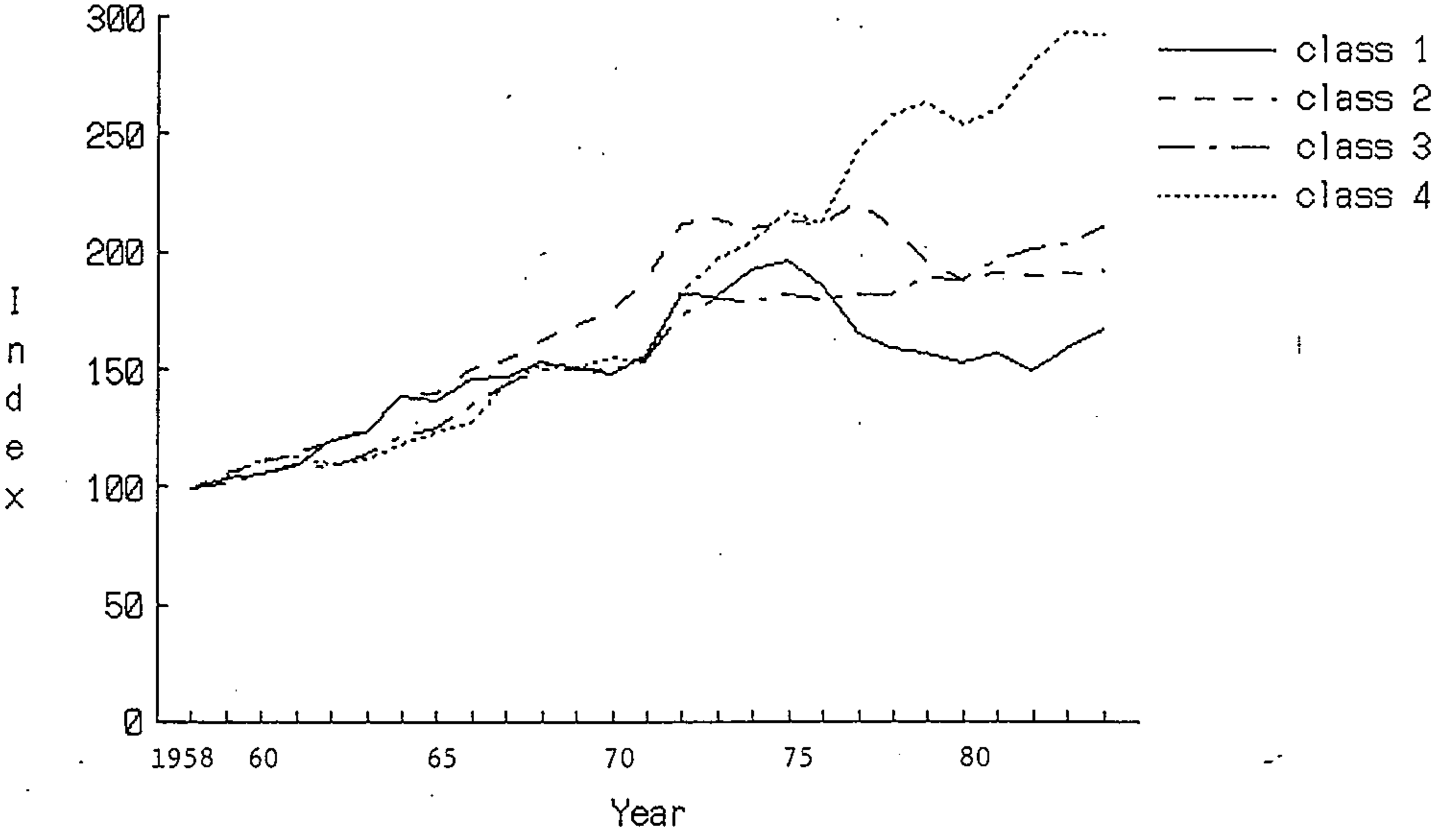


Figure 2. Index of Total Input(1958-84)

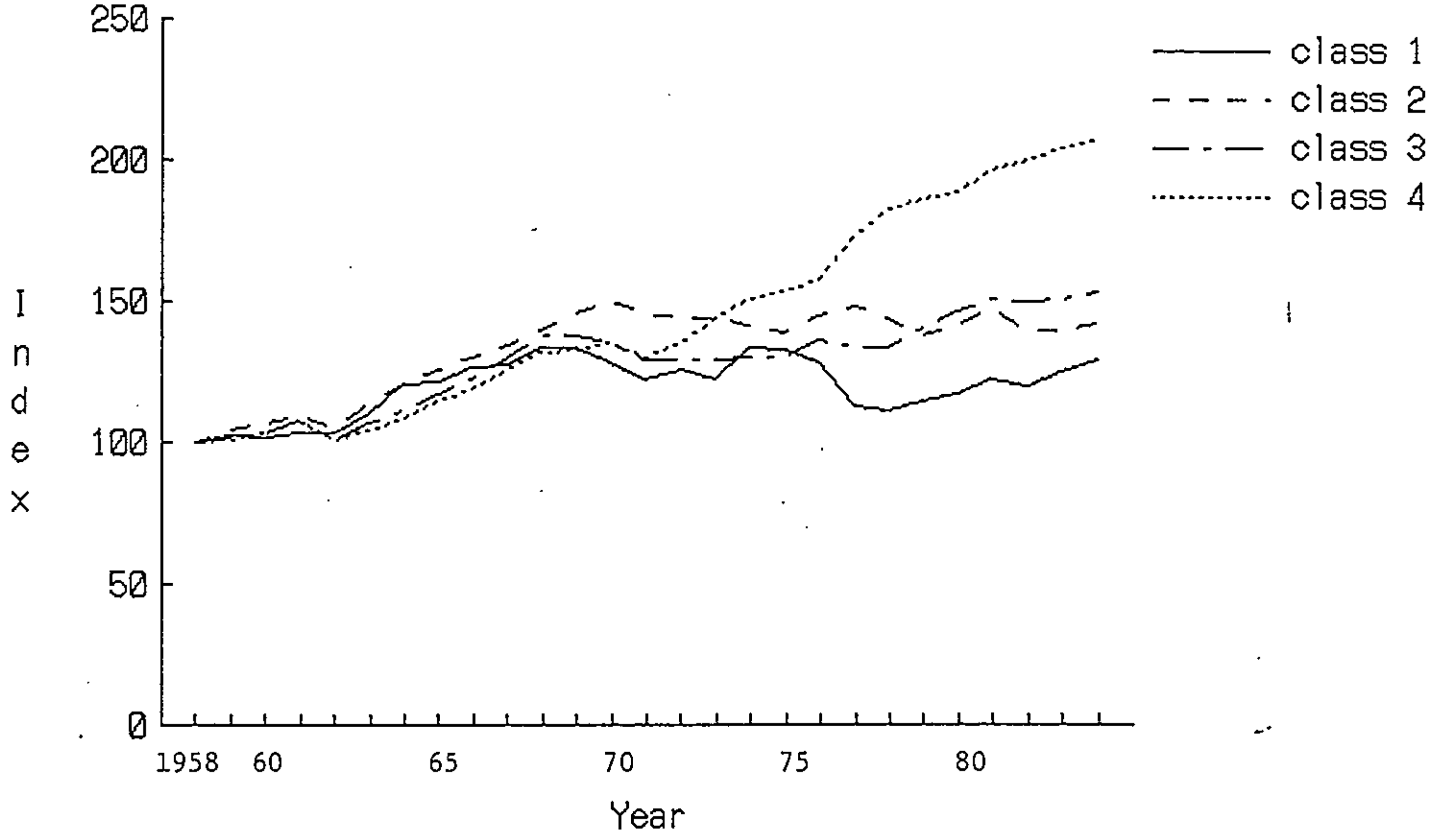


Figure 3.

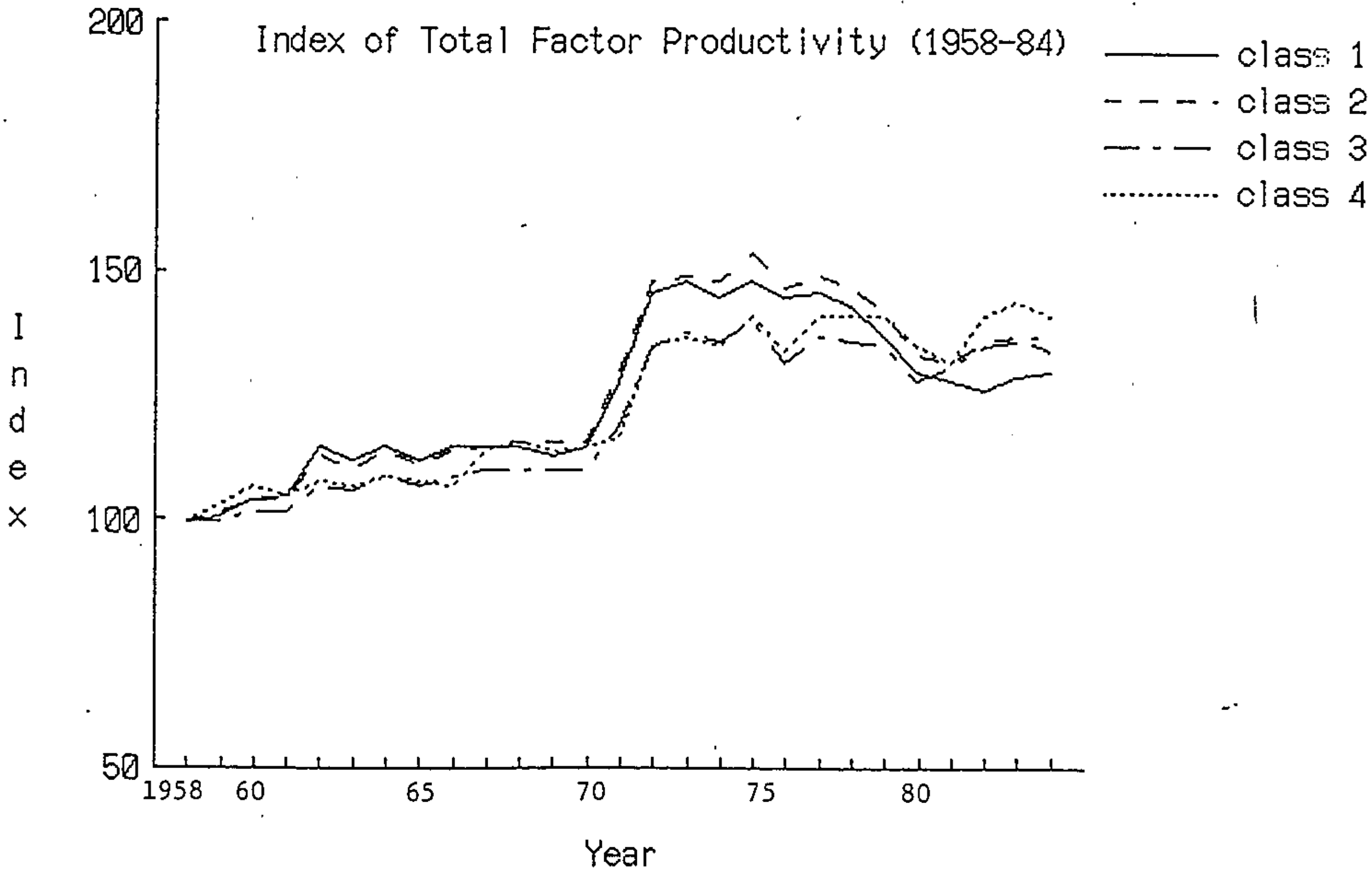
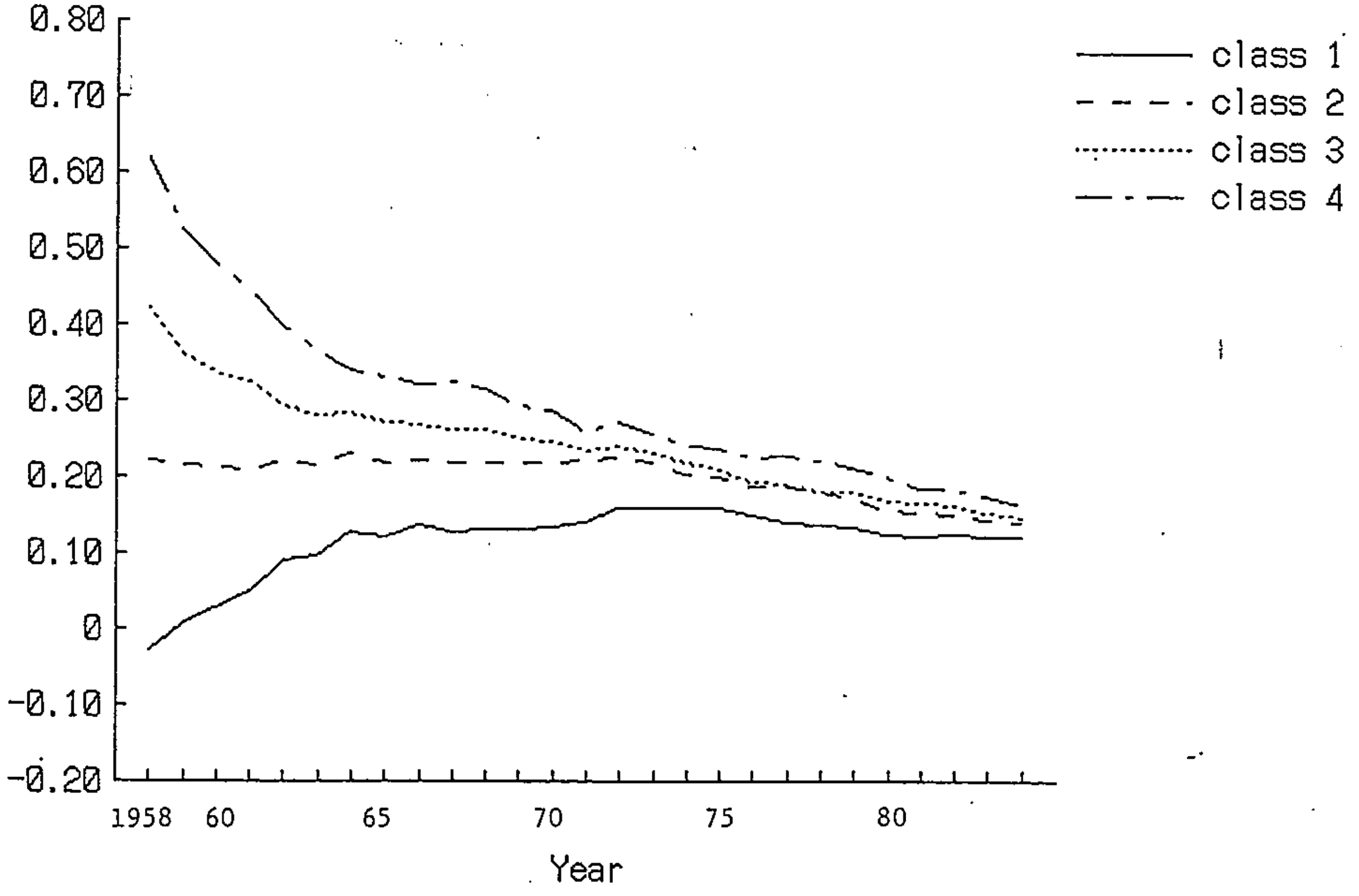

Index of Total Factor Productivity (1958-84)
class 1
class 2
class 3
class 4
200
150
100
50
Index
1958
60
65
70
75
80
Year

Figure 4. Economies of Scale (1958-84)



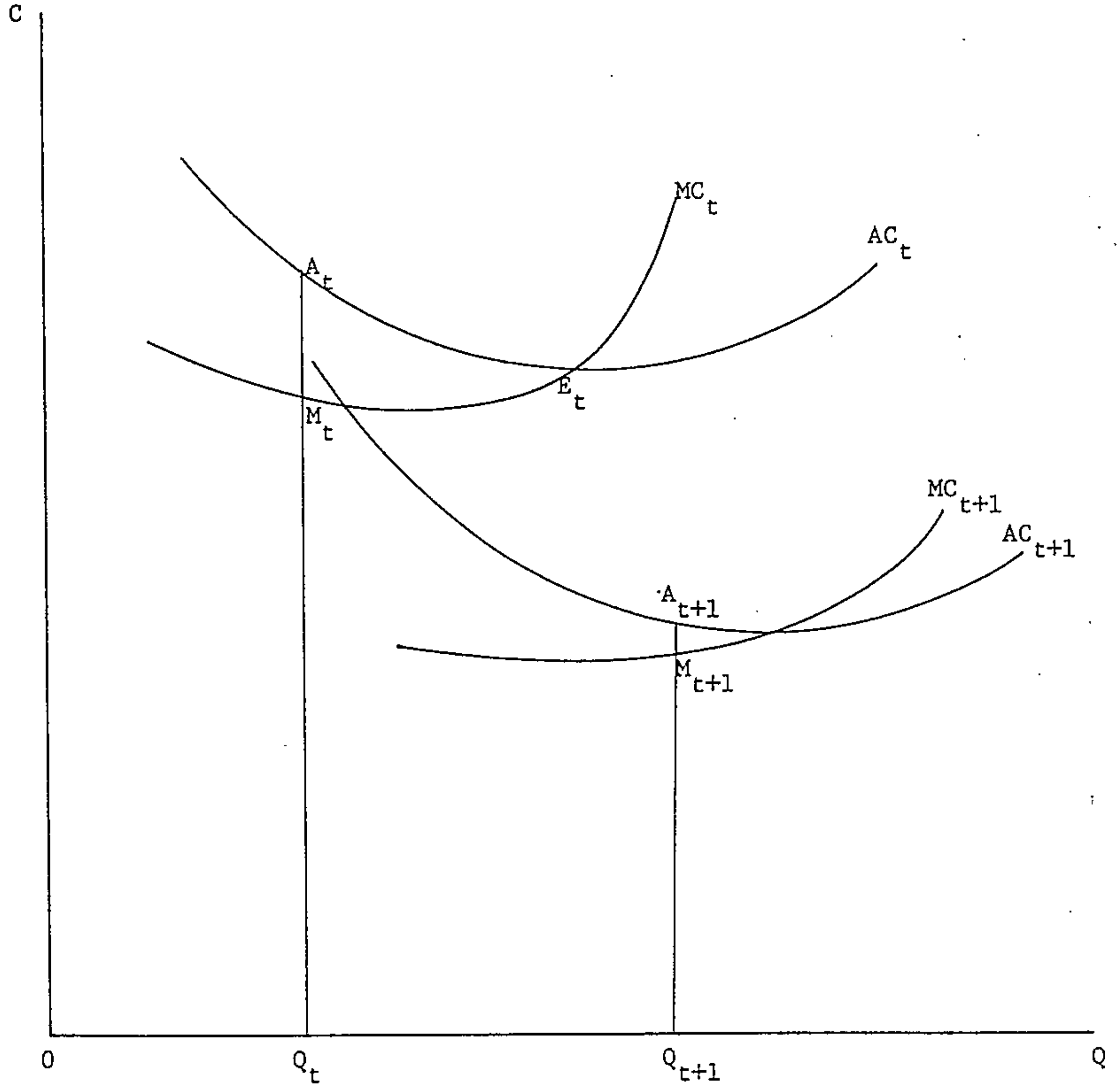


Figure 5. Impacts of Technological Change on Economies of Scale

Figure 6.

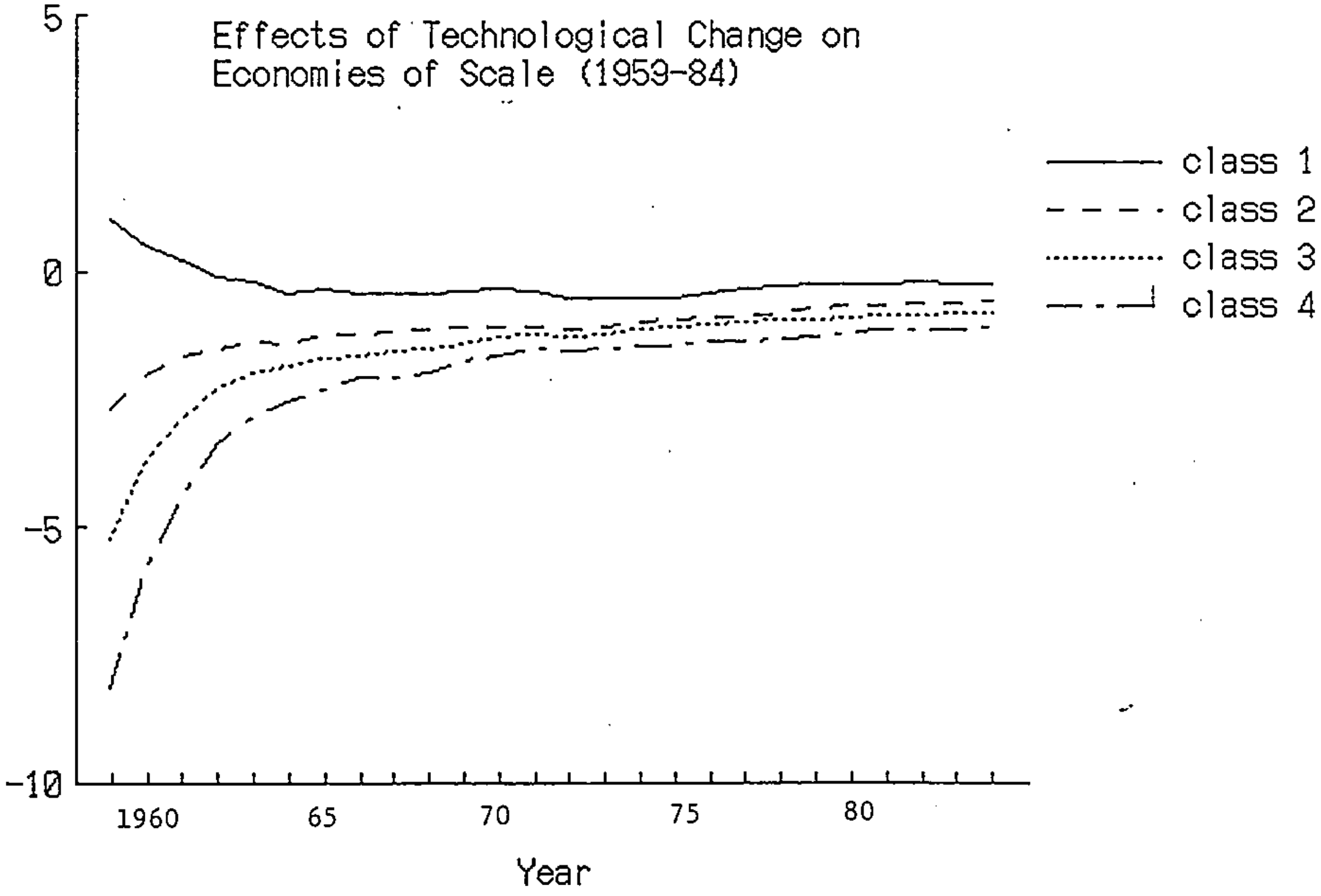

Effects of Technological Change on
Economies of Scale (1959-84)
5
0
-5
-10
1960
65
70
75
80
Year
class 1
class 2
class 3
class 4

Table 1. Growth Rate of Total Output and Contribution of Each Component (1958-84)

(Unit: %)

Size class	Period	Total output $\dot{Q}$	Rice $r_1\dot{Q}_1$	Vegetables $r_2\dot{Q}_2$	Fruits $r_3\dot{Q}_3$	Livestock $r_4\dot{Q}_4$	Others $r_5\dot{Q}_5$
Class I (0.5-1.0 ha)	1958-75	3.93 (100.0)	0.01 (0.3)	1.00 (25.4)	0.58 (14.8)	1.88 (47.8)	0.46 (11.7)
	1975-84	-1.84 (100.0)	-0.60 (32.6)	-0.12 (6.5)	-0.08 (4.3)	-0.63 (34.2)	-0.41 (22.3)
	1958-84	1.80 (100.0)	-0.07 (-3.9)	0.69 (38.3)	0.40 (22.2)	0.74 (41.1)	0.04 (2.2)
Class II (1.0-1.5 ha)	1958-75	4.80 (100.0)	0.11 (2.3)	1.13 (23.5)	0.95 (19.8)	2.18 (45.4)	0.43 (9.0)
	1975-84	-1.64 (100.0)	-0.63 (38.4)	0.01 (-0.6)	-0.26 (15.9)	-0.74 (45.1)	-0.02 (1.2)
	1958-84	2.74 (100.0)	-0.10 (-3.6)	0.87 (31.8)	0.58 (21.2)	1.20 (43.8)	0.19 (6.9)
Class III (1.5-2.0 ha)	1958-75	3.87 (100.0)	0.22 (5.7)	0.92 (23.8)	0.54 (14.0)	1.71 (44.2)	0.48 (12.4)
	1975-84	1.74 (100.0)	-1.00 (-57.5)	0.52 (29.9)	0.30 (17.2)	1.50 (86.2)	0.42 (24.1)
	1958-84	2.96 (100.0)	-0.13 (-4.4)	0.96 (32.4)	0.47 (15.9)	1.23 (41.6)	0.43 (14.5)
Class IV (2.0 ha-)	1958-75	4.48 (100.0)	0.20 (4.5)	0.52 (11.6)	0.42 (9.4)	2.88 (64.3)	0.46 (10.3)
	1975-84	3.40 (100.0)	-1.20 (-35.3)	1.31 (38.5)	0.61 (17.9)	2.18 (64.1)	0.50 (14.7)
	1958-84	4.57 (100.0)	-0.15 (-3.3)	0.84 (18.4)	0.53 (11.6)	2.77 (60.6)	0.58 (12.7)

Notes: 1) The average annual growth rate was computed by fitting $\ell n\ y = a + gt$ where y is the Törnqvist index of either total output or revenue-share weighted index of each output component; t is an index of time; and a and g are parameters to be estimated.

2) Figures in parentheses indicate the degrees of contribution to the growth rate of total output.

Table 2. Growth Rate of Total Input and Contribution of Each Component

(Unit: %)

Size Class	Period	Total input $\dot{F}$	Labor $s_L\dot{X}_L$	Machinery $s_M\dot{X}_M$	Intermediate inputs $s_I\dot{X}_I$	Land $s_T\dot{X}_T$	Other inputs $s_O\dot{X}_O$
Class I (0.5-1.0 ha)	1958-75	1.72 (100.0)	-2.09 (-121.5)	1.26 (73.3)	2.37 (137.8)	-0.01 (-0.6)	0.18 (10.5)
	1975-84	0.07 (100.0)	-0.91 (-1300.0)	1.72 (2457.1)	-0.84 (-1200.0)	-0.05 (-71.4)	0.15 (214.3)
	1958-84	0.58 (100.0)	-1.78 (-306.9)	1.17 (201.7)	1.12 (193.1)	-0.02 (-3.4)	0.08 (13.8)
Class II (1.0-1.5 ha)	1958-75	2.39 (100.0)	-1.54 (-64.4)	1.14 (47.7)	2.53 (105.9)	0.01 (0.4)	0.25 (10.5)
	1975-84	-0.09 (100.0)	-1.20 (1333.3)	1.68 (-1866.7)	-0.45 (500.0)	-0.04 (44.4)	-0.08 (88.9)
	1958-84	1.29 (100.0)	-1.38 (-107.0)	1.05 (81.4)	1.49 (115.5)	-0.02 (-1.6)	0.14 (10.9)
Class III (1.5-2.0 ha)	1958-75	1.94 (100.0)	-1.53 (-78.9)	1.07 (55.2)	2.23 (114.9)	0.01 (0.5)	0.17 (8.8)
	1975-84	1.86 (100.0)	-0.55 (-29.6)	1.50 (80.6)	0.59 (31.7)	-0.02 (-1.1)	0.35 (18.8)
	1958-84	1.56 (100.0)	-1.14 (-73.0)	1.06 (67.9)	1.49 (95.5)	0.00 (0)	0.15 (9.6)
Class IV (2.0 ha-)	1958-75	2.66 (100.0)	-1.34 (-50.3)	0.98 (36.8)	2.70 (101.5)	0.06 (2.3)	0.27 (10.2)
	1975-84	3.28 (100.0)	-0.15 (-4.6)	1.70 (51.8)	1.01 (30.8)	0.11 (3.4)	0.61 (18.6)
	1958-84	3.08 (100.0)	-0.75 (-24.4)	1.09 (35.4)	2.22 (72.1)	0.11 (3.6)	0.40 (13.0)

Notes: 1) For the computation of the average annual growth rates, the same procedure as used for Table 1 was applied.

2) Figures in parentheses indicate the degrees of contribution to the growth rate of total input.

Table 3. Growth Accounting of Total Output (1958-84)

(Unit: %)

Class	Period	$\dot{Q}$	$\dot{F}$	$T\dot{F}P$
Class I (0.5-1.0 ha)	1958-75	3.93 (100.0)	1.72 (43.8)	2.21 (56.2)
	1975-84	-1.84 (100.0)	0.07 (-3.8)	-1.91 (103.8)
	1958-84	1.80 (100.0)	0.58 (32.2)	1.22 (67.8)
Class II (1.0-1.5 ha)	1958-75	4.80 (100.0)	2.39 (49.8)	2.41 (50.2)
	1975-84	-1.64 (100.0)	-0.09 (5.5)	-1.55 (94.5)
	1958-84	2.74 (100.0)	1.29 (47.1)	1.45 (52.9)
Class III (1.5-2.0 ha)	1958-75	3.87 (100.0)	1.94 (50.1)	1.92 (49.6)
	1975-84	1.74 (100.0)	1.86 (106.9)	-0.12 (-6.9)
	1958-84	2.96 (100.0)	1.56 (52.7)	1.41 (47.6)
Class IV (2.0 ha-)	1958-75	4.48 (100.0)	2.66 (59.4)	1.82 (40.6)
	1975-84	3.40 (100.0)	3.28 (96.5)	0.12 (3.5)
	1958-84	4.57 (100.0)	3.08 (67.4)	1.49 (32.6)

Note: Figures in parentheses indicate the degrees of contribution to the growth rate of total output.

Table 4. Parameter Estimates of the Translog Cost Function

α	5.692^{*}	γ_{MO}	0.032^{o}	γ'_{II}	0.148^{*}
α_{Q}	1.026^{*}	γ_{IT}	-0.013	γ'_{TT}	0.033^{*}
α_{L}	0.647^{*}	γ_{IO}	-0.117^{o}	γ'_{OO}	-0.038^{o}
α_{M}	0.061^{*}	γ_{TO}	0.002^{o}	γ'_{LM}	0.034^{*}
α_{I}	0.165^{*}	δ_{QL}	-0.063^{*}	γ'_{LI}	-0.020^{**}
α_{T}	0.049^{*}	δ_{QM}	0.071^{*}	γ'_{LT}	-0.008
α_{O}	0.079^{o}	δ_{QI}	-0.023^{*}	γ'_{LO}	0.019^{o}
γ_{QQ}	-0.555^{*}	δ_{QT}	0.029^{*}	γ'_{MI}	-0.170^{*}
γ_{LL}	0.129^{*}	δ_{QO}	-0.014^{o}	γ'_{MT}	-0.016^{*}
γ_{MM}	-0.365^{*}	α'	-0.067^{*}	γ'_{MO}	-0.021^{o}
γ_{II}	-0.335^{*}	α'_{Q}	-0.026	γ'_{IT}	-0.004
γ_{TT}	-0.008	α'_{L}	-0.065^{*}	γ'_{IO}	0.046^{o}
γ_{OO}	0.107^{o}	α'_{M}	0.046^{*}	γ'_{TO}	-0.005^{o}
γ_{LM}	-0.128^{*}	α'_{I}	0.031^{*}	δ'_{QL}	0.003
γ_{LI}	0.049^{**}	α'_{T}	-0.002	δ'_{QM}	-0.024^{*}
γ_{LT}	-0.026	α'_{O}	-0.010^{o}	δ'_{QI}	0.014^{*}
γ_{LO}	-0.024^{o}	γ'_{QQ}	0.158^{*}	δ'_{QT}	-0.0003
γ_{MI}	0.417^{*}	γ'_{LL}	-0.025^{**}	δ'_{QO}	0.007^{o}
γ_{MT}	0.045^{*}	γ'_{MM}	0.173^{*}		

Notes: 1) * and ** indicate that the coefficients are statistically significant at the 5 and 10 percent levels, respectively.

2) Coefficients with o were obtained by making use of parameter restrictions of the linear homogeneity.

Table 5. Decomposition of the Rate of Growth of Total Factor Productivity, 1958-84

(Unit: %)

					Contributions to $\dot{TFP}$	
Size class	Period	$\dot{TFP}$ (1)	Scale effect $(1-\varepsilon_{CQ})\dot{Q}$ (2)	Technological change effect $-\lambda$ (3)=(1)-(2)	Scale effect (4)=(2)/(1)	Technological change effect (5)=(3)/(1)
Class I (0.5-1.0 ha)	1958-75	2.21	0.43	1.78	19.5	80.5
	1975-84	-1.91	-0.25	-1.66	13.1	86.9
	1958-84	1.22	0.21	1.01	17.2	82.8
Class II (1.0-1.5 ha)	1958-75	2.41	1.05	1.36	43.6	56.4
	1975-84	-1.55	-0.28	-1.27	18.1	81.9
	1958-84	1.45	0.55	0.90	37.9	62.1
Class III (1.5-2.0 ha)	1958-75	1.92	1.08	0.84	56.3	43.7
	1975-84	-0.12	0.31	-0.43	-258.3	358.3
	1958-84	1.41	0.72	0.69	51.1	48.9
Class IV (2.0 ha -)	1958-75	1.82	1.58	0.24	86.8	13.2
	1975-84	0.12	0.69	-0.57	575.0	-475.0
	1958-84	1.49	1.38	0.11	92.6	7.4

Notes: 1) $\dot{TFP}$ and $\dot{Q}$ are from Table 3.

2) For the computation of the scale effect, the simple average of $1-\varepsilon_{CQ}$ was used for each period.

Table 6. Effects of Changes in Output and Factor Prices on Scale Economies $(1-\epsilon_{CQ})$, 1958-84

Period	$\ell n\ Q$	$\ell n\ P_L$	$\ell n\ P_M$	$\ell n\ P_I$	$\ell n\ p_T$	$\ell n\ P_O$
1958-75	0.235	0.056	-0.022	-0.006	-0.028	0.000
1975-84	0.063	0.052	-0.005	-0.021	-0.028	-0.008
1958-84	0.176	0.054	-0.013	-0.011	-0.028	-0.003

Footnotes

1/ The following paragraphs of the formulation draws heavily on Denny, Fuss, and Waverman (pp.187-188).

2/ The categorization of inputs was made consistent with the arguments of the cost function specified in section four.

3/ The following formulation draws heavily on Denny, Fuss, and Waverman.

4/ Christensen, Jorgenson, and Lau (p.35) make a clear distinction between the "symmetry" resctrictions and the "equality" restrictions. The former is related to the symmetric Hessian of a twice-differentiable function, while the latter refers to the equality of parameters appearing in more than two equations in the system of, say, the translog cost function and the cost share function. The imposition of equality restrictions in this study (i.e., $\alpha_i = \alpha_i$, $\alpha'_i = \alpha'_i$, $\gamma_{ij} = \gamma_{ij}$, $\gamma'_{ij} = \gamma'_{ij}$, $\delta_{Qi} = \delta_{Qi}$, $\delta'_{Qi} = \delta'_{Qi}$ for all $i = j = L, M, I, T, O$) implies that the assumption of cost-minimizing behavior is maintained. Instead, one may explicitly test this maintained hypothesis in the process of estimation of the system of the cost function and the cost share equations.

5/ The indexes of total output, total input, and total factor productivity in section two were, however, computed separately for each size class by setting the base year at 1958 in each size class.

No procedure has yet been formulated for computing such indexes of two bases at the same time (e.g., year and size class in the case of this study) by the Törnqvist approximation method (refer for details to Denny and Fuss).

6/ The definition of P_M in this paper is different from the previous study (Kuroda, 1986). In the previous paper, it was obtained by dividing the expenditure on machinery inputs (C_M) by the number of hours of machinery use, while in this study a Törnqvist-approximated price index was computed for machinery inputs. The major reason for this change in the definitions of P_M is that the number of machinery hours reported in the FHE does not take into consideration changes overtime in the quality of machinery. For example, a one hour use of a hand-driven cultivator is treated to be equivalent to a one hour use of a riding-type tractor.

7/ The maintained hypothesis of equality restrictions was also tested. The result of an F-test for this hypothesis is that the computed F was 1.72 for the degrees of freedom (48, 450). Since the critical F values with the degrees of freedom are 1.36 and 1.51 at the 5 and 1 percent levels of significance, respectively, the hypothesis of cost iminimization is rejected. However, as this rejection is made only barely, at least at the 1 percent significance level, the assumption of cost-minimizing behavior for farms may not be far from reality.

8/ Since technological change biases were fully analyzed elsewhere (Kuroda, 1986), repetition will not be made in this paper.

9/ The estimates in Table 4 are slightly different from those in Kuroda (1986) due to the change in the definition of the machinery price (refer to footnote 6).

10/ Monotonicity and concavity of the cost function were also checked for each observation. The results were that these regularity conditions are satisfied, implying that the translog cost function represented by the estimated parameters in Table 4 is well-behaved within the region of the sample observations.

11/ Although it is assumed that all farms in all size classes have the same cost function and hence the same coefficients of the translog cost function, it is possible for each size class to have different degrees of scale economies, since, as seen in equation (20), the average farms of different size classes have different values for output (Q) and factor prices (P_i).

12/ This implies that the residually determined technological change effect may include errors resulting from the estimation of cost elasticities.

13/ We are here implicitly treating the total cost curve represented by equation (16) as an envelope of the total cost curves of the four size classes of farms, so that the corresponding four different average cost curves may be derived. In this sense, indeed, it might have been better to introduce scale dummy variables in the estimating equation (21).

14/ However, since $\gamma^t_{QQ} = \gamma_{QQ} + \gamma'_{QQ} \ell n\ t$ and $\delta^t_{Qi} = \delta_{Qi} + \delta'_{Qi} \ell n\ t$ $(i = L, M, I, T, O)$, they take different values for different points of time.

15/ One could think of a possibility of a downwards-left shift of the average cost curve when technological progress occurs. Analogously, an upwards-right shift of the average cost curve could be considered when technological retrogression occurs. But both cases may be regarded as unlikely.

16/ Stevenson defines $TS_C = \partial\varepsilon_{CQ}/\partial t$ as a measure of technological change bias. However, as Greene pointed out, his interpretation of the sign of TS_C as corresponding to the minimum efficient scale is incorrect, since changes in ε_{CQ} are in fact related to changes in the slope of the average cost curve rather than to changes in its location.

References

Berndt, E.R. and M. Khaled. "Parametric Productivity Measurement and Choice among Flexible Functional Forms." *J. of Polit. Econ.* 87 (1979): 1220-1245.

Chino, J. *An Econometric Analysis of the Structure of Rice Production.* Special Bulletin No.42, College of Agriculture, Utsunomiya University. Utsunomiya, Japan, 1984 (in Japanese).

Christense, L.R. "Concepts and Measurement of Agricultural Productivity." *Amer. J. Agr. Econ.* 57 (1975): 910-915.

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

Christensen, L.R., D.W. Jorgenson, and L.J. Lau. "Transcendental Logarithmic Production Frontiers." *Rev. Econ. and Statist.* 55 (1973): 28-45.

Denny, M. and M. Fuss. "A General Approach to Intertemporal and Interspatial Productivity Comparisons." *J. of Econometrics* 23 (1983): 315-330.

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

Diewert, W.E. "Applications of Duality Theory." Frontiers of Quantitative Economics, eds. M.D. Intriligator and D.A. Kendrick. Amsterdam: North-Holland, 1974.

Greene, W.H. "Simultaneous Estimation of Factor Substitution, Economies of Scale, Productivity, and Non-Neutral Technical Change." Development in Economic Analysis of Productivity: Measurement and Modeling Issues, ed. A. Dogramaci. London: Kluwer-Nijhoff, 1983.

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

Kako, T. "Decomposition Analysis of Derived Demand for Factor Inputs: The Case of Rice Production in Japan." Amer. J. Agr. Econ. 60 (1978): 628-35.

Kako, T. "Measurement of Scale Economies in Rice Production in Postwar Japan." Economic Studies Quarterly 30 (1979): 160-171 (in Japanese).

Kuroda, Y. "Biased Technological Change and Factor Demand in Postwar Japanese Agriculture." Discussion Paper No.314. Institute of Socio-Economic Planning, University of Tsukuba, Ibaraki, Japan, 1986.

Kuroda, Y. "The Production Structure and the Demand for Labor in Postwar Japanese Agriculture, 1952-82." Amer. J. of Agr. Econ. 69 (1987): forthcoming.

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, annual edition.

Ministry of Agriculture, Forestry, and Fisheries, the Government of Japan. Survey Report on Prices and Wages in Rural Villages (in Japanese). Tokyo: Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, 1983.

Nadiri, M.I. and M.A. Schankerman. "The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System." Productivity Measurement in Regulated Industries, eds. T.C. Cowing and R.E. Stevenson. New York: Academic Press, 1981.

Nghiep, Le Thanh. "The Structure and Changes of Technology in Prewar Japanese Agriculture." Amer. J. Agr. Econ. 61 (1979): 687-693.

Oberhofer, W. and J. Kmenta. "A General Procedure of Obtaining Maximum Likelihood Estimates in Generalized Regression Models." Econometrica 42 (1974): 579-590.

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

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

Stevenson R. "Measuring Technological Bias." Amer. Econ. Rev. 70 (1980): 162-173.

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

Yamada, S. "The Secular Trends in Input-Output Relations of Agricultural Production in Japan, 1878-1978." Agricultural Development in China, Japan, and Korea, eds. C.M. Hou and T.S. Yu. 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. Tokyo, Japan, 1984.

Yamada, S. and Y. Hayami. "Agricultural Growth in Japan, 1880-1970." Agricultural Growth in Japan, Taiwan, Korea, and the Philippines, eds. Y. Hayami, V.W. Ruttan and H.M. Southworth. Honolulu: The University Press of Hawaii, 1979.

Yamada, S. and V.W. Ruttan. "International Comparisons of Productivity in Agriculture." New Developments in Productivity Measurement and Analysis, eds. J.W. Kendrick and B.N. Vaccara, Chicago: The University of Chicago Press, 1980.

Zellner, A. "An Efficient Method for Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias." Journal of American Statistical Association. 57 (1962): 585-612.