No.447

A Decomposition Analysis of Productivity Change in Japanese Agriculture, 1953-86

by

Yoshimi Kuroda

October 1990

Surpassing the mere rehabilitation from the destruction caused by World War II, Japanese agriculture experienced a considerably high growth (more than three percent per annum in terms of total output[1]) from the early-1950s through the late-1960s. However, after the late-1960s, when an acreage allotment restriction program for rice production was introduced for the first time in history, the growth of agriculture slowed down substantially; the annual growth rate of total output was only less than one percent for the 1968-86 period.

There are few studies other than Yamada (1982, 1984) in the literature which have investigated the factors for such a sharp decline in the growth of production at the aggregate level of the Japanese agricultural sector for the postwar years. According to Yamada (1984) who covered the 1945-80 period, the major factor which accounted for the growth of agricultural production before and after the late-1960s was the growth of total factor productivity (TFP), a measure of efficiency in which factor inputs are utilized in production. This suggests that the substantial decline in the growth of agricultural production during the second of the two distinctive periods in relation to the first was caused mainly by a sharp decline in the TFP growth from the former period to the latter.

However, Yamada (1984) assumed constant returns to scale in the estimation of the TFP index. This implies that the rate of growth of TFP is identically equal to the rate of technological progress (Denny, Fuss, and Waverman). It thus follows that the substantial decline in the TFP growth which occurred during the latter period (i.e., the late-1960s to 1986) was totally due to the sharp reduction in the rate of technological progress.

However, recent empirical studies give evidence that increasing returns to scale have existed in postwar Japanese agriculture (Kako; Chino; Yamamoto; Kuroda, 1989; Hayami and Kawagoe). In a seminal work, Denny, Fuss, and Waverman (D-F-W), by linking the conventional measure of TFP and the theory of production, have shown that, if scale economies exist, the growth of TFP consists not only of the effect of technical change but also of the effect due to scale economies. More specifically, the D-F-W procedure decomposes the rate of TFP growth into the rate of technological progress and the rate of growth of aggregate factor input weighted by a scale factor. This indicates that Yamada's estimates of the rates of TFP growth of Japanese agriculture overestimate the efficiency gain from technical change.

In this context, it may be intriguing to apply this D-F-W decomposition procedure in order to identify the determinants of the levels of and changes in the TFP growth in Japanese agriculture for the period under question. However, this procedure has at least the following two shortcomings.

First, it does not fully account for the dynamic aspect of technical change. That is, it fails to capture the indirect effect on the demand for factor inputs induced by technical change. Second, it does not distinguish the demand- and supply-side effects in determining the TFP growth. Although the effects induced by technical change can be classified as the supply-side determinants, the effects due to scale economies cannot simply be classified into either the demand-side or the supply-side determinant. Note however that possible determinants of changes in the demand for factor inputs are changes in factor prices and shifts in the demand curve for output in addition to technical change. Therefore if the effects due to the first two factors can be distinguished, the growth rate of TFP can be decomposed explicitly into the demand- and supply-side determinants. In fact, the direct and indirect effects due to technical change and factor price changes can be classified as the supply-side determinants and the effect due to shifts in the output demand curve as the demand-side determinant. Taking these factors into consideration, Nadiri and Schankerman (N-S) have developed, for the case where scale econmies exist, an attractive method of decomposing the rate of TFP growth into these four specific effects.

The objective of this paper is to identify the determinants of the levels of and changes in the growth of TFP of the Japanese agricultural sector over the period 1953-86 using this Nadiri-Schankerman decomposition procedure. To carry out this objective, the index of TFP will first be estimated for the agricultural sector by the Törnqvist approximation method to the Divisia index. Next, in order to decompose the rates of the TFP growth into a number of effects by the N-S procedure, the cost-output elasticity will be obtained by estimating the translog total cost function based on the aggregate sectoral data for the 1953-86 period.

This paper is organized as follows. In section two, the conventional method of measuring the index of TFP is first given. Then, an outline of the Nadiri-Schankerman decomposition procedure is presented. Finally, the specification of the translog total cost function and the statistical procedure are discussed. Section three explains the data used for empirical estimation, and empirical results are analyzed in section four. In section five, some concluding remarks are offered.

Methodology

Decomposition of Total Factor Productivity Growth

Total factor productivity (TFP) is formally defined as the ratio of total (or aggregate) output (Q) to total (or aggregate) input (F).

$$(1) \quad TFP = Q/F.$$

Thus, the proportional rate of growth of TFP is defined as the rate of growth of total output minus the rate of growth of total input:

$$(2) \quad \dot{TFP} = \dot{Q} - \dot{F},$$

where a dot represents a rate of growth rather than a time derivative.

For the measurement of the indexes of growth of total output, total input, and total factor productivity, the conventional Divisia aggregation procedure is employed in this paper. The

Divisia indexes for total output(Q) and total input(F) are defined in terms of proportional rates of growth as

$$(3) \qquad \dot{Q} = \sum_j \frac{q_j Q_j}{R} \dot{Q}_j \quad \text{and}$$

$$(4) \qquad \dot{F} = \sum_i \frac{P_i X_i}{C} \dot{X}_i ,$$

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

The formulas (2)-(4) are expressed however in terms of instantaneous changes. The data to be used in this study are available at yearly intervals. The Törnqvist discrete approximation procedure is then introduced to (3) and (4):

$$(5) \qquad \Delta \ln Q = \ln(Q_t/Q_{t-1}) = \frac{1}{2} \sum_j (R_{jt} + R_{jt-1}) \ln(Q_{jt}/Q_{jt-1})$$

and

$$(6) \qquad \Delta \ln F = \ln(F_t/F_{t-1}) = \frac{1}{2} \sum_i (S_{it} + S'_{it-1}) \ln(X_{it}/X_{it-1})$$

where $R_j = q_jQ_j/R$, the revenue share of output j; $S_i = P_iX_i/C$, the cost share of factor input i; and t denotes time period. The corresponding discrete approximation to formula (2) is given by

$$(7) \quad \Delta TFP = \Delta \ln Q - \Delta \ln F.$$

Note here that the assumptions underlying this procedure include constant returns to scale and perfect competition in input and output markets. $\dot{TFP}$ can be used to approximate the rate of technological progress if these assumptions are satisfied.

However, when these assumptions are not satisfied, conventional indexes of $\dot{TFP}$ include the effects due to scale economies (or diseconomies) and market imperfections. In order to separate these effects, Denny, Fuss, and Waverman suggest to link the conventionally-measured rate of TFP growth to the theory of production.

It is assumed here that the agricultural sector has a production function which satisfies the usual neoclassical regularity conditions.

$$(8) \quad Q = f(X,t)$$

where Q is aggregate output; X is a vector of factor inputs; and t is an index of time to be used as a proxy of a level of technology. Differentiating with respect to time and dividing by Q,

$$(9) \qquad \dot{Q} = \sum_i \frac{\partial f}{\partial X_i} \frac{X_i}{Q} \dot{X}_i + \dot{T}$$

where $\dot{T} = \frac{\partial f}{\partial t} \frac{1}{f}$ which need not be Hicks neutral.

Assuming cost minimization, $\partial f / \partial X_i = P_i / (\partial C / \partial Q)$,

$$(10) \qquad \dot{Q} = \varepsilon_{CQ}^{-1} \sum \frac{P_i X_i}{C} \dot{X}_i + \dot{T},$$

where ε_{CQ} is the cost elasticity and P_i is the price of factor input i. Substituting (4) into (10) yields

$$(11) \qquad \dot{Q} = \varepsilon_{CQ}^{-1} \dot{F} + \dot{T}.$$

Substituting (11) into the Divisia index of $\dot{TFP}$ given in (2),

$$(12) \qquad \dot{TFP} = \dot{T} + (\varepsilon_{CQ}^{-1} - 1)\dot{F}.$$

Note that the inverse of the cost elasticity is the scale elasticity. If constant returns to scale exist, then $\varepsilon_{CQ} = 1$ and

$\dot{TFP} = \dot{T}$. That is, the conventionally-measured $\dot{TFP}$ is identically equal to the rate of technological progress. If, however, increasing returns to scale exist (i.e., $\varepsilon_{cq} < 1$), then it turns out that $\dot{TFP}$ includes both scale effect and technical change effect. If the cost elasticity (ε_{cq}) is known, the magnitude of the scale effect, $(\varepsilon_{cq}^{-1} - 1)\dot{F}$, can easily be estimated using the result of (4) and hence the technical change effect, $\dot{T}$, can be obtained as a residual using (2) and (12). Using this procedure, one can identify the relative contributions of these two effects to the growth of TFP [2].

However, it has the following two shortcomings. First, the technical change effect ($\dot{T}$) in equation (12) does not properly identify the full contribution of technical change to $\dot{TFP}$. As shown clearly afterwards, if scale economies exist, part of the growth in factor input is induced by technical change. This input inducement effect makes an indirect contribution of technical change to the growth of TFP.

Second, one cannot distinguish by equation (12) between supply-side effects and demand-side effects on $\dot{TFP}$. In fact, there are two possible sets of factors other than technical change that could affect the growth in total factor input ($\dot{F}$); they are changes in factor prices and exogenous shifts in the output demand curve. The effects due to technical change and factor price changes can be classified as the supply-side determinants of the growth of TFP whereas the effect due to exogenous shifts in the output demand curve may be classified as the demand-side determinant.

Taking account of these shortcomings associated with the D-F-W decomposition method, Nadiri and Schankerman (N-S) have proposed a further-advanced decomposition procedure of the growth rate of TFP. They distinguish four determinants of the TFP growth rate when there exist scale economies in production and imperfections in output market; (i) the direct and (ii) indirect effects induced by technical change, (iii) the effect due to changes in factor prices, and (iv) the effect due to shifts in the product demand curve.

This paper employs this N-S decomposition procedure in order to investigate the determinants of the growth of TFP in the Japanese agricultural sector for the 1953-86 period. Only an outline of this procedure is presented below since the details are given in the pertinent article.

However, in order to apply the N-S procedure to the agricultural sector, a rather bold behavioral assumption for the agricultural sector is necessary. That is, the agricultural sector is assumed to behave as if it were a monopolist who faces a downward-sloping demand curve for the aggregate output and achieves average-cost pricing for that output[3].

Now, if there are economies of scale, the growth in total factor input ($\dot{F}$) consists of parts induced by technical change ($\dot{F}_T$), real factor price changes ($\dot{F}_r$), and exogenous shifts in product demand ($\dot{F}_d$). That is,

(13) $\dot{F} \equiv \dot{F}_T + \dot{F}_r + \dot{F}_d.$

If $\dot{F}_T$ and $\dot{F}_\tau$ are given, then the $\dot{F}_d$ can easily be obtained by (13) as a residual since $\dot{F}$ is already given by (4). Thus, if the formulas to obtain $\dot{F}_T$ and $\dot{F}_\tau$ are derived, then $\dot{F}$ can be completely decomposed into the three components ($\dot{F}_T$, $\dot{F}_\tau$, and $\dot{F}_d$). Substituting these into (12), $\dot{TFP}$ can further be decomposed into the direct and indirect technical change effect, factor price change effect, and exogenous demand shift effect.

To begin with, the formula for the rate of growth in total factor input induced by technical change ($\dot{F}_T$)is derived below.[4] Suppose there was a shift in the level of technology, other things being kept constant. Then there would be a two-pronged effect due to this shift. On one hand, as shown in Figure 1, at the old level of inputs, the shift in technology lowers the average cost curve (from AC_0 to AC_1) and hence raises the equilibrium level of output (from Q_0 to Q_1). Since the derived demand for a factor input depends on the level of output, the old level of inputs will no longer be optimal. Some input expansion will be required.

On the other hand, the same shift in technology also lowers the input requirement per unit of output, that is, it shifts isoquant toward the origin (from I to I', but the output levels are the same) as seen in Figure 2 where the possibility of factor biases is taken into account (i.e., the two isoquants are drawn in an unparallel manner).

Aggregating these two effects with opposite directions, the growth rate of total factor input induced by technical change ($\dot{F}_T$) is given by

$$(14) \quad \dot{F}_T = \varepsilon_{CQ}(\psi - 1)\dot{T}, \qquad \psi = \frac{e}{1-e(1-\varepsilon_{CQ})},$$

where e is the price elasticity of product demand (defined to be positive).

Next, the growth rate of total factor input due to factor price changes ($\dot{F}_\tau$) is derived in the following manner.[5] Factor price changes have two effects on the use of an input. The first effect is the pure output expansion effect due to the change in the equilibrium level of output induced by the shift of the cost curve (reference to Figure 1 may be helpful). Second, the same factor price changes alter the optimal input mix (e.g., a shift from A to C in Figure 2). Aggregating these two effects over all factor inputs, the impact of factor price changes on total factor input ($\dot{F}_\tau$) can be obtained by

$$(15) \quad \dot{F}_\tau = -\psi\, \varepsilon_{CQ} \sum_j S_j \dot{P}_j ,$$

where S_j is the share of the jth factor input in total cost and P_j is the price of the jth factor input deflated by output price.

Substitution of (13), (14), and (15) into (12) yields

$$(16) \quad \dot{TFP} = \varepsilon_{CQ}^{-1}(1-\varepsilon_{CQ})\dot{F}_d - (1-\varepsilon_{CQ})\psi\sum_i S_i\dot{P}_i + (1-\varepsilon_{CQ})(\psi-1)\dot{T} + \dot{T}.$$

Equation (16) says that the growth of TFP can be decomposed into the effect due to exogenous shifts in the product demand curve, the effect due to real factor price changes, the effect induced by technical change (or indirect technical change effect), and direct technical change effect. The first effect is regarded as the demand-side effect and the remaining three effects as the supply-side effects. If the cost elasticity (ε_{CQ}) and the price elasticity (e) are known, the measured rate of growth of TFP can be decomposed into these four effects.

<u>The Translog Total Cost Function</u>

The next step is to obtain these parameters. For the price elasticity (e), several hypothetical values which are less than unity will be assumed.[5] The cost elasticity (ε_{CQ}) may be most conveniently estimated using the parameters of the following translog total cost function corresponding to the production function (8) of the agricultural sector.

$$(17) \quad \ln C = \alpha + \alpha_Q \ln Q + \sum_{i=1}^{5} \alpha_i \ln P_i + \beta_t t + \frac{1}{2}\gamma_{QQ}(\ln Q)^2$$

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

$$+ \mu_{QT} \ln Qt + \sum_{i=1}^{5} \mu_{it} \ln P_i \, t + \frac{1}{2} \beta_{tt} t^2$$

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

where Q is output; P_L, P_I, P_M, P_B. and P_O refer to the prices of labor (X_L), intermediate inputs (X_I), machinery (X_M), land (X_B), and other inputs (X_O), respectively; t is an annual index of time to be used as an indicator of the level of technology; and C is the minimized total cost.

The cost-share equations are derived through the Shephard duality theorem as

$$(18) \quad S = \frac{\partial C}{\partial P_i} \frac{P_i}{C_i} = \frac{\partial \ln C}{\partial \ln P_i}$$

$$= \alpha_i + \sum_{j=1}^{5} \gamma_{ij} \ln P_j + \delta_{iQ} \ln Q + \mu_{it} t$$

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

Any sensible cost function must be homogeneous of degree one in input price. In the translog cost function (17), this requires that $\sum_{i=1}^{5} \alpha_i = 1$, $\sum_{j=1}^{5} \gamma_{ij} = \sum_{i=1}^{5} \delta_{iQ} = \sum_{i=1}^{5} \mu_{it} = 0$

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

Several hypotheses concerning the structure of technology can be statistically tested. The first hypothesis to be tested is homotheticity of the technology. The cost function is homothetic if it can be written as a separable function of factor prices and output (Shephard). This implies that changes in the scale of output do not affect the optimal factor combination, so that the expansion path is linear. It is clear from the share equations (18) that homotheticity requires $\delta_{iQ} = 0$ (i = L, I, M, B, O). Second, if the primal production function (8) exhibits constant returns to scale, then the cost function can be written as $C = Q \cdot H(P,t)$. This implies the following set of parameter restrictions on the translog cost function: $\alpha_Q = 1$, $\gamma_{QQ} = \delta_{iQ} = \mu_{Qt} = 0$ (i = L, I, M, B, O). Third, the Hicks neutrality of technical change can be tested by imposing the restrictions, $\mu_{it} = 0$ (i = L, I, M, B, O).

Given the parameters of the translog cost function, the cost elasticity can be estimated by

$$(19) \qquad \varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln C} = \alpha_Q + \gamma_{QQ} \ln Q + \sum_{i=1}^{5} \delta_{iQ} \ln P_i + \mu_{QT} t$$

which will vary with relative factor prices, and the levels of output and technology.

Statistical Procedure

For econometric estimation, restrictions for the across-equations equality [7] and the linear homogeneity in factor prices are imposed a priori on the translog cost function (17) and on the cost share equations (18). This allows arbitrary exclusion of any one of the five cost share equations. In this case, the cost share equation of other-inputs was omitted. The estimates of the coefficients of this equation can easily be obtained by using the parameter relationships of the linear homogeneity restrictions after the system is estimated.

The system of equations consisting of the translog cost function and the four cost share equations are then estimated jointly by the iterative Zellner's seemingly unrelated regression (ISUR) method which ensures invariance of the parameter estimates to the choice of the share equation that is deleted (Kmenta and Gilbert).

The sources of data and variable definitions for measuring the indexes of total factor productivity and for estimating the system of the translog cost function and the cost share equations are described in detail in the Appendix.

Empirical Results

TFP Growth in Japanese Agriculture

Using (5), (6), and (7), the indexes of total output, total input, and total factor productivity were measured for the 1953-86 period. These indexes are presented in Figure 3. Their average annual rates of growth were then computed for two subperiods, 1953-68 and 1968-86, as well as for the entire period 1953-86. The reason that the entire period was divided into these two subperiods is given below.

Overcoming the numerous difficulties in rehabilitating from the destruction caused by World War II for the 1945-53 period (Yamada, 1984), Japanese agriculture achieved a remarkable development in terms of total production for the period 1953-68. During this period, the government implemented policies to promote agricultural production. One of the most important policies was price support program for rice production which in turn caused rice surplus problems in the late-1960s.

In order to solve the rice surplus problem, the government launched a program in 1969 for paddy field retirement and diversion for the first time in history. This program has been implemented until the present time, though it was once relaxed to some extent, namely for the 1972-78 period due to the world food and energy crises occurring during this period. The introduction of this program marked a turning point: the growth of agricultural total output slowed down drastically compared to that of the previous period as seen in Figure 3.

Now, the average annual growth rates of total output, total input, and TFP for the two subperiods, 1953-68 and 1968-86, and for the entire period 1953-86 are presented in Table 1. Total output grew at an average annual rate of 1.56% for the overall 1953-86 period, while total input grew at an average annual rate of -0.17% for the same period. This negative growth rate of total input was caused mainly by persistent decrease in labor input during the entire period under question. TFP grew with an annual average rate of 1.73% [8] which implies a 111% contribution to the growth of total output.

However, it was found that substantial changes occurred in the growth rate of total output, total input, and TFP during the two subperiods. In the 1953-68 period, total output grew rather rapidly with an annual average rate of 3.55%. However, the growth of total input was slow, 0.37% per annum. Consequently, TFP grew with an annual average rate of 3.18% which accounted for as much as about 90% of the growth of total output for this period.

In contrast, the growth of all total output, total input, and TFP became much slower in the 1968-86 period. Total output grew with an annual average rate of 0.60%, while total input grew with -0.45% per annum. Thus, the annual average growth rate of TFP was 1.05% which contributed to the growth of total output by 175%. That is, it offset 75% more than the negative growth of total input.

In sum, TFP growth played a crucial role in determining the growth of agricultural production in both periods. However, the magnitude of the growth rate of TFP declined substantially over the two subperiods. What are then the causes for this sharp decline?

In order to provide an answer for this question, we proceed to decompose the rates of TFP growth using the Nadiri-Schankerman procedure.

Decomposition Analysis of TFP Growth

In order to carry out the proposed decomposition analysis, the system of the translog total cost function (17) and the cost share equations was estimated by the ISUR method so as to obtain the cost elasticity (ε_{CQ}). In the process of estimation, three hypotheses concerning the structure of production technology were statistically tested; homotheticity, constant returns to scale, and Hicks neutrality. A Wald Chi-square test was applied. The computed Chi-square statistics for these three hypotheses were 71.7, 1628.7, and 236.9 with the degrees of freedom 4, 7, and 4, respectively. Hence, all the three hypotheses were strongly rejected at the 0.01 significance level.

Thus, no restrictions other than the across-equations equality and linear homogeneity in factor prices were imposed in estimating jointly the system of the translog cost function and the cost share equations. The coefficients of the other-inputs cost share equation were obtained using the parameter relations of linear homogeneity restrictions. The result is presented in Table 2. This set of estimates is referred to as the final specification of the model and will be used for further analyses[9].

Using the estimates of the translog cost function in Table 2, the cost elasticity, ε_{CQ} was estimated by equation (19) for each year of the estimation period, 1953-86. However, in order to save space, estimates only for selected years as well as the averages for the two subperiods and for the overall period are reported in Table 3. At least two important findings emerge from this table.

First, there were significant scale economies in Japanese agriculture over the whole period under investigation. This finding supports the results obtained by Kako, Chino, and Hayami and Kawagoe, who showed that scale economies existed in rice production during the periods 1973-75, 1961-79 and 1951-84, respectively. It also supports the result of Kuroda (1989) who found significant scale economies in aggregated agricultural production for the 1958-85 period. The existence of scale economies seems to have been attributable largely to the increased indivisibility of capital assets as a result of rapid mechanization and investment in farm buildings and structures during the period under question.

Second, the degrees of scale economies became larger during the latter period than those in the former period. This may have resulted from the following fact concerning the characteristics of mechanization in the two periods. Mechanization during the first period may be characterized as smaller-scale mechanization where small-scale hand-driven power tillers were dominantly introduced. However, after the late-1960s, larger-scale machinery such as riding-type tractors and rice transplanters became popular. The larger-scale machinery apparently has greater indivisibility than smaller-scale machinery. This greater indivisibility may have caused larger degrees of scale economies in the latter period.

Using these estimates of cost elasticities, the conventionally measured TFP growth rates were decomposed by equations (12) through (16) into (i) the direct technical change effect, (ii) the indirect technical change effect, (iii) the factor price change effect, and (iv) the exogenous demand shift effect. For these calculations, three values, 0.2, 0.5, and 0.8, were used for the price elasticity of product demand (e). The results of the decomposition are presented in Table 4. Several important findings are noteworthy in this table.

First, the direct effect of technical change, which is independent of the price elasticity e, accounts for slightly more than completely (103.5%) the TFP growth for the overall period. Although there is some difference in the degrees of contribution of the direct effect of technical change on the TFP growth between the two subperiods, almost all (for the 1953-68 period) or more than all (for the 1968-86 period) part of the TFP growth is explained by this effect. This implies that the direct effect of technical change has played a critically important role in determining the levels of TFP growth in Japanese agriculture.

Second, the magnitude and the degree of contribution of the indirect effect of technical change are sensitive to the values of the price elasticity, e. When e is small (say, e = 0.2), the indirect effect gives significantly negative effects on the TFP growth. As e gets larger (say, e = 0.5, 0.8), the effect gets smaller in absolute terms and even turns to be positive. This is because the output expansion effect of technical change is highly restricted when the price elasticity is small, so the reduction of input use due to the inward shift of the isoquants predominates.

Third, the effect due to real factor price changes were negative as expected. As clearly seen in Table 4, the magnitude of the effect is sensitive to the value of the price elasticity of product demand, e. When e is small (e.g., e = 0.2), the negative effect is much less significant compared to the negative indirect technical change effect. However, as e becomes greater (e.g., e = 0.5, 0.8), this effect becomes considerably significant. In other words, if the elasticity of demand for aggregate agricultural output is fairly large (say, larger than 0.8), a rise in real factor prices will be a severe drag on the TFP growth.

Fourth, shifts in the output demand curve appear to have been an important source of TFP growth. The magnitude of the effect and the degree of contribution to the TFP growth do not vary much with the value of the price elasticity within the specific period. For the overall period, for example, the magnitude of the effect due to shifts in product demand was 0.41, 0.40, and 0.39 percent, respectively. Their contributions to the TFP growth were 23.7, 23.1, and 22.5, respectively.

However, the magnitude of the effect decreased substantially from the first period to the second for any value of the price elasticity. For example, when e = 0.2 (i.e., case a), it decreased from 0.85% during the first period to 0.18% during the second period. This may be interpreted as follows. During the 1953-68 period, the demand for agricultural commodities grew fairly rapidly thanks to the rapid increases in per capita income, implying that shifts in the demand curve for agricultural commodities were relatively large. However, the growth in agricultural demand became much slower in the 1968-86 period due to the much slower increase in per capita income, which in turn resulted from the slower or steadier growth of the Japanese economy as a whole. This indicates that shifts in the demand curve for agricultural commodities were relatively small. This decline in the degrees of shifts in the demand curve from the first to the second period may have caused the substantial decline in the effect due to exogenous shifts in the output demand curve.

Finally, it is clear from Table 4 that the indirect effect of technical change, the effect due to real factor changes, and the effect due to shifts in the demand curve offset each other, so that the (gross) scale effect turned out to be small, positive or negative. Although these effects were important sources for determining the TFP growth, it may be said that the most important factor which determined the rates of the TFP growth for either period of time and the substantial decline in the TFP growth rates from the first to the second period was the direct effect of technical change or, simply, the rate of technological progress. Recall that the major part of the growth of agricultural total output was explained by the TFP growth for the period under question (Table 1). Therefore, it may be said that the decline in the rate of technological progress was the major factor for the substantial decrease in the growth rate of total output in the 1968-86 period in comparison to the growth rate of the previous 1953-68 period.

Conclusions

This study had the objective of investigating the determinants of the growth of total factor productivity in Japanese agriculture for the 1953-86 period. This entire period was divided into the two subperiods, 1953-68 and 1968-86, which roughly coincide with the two distinctive periods of the rapid and the steady growth, respectively, of the Japanese economy as a whole. In order to carry out this objective, the Nadiri-Schankerman procedure was applied to decompose the rate of TFP growth into (i) the direct and (ii) indirect effects of technical change, (iii) the effect due to changes in real factor prices, and (iv) the effect caused by exogenous shifts in the output demand curve. The major findings may be summarized as follows.

The conventionally measured TFP growth rate for the entire 1953-86 period was 1.73% per annum. However, there occurred a substantial decline in this rate from the first period (3.18% per annum) to the second (1.05% per annum). It was found that the growth of TFP was the major factor which accounts for the growth of total output in the agricultural sector within the entire period.

The decomposition analysis by the N-S procedure shows that although the indirect effect of technical change, the effect due to real factor price changes, and the effect due to shifts in the output demand curve, played important roles in determining the TFP growth for any period of time, the most important factor which was responsible for the TFP growth was the direct effect of technical change, or simply, the rate of technological progress.

This in turn implies that the substantial deterioration in technological progress was the most important factor which caused the sharp decline in the rate of TFP growth in the 1968-86 period in comparison to the 1953-68 period.

A possible factor which explains this deterioration in technological progress is the waning of farmers' management adeptness, enthusiasm, and efforts to increase production.

In the process of the rapid and steady economic growth during the 1953-68 and 1968-86 periods, respectively, most farm households became part-timers. It became easy for them to earn incomes from off-farm jobs and agricultural incomes tended to become a minor source. Under such a situation, it would be natural for part-time farmers to have lacking motivation to work hard in farming regardless of the availability of new technological innovations.

In addition, even full-time farmers were not able to foster strong motivation to increase production by utilizing efficiently their own resources together with new technological innovations on enlarged farms, since no effective political measures have been provided to enable them to enlarge their farm size.

Finally, the continuous price support programs for farm products might have caused "slack" or "inert area" in management (Leibenstein) due to lack of competition. This so-called "X-inefficiency" seems to have been dominant especially among part-time farmers.

These factors, together with other possible factors, are considered to have caused the serious loss in farmers' incentives and hence the substantial, unfavorable difference in the rate of technological progress between the 1953-68 and 1968-86 periods.

Figure 1

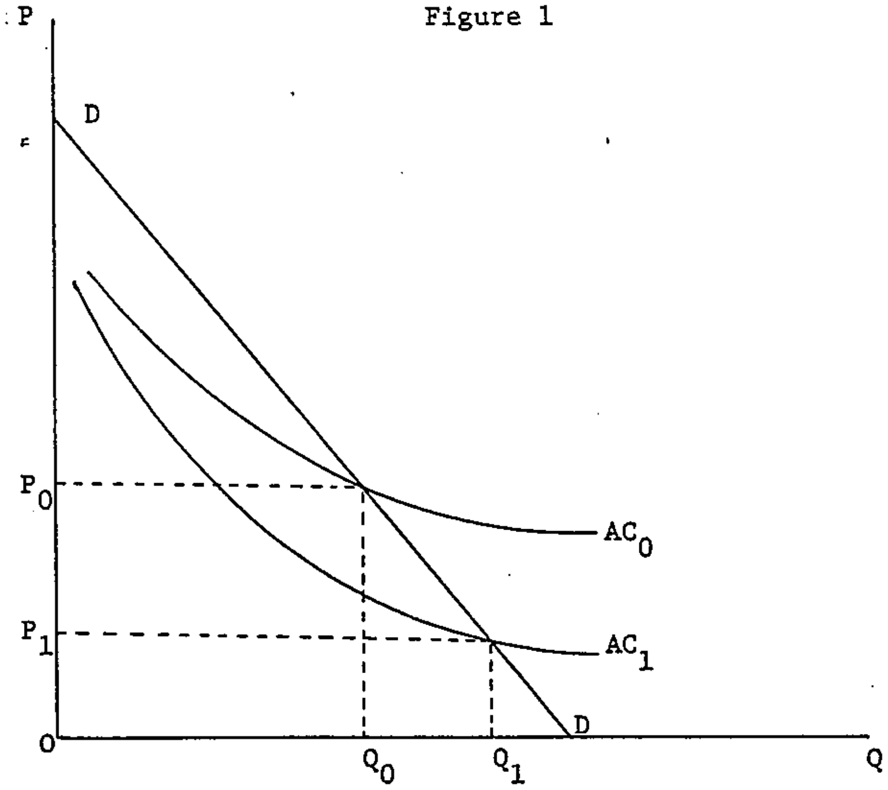

Figure 2

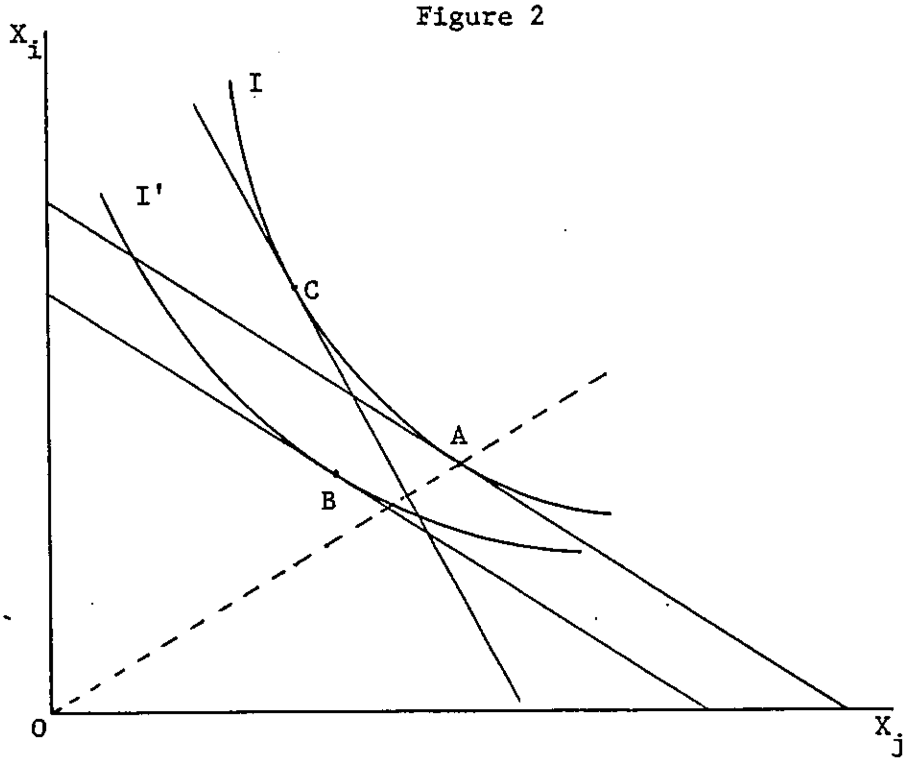

Figure 3. Total Output, Total Input, and Total Factor Productivity 1953-86

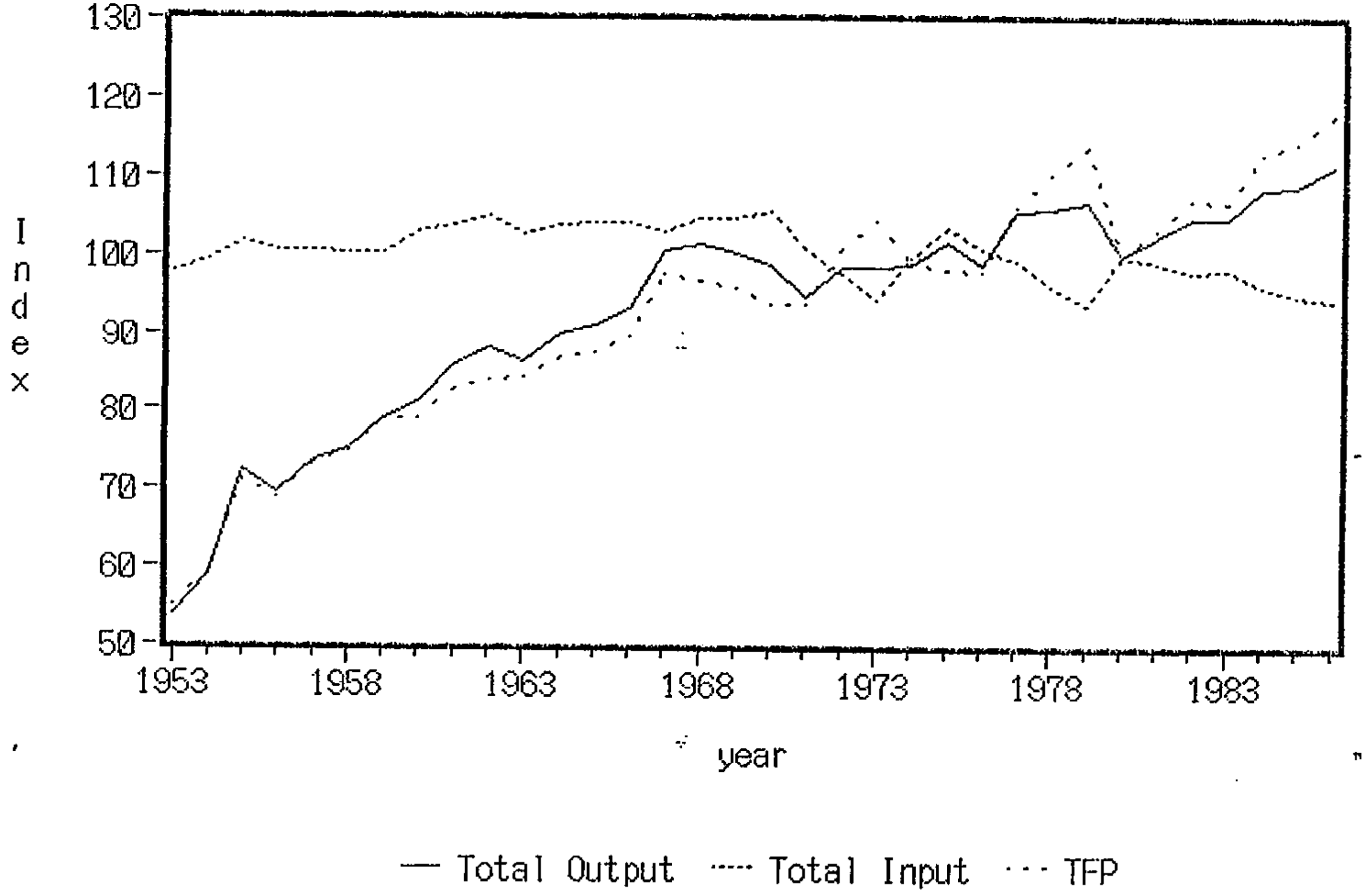

Table 1. Productivity Growth in Japanese Agriculture, 1953-86

(Unit: % per year)

period	$\dot{Q}$ (1)	$\dot{F}$ (2)	$\dot{TFP}$ (3)=(1)-(2)
1953-68	3.55	0.37	3.18
	(100.0)	(10.4)	(89.6)
1968-86	0.60	-0.45	1.05
	(100.0)	(-75.0)	(175.0)
1953-86	1.56	-0.17	1.73
	(100.0)	(-10.9)	(110.9)

Note: The average annual growth rate was computed by fitting $\ln y = a + gt$ where y is the Törnqvist index of Q, F, or TFP; t is an index of time; and a and g are parameters to be estimated.

Table 2. Estimates of the Translog cost Function, 1953-86

Parameter	Coefficient	t-value	Parameter	Coefficient	t-value
α	12.061	1252.7	γ_{IM}	0.007	0.72
α_Q	0.696	61.4	γ_{IB}	-0.076	-5.1
α_L	0.260	106.0	γ_{IO}	-0.030	
α_I	0.281	77.8	γ_{MB}	0.012	2.5
α_M	0.067	51.2	γ_{MO}	-0.010	
α_B	0.260	56.2	γ_{BO}	-0.019	
α_O	0.133		δ_{LQ}	-0.004	-0.25
β_t	-0.002	-1.0	δ_{IQ}	0.200	6.6
γ_{QQ}	0.601	5.8	δ_{MQ}	-0.032	-2.8
γ_{LL}	0.156	20.5	δ_{BQ}	-0.120	-3.0
γ_{II}	0.108	5.3	δ_{OQ}	-0.043	
γ_{MM}	-0.011	-1.8	μ_{Qt}	-0.003	-1.9
γ_{BB}	0.157	7.2	μ_{Lt}	-0.008	-14.6
γ_{OO}	0.136		μ_{It}	0.006	8.0
γ_{LI}	-0.008	-1.1	μ_{Mt}	0.002	5.3
γ_{LM}	0.003	0.78	μ_{Bt}	-0.001	-1.6
γ_{LB}	-0.074	-8.8	μ_{Ot}	0.001	
γ_{LO}	-0.076		β_{tt}	0.002	9.7

Note: The coefficients without t-values were computed using the linear homogeneity restrictions.

Table 3. Cost Elasticity (ε_{cq}):

Selected Years for 1953-86

Year	Cost Elasticity	Year	Cost Elasticity
1953	0.667	1970	0.737
1955	0.752	1973	0.713
1958	0.706	1975	0.728
1960	0.732	1978	0.734
1963	0.768	1980	0.696
1965	0.790	1983	0.705
1968	0.795	1986	0.712
1953-68[a]	0.747(0.046)		
1968-86[a]	0.725(0.023)		
1953-86[a]	0.733(0.036)		

a: Average for that period, and the figures in parentheses are the standard deviations.

Table 4. Decomposition of TFP Growth, 1953-86

(Unit: %)

	Period	Technical Change Effect Direct (1)	Scale Effect: Technical Change Effect Indirect (2)	Scale Effect: Factor Prices Change Effect (3)	Scale Effect: Exogenous Demand Shift Effect (4)	Scale Effect: Total (5)=(2)+(3)+(4)	Measured $\dot{TFP}$ (Average Annual Rate)
	1953-68	3.05	-0.61	-0.11	0.85	0.13	3.18
		(95.9)	(-19.2)	(-3.5)	(26.7)	(4.1)	(100.0)
(a)	1968-86	1.22	-0.26	-0.09	0.18	-0.17	1.05
		(116.2)	(-24.8)	(-8.6)	(17.1)	(-16.2)	(100.0)
	1953-86	1.79	-0.38	-0.10	0.41	-0.06	1.73
		(103.5)	(-22.0)	(-5.8)	(23.7)	(-3.5)	(100.0)
	1953-68	3.05	-0.33	-0.30	0.76	0.13	3.18
		(95.9)	(-10.4)	(-9.4)	(23.9)	(4.1)	(100.0)
(b)	1968-86	1.22	-0.14	-0.23	0.20	-0.17	1.05
		(116.2)	(-13.3)	(-21.9)	(19.0)	(-16.2)	(100.0)
	1953-86	1.79	-0.20	-0.26	0.40	-0.06	1.73
		(103.5)	(-11.6)	(-15.0)	(23.1)	(-3.5)	(100.0)
	1953-68	3.05	0.00	-0.52	0.65	0.13	3.18
		(95.9)	(0.0)	(-16.4)	(20.4)	(4.1)	(100.0)
(c)	1968-86	1.22	0.01	-0.41	0.24	-0.17	1.05
		(116.2)	(1.0)	(-39.0)	(22.9)	(-16.2)	(100.0)
	1953-86	1.79	0.01	-0.46	0.39	-0.06	1.73
		(103.5)	(0.6)	(-26.6)	(22.5)	(-3.5)	(100.0)

Note: For (a), e=0.2 and ε_{CQ} =0.747; for (b), e=0.5 and ε_{CQ} =0.725; and for (c), e=0.8 and ε_{CQ} =0.733. The components of the four effects are as follows: (1)=$\dot{T}$; (2)=$(1-\varepsilon_{CQ})(\psi-1)\dot{T}$; (3)=$-(1-\varepsilon_{CQ})\psi\sum_i S_i \dot{P}_{ij}$; and (4)=$\varepsilon_{CQ}^{-1}(1-\varepsilon_{CQ})\dot{F}_d$.

Footnotes

1) The two terms, total output and total production, are assumed to be equivalent and used interchangeably in the paper.

2) A formula analogous to (12) based on the dual cost function, $\dot{TFP} = -\dot{B} + (1-\varepsilon_{CQ})\dot{Q}$, seems to have been more widely used in the literature (e. g., Nelson and Wohar; Capalbo; Kuroda, 1989: Yamamoto). Here $\dot{B}$ is defined as the dual rate of technical change or the rate of cost diminution which is related to the primal rate of technical change as $-\dot{B} = \varepsilon_{CQ}\dot{T}$ (Ohta).

3) Such an assumption may be permitted considering the following facts in postwar Japanese agriculture. More than 80% of agricultural products have been covered by price-support programs (Kuroda, 1982). In addition, government-supported price level of each product has been determined based in general on average cost of the "average" farm. Thus, if the agricultural sector and the government are treated as a combined economic agent, this agent could be regarded as a monopolist achieving average-cost pricing.

4) Refer to the discussion related to equations (22) through (27) in Nadiri and Schankerman.

5) Refer to the exposition associated with equations (29) through (31) in Nadiri and Schankerman.

6) According to Sasaki, the price elasticity of food demand was 0.45 in absolute term for the 1961-82 period in Japan.

7) Christensen, Jorgenson, and Lau (p.35) make a clear distinction between the "symmetry" restrictions 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 equations. The imposition of equality restrictions in this study ($\alpha_i = \alpha_i$, $\gamma_{ij} = \gamma_{ij}$, $\delta_{iQ} = \delta_{iQ}$, $\mu_{it} = \mu_{it}$ for all i = j = L, I, M, B, O) implies that the assumption of cost-minimizing behavior is maintained.

8) This growth rate of Japanese agriculture happened to be very similar to those for U. S. agriculture; 1.75% for the 1948-79 period obtained by Ball and 1.56% for the 1950-82 period obtained by Capalbo.

9) Monotonicity and concavity of the cost function were checked and satisfied for the approximation point.

References

Ball, V. E. "Output, Input, and Productivity Measurement in U. S. Agriculture, 1948-79." Amer. J. Agr. Econ. 67(1985): 475-486.

Capalbo, S. M. "Measuring the Components of Aggregate Productivity Growth in U. S. Agriculture." West. J. Agr. Econ. 13(1988): 53-62.

Chino, J. "Inasaku Seisan Kozo no Keiryo Keizai Bunseki (An Econometric Analysis of the Structure of Rice Production)." Special Bulletin No.42, College of Agriculture, Utsunomiya University, Ustunomiya, Japan, 1984.

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

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

Hayami, Y. and T. Kawagoe. "Farm Mechanization, Scale Economies and Polarization: The Japanese Experience." J. Devel. Econ. 31(1989): 221-39.

Izumida, Y. "Shihon oyobi Toshi no Shueki-ritsu ni-kansuru Riron-teki Jissho-teki Kenkyu (Theoretical and Empirical Study on the Rates of Return to Capital and Investment in Postwar Japanese Agriculture)." Special Bulletin No.44, College of Agriculture, Utsunomiya University, Utsunomiya, Japan, 1987.

Jorgenson, D. W. "The Economic Theory of Replacement and Depreciation." Econometrics and Economic Theory, ed. W. Sellekaerts. London: Macmillan & Co., 1974.

Japan, Bureau of Statistics, Office of the Prime Minister. Nihon Tokei Nenkan (Japan Statistical Yearbook). Tokyo: Bureau of Statistics, Office of the Prime Minister, various issues.

Japan, Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries. Nogyo oyobi Noka no Shakai Kanjo (Social Accounts of Agriculture and Farm Households). Tokyo: Norin Tokei Kyokai, various issues.

________. Nogyo Hakusho Fuzoku Tokei-hyo (Appendix Statistics of the Agricultural White Book). Tokyo: Norin Tokei Kyokai, various issues.

________. Noka Keizai Chosa Hokoku (Survey Report on Farm Household Economy). Tokyo: Norin Tokei Kyokai, various issues.

________. Noson Bukka Chingin Chosa Hokoku (Survey Report on Price and Wages in Rural Villages). Tokyo: Norin Tokei Kyokai, various issues.

________. Norin-Suisan-Sho Tokei-hyo (Statistical Yearbook of the Ministry of Agriculture, Forestry, and Fisheries). Tokyo: Norin Tokei Kyokai, various issues.

Kako, T. "Inasaku ni-okeru Kibo no Keizai no Keisoku (Measuring Scale Economies in Rice Production)." Kikan Riron Keizai Gaku (Economic Studies Quarterly). 30(1979): 160-171.

Kmenta, J. and R. F. Gilbert. "Small Sample Properties of Alternative Estimators of Seemingly Unrelated Regressions." J. Amer. Statist. Assoc. 63(1968): 1180-1200.

Kuroda, Y. "The Present State of Agriculture in Japan." U. S.-Japanese Agricultural Relations, eds. E. N. Castle and K. Henmi. Baltimore: The Johns Hopkins University Press, 1982.

________. "Impacts of Economies of Scale and Technological Change on Agricultural Productivity in Japan." J. Japanese and International Econ. 3(1989): 145-173.

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

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. G. Cowing and R. E. Stevenson. New York: Academic Press, 1981.

Nelson, R. A. and M. E. Wohar. "Regulation, Scale Economies, and Productivity in Steam-Electric Generation." Int. Econ. Rev. 24(1983): 57-79.

Ohkawa, K., M. Shinohara, and M. Umemura, eds. Long-Term Economic Statistics of Japan since 1868, vol.9 Noringyo (Agriculture and Forestry). Tokyo: Toyo Keizai Shinpo-sha, 1966.

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

Sasaki, K. "An analysis of the Japanese Expenditure Pattern: An Application of Dynamic Linear Expenditure System to the 1961-1982 Data." Agribusiness. 3(1987): 51-68.

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 Bull., 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.

________. "Country Study on Agricultural Productivity and Analysis: 1945-1980. Japan." Institute of Oriental Culture, University of Tokyo, Tokyo, 1984.

Yamamoto, Y. "Keiran no Seisansei-Kojo nikansuru Keiryo Bunseki (Econometrical Analysis of the Productivity Growth in Egg Production)." Nokei Ronso (Hokkaido University). 29(1986): 1-28.

Zellner, A. " An Efficient Method for Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias." J. Amer. Statist. Assoc. 57(1962): 585-612.

Appendix

The basic data required to estimate the Törnqvist indexes of total output, total input, and total factor productivity 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 share equations. However, it is more convenient to start from the variable definitions for and data processings of 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 quantity of total output, and the prices and cost shares of the five factors of production; labor, intermediate inputs, machinery, land, and other inputs. The data were collected and processed for the Japanese agricultural sector for the period 1953-86.

The quantity and price indexes of total output (Q and P) were computed by the Törnqvist approximation method of the Divisia index. For this computation, eleven categories of farm products were distinguished, from among crop and livestock products as well as agricultural services. The base year of these and the following indexes were set at 1980.

The sources of data for the values of products are: (i) for 1953-59, K. Ohkawa, M. Shinohara, and M. Umemura, eds., Long-Term Economic Statistics of Japan since 1868 (LTES), vol. 9, (Toyo Keizai Shinposha, 1966), and (ii) for 1960-86, Ministry of Agriculture, Forestry, and Fisheries (MAFF), Social Accounts of Agriculture and Farm Households (SAAF), various years. The data obtained from LTES were linked to the data from the SAAF at 1960. The data sources for the price indexes of products are: for 1953-59, MAFF, the Survey Report on Prices and Wages in Rural Villages (PWRV), various issues; and for 1960-86, the SAAF, various issues. The PWRV data were linked to the SAAF data at 1960.

The quantity and price indexes 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 1953-81 were taken from Yamada (1984) (Appendix Table 9, p. 145). The work-hours data for the years 1982-86 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 indexes 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, X_L^f, P_L^m, and P_L^f.

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

In order to obtain the quantity and price indexes 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_τ) is yielded by

$$(A\text{-}1) \quad P_t = q_t(r_t + \delta_t),$$

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:

$$(A\text{-}2) \quad K_t = K_{t-1} + I_t - \delta_t K_{t-1},$$

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,

$$(A\text{-}3) \quad V_t = P_t K_{t-1}$$

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 indexes of machinery inputs (X_M and P_M) were computed.

The same procedure was applied in order to obtain the cost ($P_O X_O$) and the quantity and price indexes (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 the capital stocks and gross investments for these capital assets for the 1960-1979 are from Izumida. The data for the period 1980-86 were obtained following Izumida's procedures based on the same set of the original data sources used by Izumida. The data for the 1953-59 period were taken from Yamada (1984) and linked to the Izumida data at 1960. However, the data of farm automobiles for the 1953-66 period could not be obtained for want of data.

The asset price indexes were obtained from the SAAS, 1963 and 1988 issues. The market interest rate used here is the rate for loan trust taken from Japan Statistical Yearbook published by the Bureau of Statistics, office of the Prime Minister, various issues.

The quantity and price indexes 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. In addition, the service flow of land improvement investments was obtained by multiplying the value of land improvement investments by the same market interest rate. 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 land improvement investments, and the respective values of the service flows, the Törnqvist quantity and price indexes 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 data on land improvement investments are from the SAAS, various issues. The prices of land were taken from <u>Appendix Statistics of the Agricultural White Book</u> (AWB) published annually by the Statistical Association of Agriculture and Forestry. 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 indexes by setting the 1980 prices to 1.0. The price index of land improvement investments was taken from the SAAS various issues.

The total cost (C) was calculated as

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

The cost share of each component was then obtained by

(A-5) $S_i = P_i X_i / C, \quad i = L, I, M, B, O.$

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