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Productivity Growth, Efficiency Change and Technical Change in Japanese Agriculture : 1965-1995

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Though there are many studies on Japanese agricultural productivity, studies in relation to efficiency of Japanese agriculture are very few. In this study an attempt is made to measure the technical efficiency and technical change in Japanese agriculture from 1965 to 1995. Both data envelopment analysis (DEA) and stochastic frontier analysis (SFA) methods are used to measure the efficiency. We obtained a consistent result between these two analyses. We also found that a fair amount technical progress existed, but at the same time technical efficiency declined in these thirty years. Prefectures which have large-scale rice farming such as Hokkaido, Niigata, Ishikawa, and Toyama possess high technical efficiencies. Also, prefectures which are near big cities such as Tokyo, Kanagawa and Aichi possess high technical efficiencies. On the other hand, cold, mountainous and less populated prefectures such as Iwate, Tottori and Shimane possess low technical efficiencies. Also, we found that technical efficiency diverged rather than converged over these 30 years.

Key words : Japanese agriculture, technical efficiency ranking, DEA, stochastic frontier production function.

1. Introduction

It is not easy for young Japanese to believe that Japanese agriculture used to be the best in the world even though the land endowment had been the worst among the advanced countries. Per capita arable land for one Japanese is only 4 a (are) which is one of the smallest amounts in the world. For example, the new continental countries such as Australia, Canada and USA have more than 3,000 a, 300 a and 180 a respectively. The old continental countries such as France, England, Germany, and Italy have around 55 a, 30 a, 20 a, and 30 a. Even China and India, which have the largest and second largest population in the world, have 39 a and 24 a (FAO, *Production Yearbook*, 2000). From these data, we can understand how Japanese agriculture suffered from severe land constraint.

However, the growth rate of Japanese agriculture for 100 years since the Meiji restoration (1868) until 1970 which is the starting year of the heavy pressure of trade liberalization for Japanese agriculture was highest in the world. But after 1970, Japanese trade liberalization in agriculture proceeded fiercely. Then, the Japanese agriculture started to be destroyed and the agricultural output decreased until the lowest level around the year of 1950 (i.e., Food Crisis time after World War II). Also, the Japanese food consumption pattern changed to consume more meat and dairy products. Conversely, Japanese people have continued to have a habit of consuming less and less rice. But one-calorie beef production needs 7 calories feed, such as cereals. Also, the land constraint is very strict as we saw above. Therefore, Japanese agriculture could not adjust to this new situation

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and the self-sufficiency rate for food decreased continuously. By these two facts, the agricultural sectors were destroyed in almost all prefectures. However, some prefectures in Japan could survive and run efficiently but the most of Japanese agriculture were not operated efficiently.

Kuroda [12][13] worked energetically on the productivity of Japanese agriculture, although he did not analyze the efficiency problem as we did in this paper. Here, an extension is made to measure the efficiency of agriculture in each Japanese prefecture. We can hypothesize that the agriculture of the prefectures which produce rice and hold relatively large scale land such as Hokkaido, Niigata, Ishikawa, Toyama; the agriculture which is operated near a big city (as Schulz [17] shows) such as Tokyo, Kanagawa and Aichi; and the agriculture which belongs to the warm regions such as Miyazaki and Kagawa would have a large efficiency. On the other hand, the agriculture of the prefectures with cold weather such as Iwate, and mountainous and less populated prefectures such as Tottori and Shimane would have a poor efficiency.

2. Methodology and Data

In this section, we introduce two methodologies and data, which are used in our analysis. First, we introduce two methodologies, stochastic frontier analysis (SFA) and data envelopment analysis (DEA), which are used to estimate the technical efficiencies of Japanese agriculture. Second, we introduce data and data sources, which are utilized for our analysis.1)

1) Methodology

We analyze the technical efficiency, using the stochastic frontier analysis method, which was suggested by Battese and Coelli [3] and the data envelopment analysis method, which was suggested by Fare et al. [8]. As mentioned in footnote 1, the former is a parametric method and the latter is a non-parametric method.

Stochastic Frontier Production Function Analysis (SFA) : With respect to the stochastic frontier analysis method, following the specification of Pitt and Lee [15], which specified a panel-data version of the Aigner et al. [1] half-normal model, we can specify our model as,

$$Y_{i,t} = f(X_{i,t}\beta)\exp(V_{i,t}-U_{i,t}),\quad i=1,\cdots,N,\quad t=1,\cdots,T, \qquad (1)$$

where $Y_{i,t}$ denotes the production level for i-th firm in t-th year. $X_{i,t}$ denotes a $1\times K$ input vector associated with the production of i-th firm in t-th period. β is a vector of $K\times1$ unknown parameter to be estimated. $f(\cdot)$ is a suitable function which describes the production technology. $V_{i,t}$ is assumed to be independently and identically distributed as a normal random error with mean zero and variance (σ_V^2). $U_{i,t}$ is a non-negative random variable, which is called the technical inefficiency effect. In respect of the distribution of technical inefficiency effects $(U_{i,t})$, there are several cases in the panel data model of stochastic frontier production function. In our model, we employ the assumption that technical inefficiency effects are time-invariant such as,

$$U_{i,t} = U_i,\quad i=1,\cdots,N,\quad t=1,\cdots,T, \qquad (2)$$

Battese and Coelli [3] extended this model so that the $U_{i,t}$'s had the generalized truncated-normal distribution proposed by Stevenson [18]. We define technical efficiency of a given firm $(TE_{i,t})$ as

$$TE_{i,t} = \frac{f(X_{i,t}\beta)\exp(V_{i,t}-U_{i,t})}{f(X_{i,t}\beta)\exp(V_{i,t})} = \exp(-U_{i,t}) \qquad (3)$$

We assume Cobb-Douglas type production function2) and the technical inefficiency term followed truncated normal distribution, according to the way of Battese and Coelli [3]. Hence our model is as follows.

$$Y_{i,t} = \beta_0+\beta_1\ln K_{i,t}+\beta_2\ln L_{i,t}+\beta_3\ln B_{i,t} +\beta_4\ln F_{i,t}+\beta_T T+v_{i,t}-u_{i,t} \qquad (4)$$

where

$$v_{i,t}\sim N(0,\sigma_V^2),\qquad u_{i,t}\sim|N(\mu,\sigma^2)|$$

First, we will test whether technical inefficiency exists or not in our observations by the generalized likelihood-ratio tests, because the existence of technical inefficiency is one of our main issues. We define γ to be

$$\gamma\equiv\sigma^2/\sigma_S^2 \qquad (5)$$

where

$$\sigma_S^2\equiv\sigma^2+\sigma_V^2 \qquad (6)$$

As we know, σ^2 and σ_V^2 are the variance of technical inefficiency and disturbance term and σ_S^2 is the sum of them. The test statistics is calculated as,

$$\lambda\equiv-2\ln\ (\text{likelihood function}(H_0)/\text{likelihood function}(H_1)) \qquad (7)$$

where

$$H_0 : \gamma = 0 \qquad H_1 : \gamma \neq 0$$

and this test statistics follows mixed χ^2 distribution whose degree of freedom is the number of restrictions. In our case, the degree of freedom is unity. λ follows mixed χ^2 distribution. The table for this mixed χ^2 distribution is shown in Kodde and Palm [11]. We refer to this table in our estimation.

Data Envelopment Analysis (DEA) : With respect to DEA, technical efficiency is measured as the distance from the production technology frontier. When we define the production technology as the set S^t and the combination of input and output as (x^t, y^t), with the output based on distance function, following Fare et al. [8], technical efficiency of t-th period is defined as

Technical Efficiency of t-th period

$$\equiv D_o^t(x^t, y^t) \equiv \inf\{\theta : (x^t, y^t/\theta) \in S^t\} \quad (8)$$

The distance functions, $(D_o^t(x^t, y^t))$, which are defined above, are at the minimum rate (θ) which enables us to put the combination of input and output (x^t, y^t) of t-th period on the production technology frontier of t-th period. Note that $D_o^t(x^t, y^t) \leq 1$ if and only if $(x^t, y^t) \in S^t$. Moreover, $D_o^t(x^t, y^t) \leq 0$ if and only if (x^t, y^t) is on the frontier of the technology. By using the distance function, we can define the minimum rate (θ) which enables us to put the combination of input and output of $t+1$th period (x^{t+1}, y^{t+1}) on the production technology frontier of t-th period.

It is as

$$D_o^t(x^{t+1}, y^{t+1}) \equiv \inf\{\theta : (x^{t+1}, y^{t+1}/\theta) \in S^t\} \quad (9)$$

This distance function measures the maximal proportional change of output required to make (x^{t+1}, y^{t+1}) feasible in relation to the technology at t-th period. Also, we can define the minimum rate (θ) which enables us to put the combination of input and output of t-th period (x^t, y^t) on the production technology frontier of $t+1$-th period as,

$$D_o^{t+1}(x^t, y^t) \equiv \inf\{\theta : (x^t, y^t/\theta) \in S^{t+1}\} \quad (10)$$

This distance function measures the maximal proportional change of output required to make (x^t, y^t) feasible in relation to the technology at $t+1$-th period.

Following Fare et al. [8], we can also define the technical efficiency change index and technical change index as follows.

Technical Efficiency Change Index

$$\equiv \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad (11)$$

Technical Change Index

$$\equiv \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right]^{(1/2)} \quad (12)$$

Next we define the Malmquist Total Factor Productivity (TFP) index[3] and decompose it into technical efficiency change index and technical change index, which are defined by Fare et al. [8], as follows.

$$\begin{aligned} M_O(x^{t+1}, y^{t+1}, x^t, y^t) &\equiv \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right]^{(1/2)} \\ &= \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \\ &\quad \times \left[\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right]^{(1/2)} \\ &= \text{Technical Efficiency Change Index} \\ &\quad \times \text{Technical Change Index} \end{aligned} \quad (13)$$

The term outside the parenthesis is technical efficiency change index and the term inside the parenthesis is technical change index. Note that if the efficiency change is larger than unity, this means that there is an efficiency improvement in the economy. Also, if technical change is larger than unity, this means that there exists technical progress in the economy.

2) Data source

The data used in this study are outputs and inputs of 46 prefectures in Japan for the period from 1965 to 1995. We omitted Okinawa Prefecture from observations, since we cannot obtain the data for Okinawa until 1970. If we want to know the technical change and technical efficiency change in post-war Japanese agriculture, we should use the data from 1945 to 2000. However, our analysis is restricted to the period from 1965 to 1995, since the criterion of data for capital stock and labor changed in 1965. Moreover, we can not obtain prefecture level data since 1996. However, we can get the data for 31 periods, and this length of time period is enough to analyze the productivity growth and technical change of post-war Japanese agriculture.

The common variables used in SFA and DEA are total value of agricultural production $(Y_{i,t})$, capital stock $(K_{i,t})$, labor $(L_{i,t})$, land $(B_{i,t})$, and fertilizer $(F_{i,t})$.[4] The time $(T_{i,t})$ variable is adopted only for the stochastic frontier production function analysis. First of all, the data of production $(Y_{i,t})$ is an aggregated gross agricultural output, such as product of crops, vegetables, livestock, cocoon, and others. This data is deflated by the deflator of agricultural goods obtained from *Japanese Statistical Yearbook* (published annually by the Bureau of Statistics, Office of the Prime Minister). This deflator is the weighted average of all prices of agricultural products. We consider that capital stock, labor, land and fertilizer are four main inputs in Japanese agricultural production. The data of capital stock ($K_{i,t}$) consist of machinery and small tools used in agricultural production (in the future, we want to calculate the data for more sophisticated capital stock and use them for estimation of production function).

These data are also real values deflated by the deflator of agricultural implements (i. e., weighted average deflator of machinery and small tools for agriculture production). Labor ($L_{i,t}$) is measured by total working hours. These total working hours are calculated as the effective weighted average between total working hours of men and women. Land ($B_{i,t}$) is defined as cultivated land and includes paddy fields, fields for vegetables, fruits and meadow. Fertilizer is measured by the cost of fertilizer, which is deflated by the price index of fertilizer in Japan. Since we want to know the contribution of fertilizer to agricultural production, we adopted the cost of fertilizer as one of the most important inputs. When we adopt the fertilizer as one of the inputs, we have to adopt gross output rather than value added, because of accounting. Time trends are years of the observation. All data are prefectural level of 46 prefectures of Japan and were collected from Survey Report on Farm Household Economy, published annually by the Ministry of Agriculture, Forestry and Fishery of Japan (MAFF).

3. Discussion of Empirical Results

Our purpose in this section is to interpret and discuss the results of our empirical research conducted with the stochastic frontier production function analysis (SFA) and the data envelopment analysis (DEA). Firstly, we show the estimated parameters of the stochastic frontier production functions. Secondly, we test the existence of the technical inefficiency of Japanese agriculture by the generalized likelihood-ratio test, which is conducted with the stochastic frontier production function analysis. We also predict the technical efficiency of Japanese agriculture (in every prefecture) from 1965 to 1995, by both SFA and DEA methods. After that, we choose 10 most technically efficient prefectures and 10 least technically efficient prefectures, and we consider the characteristics of these prefectures. Thirdly, we discuss the frequency of technical efficiency of Japanese agriculture from 1965 to 1995. Fourthly, we consider the differences in technical change and technical efficiency change among regions. Finally, we try to see the relationships between technically efficient prefecture and innovative prefectures.

1) Hypothesis and most or least technically efficient prefectures

The parameters of our model are estimated by using the FRONTIER 4. 1 program suggested by Coelli [5].[5] Table 1 shows the estimated parameters. Technical change took place constantly between 2 to 3% annually from 1965 to 1995. Further, constant return to scale prevailed in Japanese agriculture (from 1965 to 1990). This comes from the fact that the sums of the estimated coefficients of inputs are always close to unity. Then, we tested whether there are technical inefficiencies in the production of Japanese agriculture. As shown in Table 2, generalized likelihood-ratio tests were performed for all periods and all null hypotheses were rejected. Therefore, we can say that there are technical inefficiencies in Japanese agriculture for all periods.

Next, we decided which prefectures were the most or least technically efficient in each period (i. e., from 1965 to 1970, from 1971 to 1975, from 1976 to 1980, from 1981 to 1985, from 1986 to 1990, and from 1991 to 1995). As we discussed above, we could recognize that constant return to scale prevailed in Japanese agriculture for 30 years. Therefore, we compared the technical efficiencies between SFA and DEA which assumes constant return to scale. From this comparison, we obtained the following results. The results are shown in Table 3 and the technical efficiencies were obtained by using FRONTIER 4. 1 and DEAP 2. 1 suggested by Coelli [6].[6] If

Table 1. Maximum-likelihood estimates for stochastic production function

	1965-70	1971-75	1976-80	1981-85	1986-90	1991-95
β_0	0.208	0.547	1.479	1.920	0.856	0.589
	(0.498)	(1.006)	(3.405)	(4.507)	(2.271)	(1.591)
β_1	0.053	0.143	0.072	0.025	0.050	0.174
	(1.497)	(3.331)	(1.910)	(0.584)	(1.329)	(3.510)
β_2	0.569	0.503	0.455	0.442	0.557	0.565
	(9.620)	(6.264)	(6.601)	(6.645)	(9.970)	(8.518)
β_3	0.178	0.139	0.082	0.257	0.276	0.173
	(4.388)	(2.792)	(1.397)	(3.927)	(4.494)	(2.508)
β_4	0.216	0.221	0.381	0.159	0.181	0.164
	(5.457)	(4.275)	(8.313)	(3.128)	(3.819)	(2.804)
β_T	0.026	0.078	0.004	0.022	0.001	0.025
	(6.336)	(20.830)	(0.864)	(6.912)	(0.336)	(4.755)
σ_2	0.022	0.029	0.025	0.024	0.022	0.033
	(2.246)	(2.395)	(6.828)	(7.482)	(3.801)	(4.746)
γ	0.854	0.845	0.865	0.912	0.904	0.835
	(13.081)	(13.003)	(51.206)	(56.787)	(45.976)	(28.436)
μ	0.088	0.145	0.293	0.297	0.279	0.334
	(1.243)	(1.652)	(8.776)	(7.930)	(5.454)	(5.264)
log likelihood	334.205	232.775	250.907	275.292	277.020	195.150

Note : The values in parenthesis are t-values and the coefficients correspond to the ones in the equation (4).

Table 2. Generalized likelihood-ratio tests of hypothesis

	Null hypothesis	Maximum likelihood (unrestricted)	λ	$\chi^2_{0.05}$	Decision
1965-70	$H_0 : \gamma=0$	334.205	235.074	5.138	Reject
1971-75	$H_0 : \gamma=0$	232.775	194.317	5.138	Reject
1976-80	$H_0 : \gamma=0$	250.907	267.052	5.138	Reject
1981-85	$H_0 : \gamma=0$	275.292	321.704	5.138	Reject
1986-90	$H_0 : \gamma=0$	277.020	345.190	5.138	Reject
1991-95	$H_0 : \gamma=0$	195.150	222.114	5.138	Reject

Note : The value, $\chi^2_{0.05}$, is obtained from Table 1 of Kodde ad Palm[11], which gives critical value for tests of null hypothesis related to values on the boundary of the parameter space. This is mixed χ^2 statistics.

a prefecture is classified as among the top 10 most technically efficient prefectures by both methods, then we regard this prefecture as one of the most technically efficient prefectures.

On the other hand, if a prefecture is calculated to be placed among the last 10 technically efficient prefectures by both methods, then we regard this prefecture as one of the least technically efficient prefectures. According to this interpretation, we can obtain the following conclusions. The most and least technically efficient prefectures by both methods are half-tone dot meshed in Table 3. Figure 1 also shows the most and least technically efficient prefectures. The most and least technically efficient prefectures are marked with black and gray colors respectively in Figure 1. In Figure 1, the numbers on the map correspond to the numbers in Table 5. Also, prefectures which belong to Tohoku (Hokkaido is also included), Kanto and Tozan, Hokuriku, Tokai, Kinki, Chugoku, Shikoku, and Kyusyu regions are marked with superscript A, B, C, D, E, F, G and H respectively.

Table 3. Ranking of technical efficiency : Best 10 and worst 10 prefectures (1965-1995)

	1965-70	Eff.	1971-75	Eff.	1976-80	Eff.	1981-85	Eff.	1986-90	Eff.	1991-95	Eff.
	Most technically efficient prefectures (SFA)											
1	Aichi[D]	0.978	Kagawa[G]	0.982	Gunma[B]	0.985	Gunma[B]	0.990	Miyazaki[H]	0.979	Aichi[D]	0.968
2	Gunma[B]	0.977	Miyagi[A]	0.973	Kanagawa[B]	0.964	Aichi[D]	0.988	Aichi[D]	0.959	Miyazaki[H]	0.955
3	Kanagawa[B]	0.976	Gunma[B]	0.970	Miyazaki[H]	0.962	Kanagawa[B]	0.970	Gunma[B]	0.864	Niigata[C]	0.853
4	Niigata[C]	0.975	Tokyo[B]	0.959	Aichi[D]	0.931	Miyazaki[H]	0.937	Kanagawa[B]	0.858	Ishikawa[C]	0.848
5	Yamagata[A]	0.975	Yamagata[A]	0.943	Tokushima[G]	0.822	Shizuoka[D]	0.908	Niigata[C]	0.851	Kanagawa[B]	0.808
6	Kagawa[G]	0.974	Aichi[D]	0.942	Shizuoka[D]	0.814	Toyama[C]	0.867	Ishikawa[C]	0.815	Tochigi[B]	0.803
7	Toyama[C]	0.969	Kanagawa[B]	0.939	Tochigi[B]	0.802	Ishikawa[C]	0.865	Tochigi[B]	0.801	Gunma[B]	0.801
8	Miyagi[A]	0.969	Hyogo[E]	0.932	Miyagi[A]	0.801	Kagawa[G]	0.856	Toyama[C]	0.793	Saga[H]	0.796
9	Gifu[D]	0.966	Shizuoka[D]	0.929	Kagawa[G]	0.793	Shiga[E]	0.844	Miyagi[A]	0.782	Shizuoka[D]	0.794
10	Shizuoka[D]	0.948	Yamanashi[B]	0.919	Yamagata[A]	0.787	Tokushima[G]	0.841	Kagawa[G]	0.781	Ehime[G]	0.791
	Least technically efficient prefectures (SFA)											
37	Yamaguchi[F]	0.786	Iwate[A]	0.737	Wakayama[E]	0.646	Tottori[F]	0.672	Wakayama[E]	0.625	Saitama[B]	0.629
38	Kumamoto[H]	0.778	Fukui[C]	0.730	Fukui[C]	0.642	Fukushima[A]	0.664	Aomori[A]	0.597	Oita[H]	0.609
39	Oita[H]	0.778	Fukushima[A]	0.716	Iwate[A]	0.636	Kyoto[E]	0.639	Tottori[F]	0.588	Iwate[A]	0.599
40	Miyazaki[H]	0.773	Kyoto[E]	0.697	Nagasaki[H]	0.600	Iwate[A]	0.630	Kagoshima[H]	0.582	Nagasaki[H]	0.595
41	Kochi[G]	0.769	Kagoshima[H]	0.696	Kyoto[E]	0.589	Nagasaki[H]	0.598	Oita[H]	0.575	Aomori[A]	0.590
42	Fukushima[A]	0.764	Mie[E]	0.687	Oita[H]	0.560	Oita[H]	0.596	Yamaguchi[F]	0.573	Tottori[F]	0.575
43	Shimane[F]	0.756	Shimane[F]	0.673	Hiroshima[F]	0.558	Hiroshima[F]	0.595	Kyoto[E]	0.570	Yamaguchi[F]	0.533
44	Iwate[A]	0.730	Shiga[E]	0.659	Yamaguchi[F]	0.553	Yamaguchi[F]	0.586	Nagasaki[H]	0.541	Kyoto[E]	0.519
45	Nagasaki[H]	0.707	Nagasaki[H]	0.642	Kagoshima[H]	0.544	Kagoshima[H]	0.568	Hiroshima[F]	0.529	Hiroshima[F]	0.502
46	Kagoshima[H]	0.648	Yamaguchi[F]	0.639	Shimane[F]	0.511	Shimane[F]	0.522	Shimane[F]	0.500	Shimane[F]	0.498
	Most technically efficient prefectures (DEA)											
1	Kagawa[G]	1.000	Miyagi[A]	1.000	Hokkaido[A]	1.000	Hokkaido[A]	1.000	Hokkaido[A]	1.000	Hokkaido[A]	1.000
2	Shizuoka[D]	0.997	Tokyo[B]	1.000	Miyagi[A]	1.000	Kanagawa[B]	1.000	Kanagawa[B]	1.000	Niigata[C]	1.000
3	Tokyo[B]	0.995	Shizuoka[D]	0.988	Tokyo[B]	1.000	Miyazaki[H]	0.990	Niigata[C]	1.000	Aichi[D]	1.000
4	Toyama[C]	0.994	Toyama[C]	0.986	Akita[A]	0.989	Gunma[B]	0.987	Aichi[D]	1.000	Miyazaki[H]	1.000
5	Niigata[C]	0.992	Hokkaido[A]	0.976	Kanagawa[B]	0.982	Toyama[C]	0.984	Miyazaki[H]	1.000	Tokyo[B]	0.981
6	Miyagi[A]	0.991	Kagawa[G]	0.969	Aichi[D]	0.980	Miyagi[A]	0.977	Shiga[E]	0.964	Kanagawa[B]	0.967
7	Yamagata[A]	0.988	Kanagawa[B]	0.965	Toyama[C]	0.977	Shizuoka[D]	0.972	Toyama[C]	0.949	Ishikawa[C]	0.966
8	Hokkaido[A]	0.987	Hyogo[E]	0.960	Shizuoka[D]	0.947	Niigata[C]	0.969	Ishikawa[C]	0.941	Shizuoka[D]	0.954
9	Kanagawa[B]	0.982	Yamagata[A]	0.953	Yamagata[A]	0.943	Aichi[D]	0.966	Tokyo[B]	0.941	Kochi[G]	0.948
10	Gunma[B]	0.972	Gunma[B]	0.939	Miyazaki[H]	0.939	Ishikawa[C]	0.963	Miyagi[A]	0.928	Tochigi[B]	0.923
	Least technically efficient prefectures (DEA)											
37	Shimane[F]	0.813	Hiroshima[F]	0.750	Tottori[F]	0.727	Wakayama[E]	0.704	Aomori[A]	0.704	Iwate[A]	0.683
38	Miyazaki[H]	0.803	Kumamoto[H]	0.746	Fukushima[A]	0.711	Fukushima[A]	0.702	Wakayama[E]	0.664	Nara[E]	0.680
39	Kochi[G]	0.797	Iwate[A]	0.740	Mie[E]	0.699	Tottori[F]	0.686	Nagasaki[H]	0.644	Kagoshima[H]	0.675
40	Oita[H]	0.794	Shiga[E]	0.739	Iwate[A]	0.697	Hiroshima[F]	0.635	Oita[H]	0.629	Saitama[B]	0.671
41	Fukushima[A]	0.780	Fukushima[A]	0.698	Hiroshima[F]	0.678	Yamaguchi[F]	0.633	Tottori[F]	0.618	Oita[H]	0.642
42	Iwate[A]	0.779	Mie[E]	0.690	Kyoto[E]	0.658	Shimane[F]	0.628	Kagoshima[H]	0.617	Tottori[F]	0.612
43	Yamaguchi[F]	0.776	Kagoshima[H]	0.676	Oita[H]	0.655	Oita[H]	0.626	Kyoto[E]	0.612	Kyoto[E]	0.570
44	Kumamoto[H]	0.776	Kyoto[E]	0.672	Shimane[F]	0.641	Nagasaki[H]	0.624	Yamaguchi[F]	0.607	Yamaguchi[F]	0.566
45	Nagasaki[H]	0.774	Yamaguchi[F]	0.644	Nagasaki[H]	0.631	Kyoto[E]	0.620	Hiroshima[F]	0.549	Shimane[F]	0.536
46	Kagoshima[H]	0.727	Nagasaki[H]	0.639	Kagoshima[H]	0.584	Kagoshima[H]	0.573	Shimane[F]	0.518	Hiroshima[F]	0.521

Note : 1) Eff. means the technical efficiency.
2) The numbers in the first column denote the ranking with respect to technical efficiencies.

From 1965 to 1970, 8 prefectures are found to be among the top 10 efficient prefectures, according to the technical efficiency ranking. They are Miyagi, Gunma, Kanagawa, Yamagata, Niigata, Toyama, Shizuoka and Kagawa. Also, in this period, the prefectures Iwate, Fukushima, Kochi, Shimane, Yamaguchi, Oita, Nagasaki, Kumamoto, Miyazaki and Kagoshima are considered the least technically efficient prefectures. From 1991 to 1995, the most efficient prefectures are Tochigi, Kanagawa, Ishikawa, Niigata,

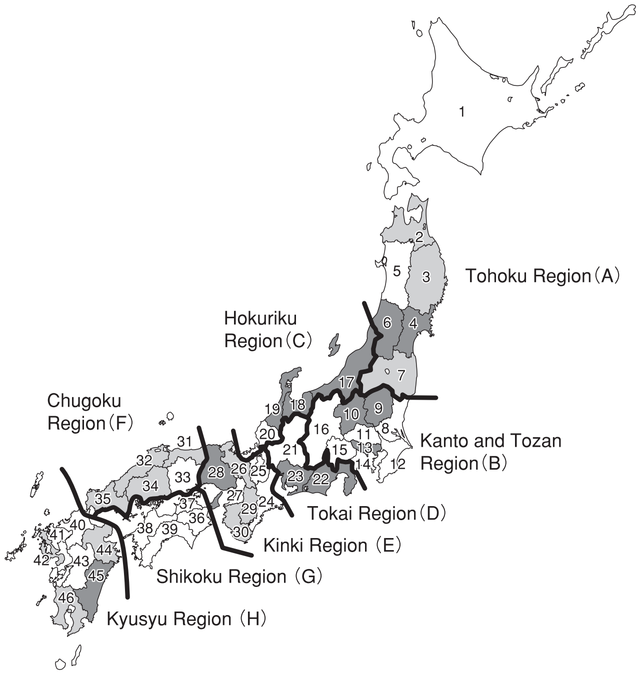

Figure 1. Most technical efficient and least technical efficient prefectures

Note : Numbers in the map are corresponding to the numbers, which are used in Table 5. The most technically efficient and least technically efficient prefectures are black-colored and gray-colored respectively.

Shizuoka, Aichi and Miyazaki. The least efficient prefectures are Iwate, Kyoto, Tottori, Shimane, Hiroshima Yamaguchi and Oita. For 30 years, the numbers of common prefectures of top and bottom 10 prefectures (in technical efficiencies calculated by both SFA and DEA methods) were between 6 and 10. Furthermore, the top and bottom 10 prefectures did not change so much over time. From these facts, the commonly appearing top and bottom 10 prefectures could be recognized as the most or least efficient prefectures.

Having said this, now let us see the characteristics of the most technically efficient prefectures. Yamagata, Miyagi, Niigata, Toyama, Ishikawa and Hyogo prefectures are well known as having large-scale rice based agriculture. Also, Gunma, Tochigi, Tokyo, Kanagawa, and Shizuoka and Aichi prefectures have large cities near them. For example, Gunma, Tochigi and Kanagawa have Tokyo and Yokohama. Further, Shizuoka is near to both Tokyo and Aichi (Nagoya) and has a fairly large city in itself. These technically efficient prefectures have farmers producing vegetables and fruits in the suburbs of these big cities, anticipating big consumption. As Schulz [17] says, closeness to big cities would have a benefit from getting information of changing demand structure, transportation, agricultural extensions such as research and development, farmers training service, infrastructure and others. These aspects enabled farmers near big cities to produce agricultural goods in more efficient and effective ways. Though Miyazaki is not near to any special big city, Miyazaki is listed in the top 10 technically efficient prefectures. Probably, this would come from the fact that Miyazaki is a warm and good prefecture for growing vegetables and fruits by using green houses.

Next, we will shift our attention to the worst 10 prefectures. The least technically efficient prefectures are Aomori, Iwate, Fukushima, Kyoto, Nara, Wakayama, Tottori, Shimane, Hiroshima, Yamaguchi, Nagasaki, Oita and Kagoshima. Aomori, Iwate, and Fukushima belong to the Tohoku region.

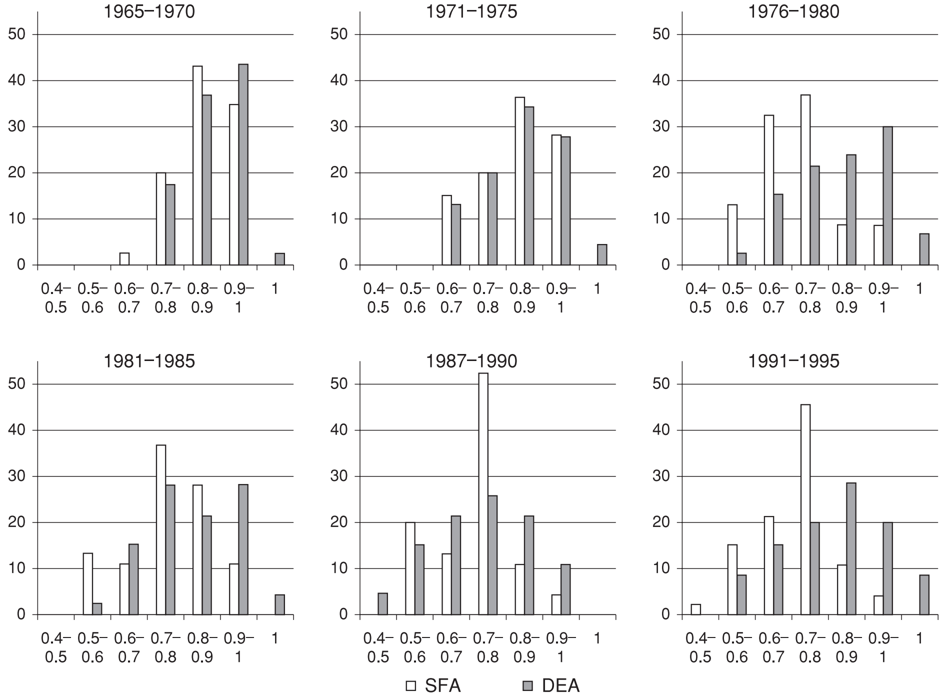

Figure 2. The frequency of technical efficiencies

Note : The category $n-(n+0.1)$ means $n \leq$ Technical Efficiency $\leq n+0.1$.

Especially, Aomori and Iwate face to the Pacific Ocean, and they often have damage from cold weather. When the cold wind called "Yamase" blows from the Pacific Ocean in summer, the harvest of crops decreases in fall. This prevents farmers of these prefectures from obtaining the maximum amount of products for a certain amount of inputs. Kyoto, Nara, and Wakayama are in the Kinki region. Tottori, Shimane, Hiroshima and Yamaguchi are in the Chugoku region and Nagasaki, Oita and Kagoshima are in the Kyusyu region. The common characteristic among these prefectures is that they are mountainous prefectures. Fukushima is also mountainous prefecture. Owing to these facts, farming in these prefectures is operated in very small scale.

As we discussed above, the scale of farming of post-war Japan did not become bigger but the part-time farmers increased in 30 years, although the agricultural Basic Law in 1961 aimed to make the large scale of farming. When a farmer became a part-time farmer, the main workers of agriculture were women and old people. Also, many part-time farmers are engaged in their farming only on weekends, because they usually work in off-farm jobs. Therefore, the part-time farmer introduced machines in order to compensate for the labor. All farmers did not need their own machines for their production. However, part-time farmers need machines at the same period, for example on weekends. Therefore, they cannot share the machines. Consequently, they purchased too many machines to produce a certain amount of agricultural products. This caused the farmers of those prefectures to work in a less technically efficient way.

In mountainous prefectures, there are not enough people and land for the industrial sector to build its offices and factories. Therefore, young people usually move to other prefectures where non-agricultural industries are prevailing, rather than work as a part-time farmer. Consequently, old people became the main agricultural workers in mountainous prefectures. Therefore, the farmers of those mountainous prefectures suffered from small

Table 4. Malmquist productivity change index

	Malmquist productivity change	Technical efficiency change	Technical change
1965-70	1.019	0.986	1.033
1971-75	1.076	0.995	1.082
1976-80	1.011	0.990	1.022
1981-85	1.021	1.006	1.015
1986-90	1.005	0.989	1.016
1991-95	1.016	1.011	1.005
1965-95	1.024	0.996	1.029

land, out-migration of young people and other related characteristics. Because of these factors, farmers cannot buy too many machines which are very different from other ordinary farmers who have over-invested on agricultural machines. All these reasons discussed above led those prefectures to be less technically efficient. When we consider the reason why those prefectures were less technically efficient from the natural environmental aspect, we might say this as follows. Although the insect damage of Kyusyu may be more severe, Nara also might suffer from insect damage since it is an inland prefecture. Shimane and Tottori would have been damaged by wind blown from the Sea of Japan although wind damage in Hokkaido may be more severe. In Kagoshima, the lack of daylight caused by volcanic ash might prevent the crops from growing. These factors would prevent the farmers of these prefectures from achieving technically efficient production.

2) Frequencies of technical efficiencies

Here, we discuss the frequencies of technical efficiency of Japanese agriculture. As shown in Figure 2, the results which are obtained by both SFA and DEA methods are very similar. In other words, the results are enough to be supported strongly, because quite similar results were obtained by two different methods. Since the concentrated part of the distribution of the technical efficiencies moved from right to left (i. e., from large to small), we could say that the share of farmers who produces their agricultural goods in the area of frontier decreased. In short, the farmers could not do their best, in the meaning of not wasting the resources for their production over time, and most of the farmers have redundancy in inputs.

This must come from the prevailing pattern of part-time farming in Japan. Part-time farming affected the purchase of machines and also changed the farmers' attitude. In Japan, the numbers of part-time farmers, who engage mainly in off-farm activities, have been increasing as compared with the part-time farmers who engage mainly in farming rather than other jobs. When the income obtained from other job exceeds the income obtained from agricultural activities, it is easy for part-time farmers to undervalue the income earned from agricultural activities. Then, they may not make maximum effort for their farm management. From this reason, we guess that the technical efficiency has diverged rather than converged in 30 years.

3) Technical change and technical efficiency change

From Table 4, we can say that Japanese agricultural total factor productivity (TFP) increased by about 2% from 1965 to 1995. Also, TFP decreased in the period 1976-1990. Moreover, the total factor productivity growth has been mainly driven by technical changes. These facts are consistent with Kuroda's findings [12][13]. Almost all efficiency changes are lower than unity. However, almost all technical changes are higher than unity. This is consistent with the result of Nishimizu and Page [14] which shows that technical change and efficiency have negative correlation. Also, we could say that the productivity increase of Japanese agriculture was driven mainly by technical change rather than efficiency change. Figure 3 shows the cumulative Malmquist TFP index, the cumulative technical change index and the cumula-

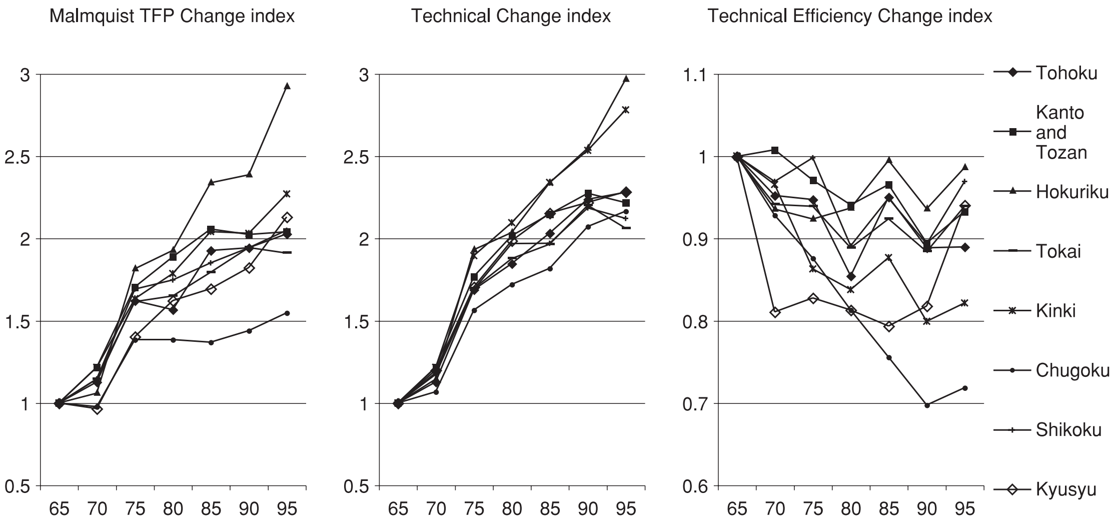

Figure 3. Cumulative Malmquist TFP, technical change and technical efficiency change indexes

tive technical efficiency change index (from 1965 to 1995). First, we can say that the Hokuriku region[7)] has the highest cumulative growth from 1965 to 1995. The Kinki, Tokai, Kanto and Tozan, Shikoku, Tohoku, Tokai and Chugoku regions follow it.

From this result, we can divide the whole 8 regions into 3 groups, namely the group of high productivity, the group of medium productivity, and the group of low productivity. The region which belonged to the group of high productivity was only the Hokuriku region. On the other hand, 6 regions, namely Kinki, Tokai, Kanto and Tozan, Shikoku and Tohoku region belonged to the group of medium productivity. Chugoku was the only region which was in the group of low productivity. What made these prefectures belong to the different groups? In order to answer this question, we must see these two figures.

With respect to the technical change, Hokuriku and Kinki regions were found to have obtained the highest cumulative technical change. The other regions had almost same level in cumulative technical change in 1995. Note that their technology levels were not the same, but they had almost the same growth rates. With respect to the cumulative technical efficiency change, Hokuriku and Shikoku have the highest cumulative technical efficiency change, and next Tokai, Kanto and Tozan take the same cumulative technical efficiency changes. They are higher than those of Tohoku, Kinki and Chugoku regions. Chugoku region had the lowest cumulative technical efficiency change. As a whole, all the regions in 1995 have lower cumulative technical efficiency changes than unity. Therefore, it could be said that technical efficiencies of all regions in 1995 were lower than those of 1965. In other words, the technical efficiency level decreased from 1965 to 1995.

4) Innovative prefectures and technically efficient prefectures

Here, we will discuss the relationships between innovative prefectures and technically efficient prefectures, based on Table 5. Decomposition of the productivity change allows us to identify the innovators who actually cause the grand frontier (or the best-practice frontier) to shift. Following the method of Fare et al. [8], we can employ the following conditions to identify the innovators under two alternative benchmark assumptions.

Technical Efficiency of t-th period

$$= D_o^{t+1}(x^{t+1}, y^{t+1})/D_o^t(x^t, y^t) > 1 \tag{14}$$

$$D_o^t(x^{t+1}, y^{t+1}) > 1 \tag{15}$$

$$D_o^{t+1}(x^{t+1}, y^{t+1}) = 1 \tag{16}$$

Prefectures which satisfy the three conditions outlined above are regarded as the ones which contributed to shift the frontier from t-th to $t+1$-th period. Table 5 shows the prefectures which satisfy this condition under

Table 5. Prefectures shifting the grand frontier : 1965-95

	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
1 Hokkaido[A]		*	*		*		*	*	*	*		*	*				*		*	*	*		*	*			*		*	
2 Aomori[A]	*																													
3 Iwate[A]																														
4 Miyagi[A]				*	*	*	*	*	*	*			*						*	*										
5 Akita[A]		*										*					*				*									
6 Yamagata[A]	*				*				*	*		*																		
7 Fukushima[A]																														
8 Ibaraki[B]																														
9 Tochigi[B]																														
10 Gunma[B]	*						*	*					*				*	*												
11 Saitama[B]																														
12 Chiba[B]																														
13 Tokyo[B]	*	*	*	*	*	*		*	*		*															*	*	*		
14 Kanagawa[B]		*	*	*				*	*	*			*	*	*	*				*				*	*					*
15 Yamanashi[B]	*	*					*	*										*	*	*										
16 Nagano[B]																														
17 Niigata[C]	*	*	*		*												*			*	*		*	*	*		*		*	
18 Toyama[C]			*							*		*	*								*									
19 Ishikawa[C]																											*		*	*
20 Fukui[C]																														
21 Gifu[D]	*																													
22 Shizuoka[D]			*	*		*	*		*	*																				
23 Aichi[D]		*	*							*			*	*	*									*	*		*			*
24 Mie[E]																														
25 Shiga[E]																			*	*	*									
26 Kyoto[E]																														
27 Osaka[E]																														
28 Hyogo[E]		*				*																								
29 Nara[E]																														
30 Wakayama[E]		*			*	*																								
31 Tottori[F]																														
32 Shimane[F]																														
33 Okayama[F]																														
34 Hiroshima[F]																														
35 Yamaguchi[F]																														
36 Tokushima[G]																														
37 Kagawa[G]	*	*	*	*			*		*	*																				
38 Ehime[G]																														*
39 Kochi[G]																														
40 Fukuoka[H]																														
41 Saga[H]																														
42 Nagasaki[H]																														
43 Kumamoto[H]																														
44 Oita[H]																														
45 Miyazaki[H]															*		*			*	*	*		*	*		*		*	*
46 Kagoshima[H]																														

Note : Numbers in the table are corresponding to the numbers in Figure 1.

constant returns to scale. In other words, Table 5 shows the prefectures which were innovative in each year (i. e., the prefectures which shift the Japanese grand frontier) from 1965 to 1970. The asterisk marks (*) indicate the prefectures which were innovative in each year. From 1965 to 1970, Hokkaido, Aomori, Miyagi, Akita, Gunma, Tokyo, Kanagawa, Niigata, Toyama, Yamanashi, Gifu, Shizuoka, Aichi, Hyogo, Wakayama, and Kagawa shifted the Japanese grand frontier. That is, from 1965 to 1970, they were innovative prefectures in Japan. From 1971 to 1975, Hokkaido, Miyagi, Yamagata, Gunma, Tokyo, Kanagawa, Niigata, Toyama, Yamanashi, Shizuoka, Aichi, Hyogo, Wakayama, Kagawa were innovative.[8] Finally, from 1991 to 1995, Hokkaido, Tokyo, Kanagawa, Niigata, Ishikawa, Shizuoka, Ehime and Miyazaki shifted the Japanese grand frontier. As a whole, we can say that mainly the prefectures of Hokkaido, Niigata, Tokyo, Kanagawa and Shizuoka shifted the Japanese grand frontier.

When we compare these results with the ranking of technical efficiency shown in Table 3, we can say as follows. From 1965 to 1970 and from 1971 to 1975, the 10 most technically efficient prefectures were also innovative prefectures. From 1976 to 1980 9 out of 10, from 1981 to 1985 6 out of 10, from 1986 to 1990 and from 1991 to 1995 7 out of the 10 most technically efficient prefectures were innovative prefectures respectively.

Overall, Tokyo, Kanagawa, Niigata, Toyama, Ishikawa, Aichi and Miyazaki, which were technically efficient prefectures from 1965 to 1995, were also marked with asterisk. From these evidences we could infer that technically efficient prefectures were also innovative prefectures. As we discussed above, some technically efficient prefectures had an advantage in economies of scale. Also, other technically efficient prefectures had an advantage in information gathering which was due to their closeness to big cities. Therefore, farmers in these prefectures were superior in managerial skills. As a result, investment to technology of these prefectures was bigger than that in other prefectures. In addition, farm-household's interest in technical efficiencies was also bigger than for other prefectures.

Furthermore, Miyagi, Akita, and Yamagata were considered as the innovative prefectures from 1965 to 1985, since Miyagi, Akita and Yamagata were marked with asterisk from 1965 to 1985. However, they were not found innovative since 1986. This might be the effect of "the decreasing paddy field policy", which was implemented from 1986. As everybody knows, this policy made eligible-farmers lose their opportunities to expand their scale of farm, and they lost their inclination to do better management. On the other hand, part-time farmers who had small lands found their agricultural practice became much easier. Those consequences were not the aim of the government policy. However, our estimated results indicate that rice farmers in Miyagi, Akita and Yamagata Prefectures too might lose their ability to innovate new technology if the government continues these policies.

4. Conclusion

We can summarize the characteristics of the best 10 technically efficient prefectures as follows.

(1) Miyagi and Yamagata Prefectures, which are located in the Tohoku region, and Niigata, Toyama and Ishikawa Prefectures, which are located in the Hokuriku region, have relatively large-scale farming.

(2) Tokyo, Kanagawa, Gunma, Tochigi, Shizuoka, Aichi and Hyogo Prefectures, which are located near big cities, benefits from the close proximity to big cities and they mainly raise vegetables for urban citizens.

(3) Miyazaki Prefecture, which is located in a warm region of Kyusyu, raises vegetables in the early part of each season.

We can also summarize the characteristics of the worst 10 technically efficient prefectures as follows.

(1) Aomori, Iwate and Fukushima Prefectures, which are located in the Tohoku region, have a climate which is not so conducive for raising crops and they often suffer from the cold temperature.

(2) Small farming is very much prevalent in Kyoto, Nara and Wakayama Prefectures, where arable land size is very small although they are near or not so far from big cities.

(3) Tottori, Shimane, Hiroshima and Yama-

guchi Prefectures are located in mountainous and less populated areas of Chugoku region.

(4) Oita, Nagasaki and Kagoshima Prefectures are located in mountainous and volcanic ash land.

So far, the Japanese government has been making considerable efforts in research and development for technical change. As a result, technical change contributed a lot to Japanese agriculture. Therefore, Japanese agriculture was superior to the other countries' agriculture in relation to the quality of fertilizer and technology usage. However, as Rao and Coelli [16] mentioned, Japanese agriculture's technical efficiency was inferior to other countries'. Also, our study showed that the technical efficiency of Japanese agriculture declined, although technical change contributed a lot to increase the output. We could suggest that Japanese farmers, agricultural cooperatives, agricultural commission and government should change this idea of promoting technical change to improving the technical efficiency. The government made many efforts to increase the productivity of agriculture since 1960. Therefore, the productivity grew very much, as our study indicated. However, this productivity growth was supported by technical change only. Therefore, what should we do in order to raise the technical efficiency of Japanese agriculture?

First, we inferred that the decline of technical efficiency came from the increase of part-time farming and out-migration of young people from rural village for searching jobs. In order to shorten the time of farmwork, a farm-household bought its own machinery. In order to improve this circumstance, Japanese farmers, agricultural cooperatives, agricultural commissions and government should try to make an organization to gather farmers into a group, in which they can share machines. They have been doing it, but further efforts are necessary to mitigate this problem and improve conditions conducive for efficient farming.

Second, in spite of the declining trend of technical efficiency, some prefectures became technically efficient prefectures while others became technically inefficient ones. For prefectures which have some big cities or are near to big cities, many farmers usually produce labor-intensive vegetables which have very high land productivity. Tokyo, Kanagawa and Aichi are typical examples of this category. On the other hand, Kyoto and Saitama have the lowest technical efficiency. We should try to make efforts to increase the efficiency of these low efficient prefectures. It is true that the policies which were adopted in order to protect farmers failed in raising the productivity of farmers. However, they were, in a sense, necessary for both raising the self-sufficiency of Japanese food and the environmental preservation. Japanese decoupling system is a typical example of this type but further efforts are necessary for Japanese agriculture to be more efficient.

In order to study this problem more carefully, we emphasize that the following studies should be done in the future. First, we used aggregate gross output data in this study. However, the way of production and the management pattern would be different among the rice, vegetable and fruit productions. Therefore, we can use specific field data in order to analyze the differences of productivity growth and technical change in each field. Second, we can divide the total farm-households into several classes by scale of land. Kuroda [12] and Hu [9] estimated the total factor productivity of Japanese agriculture by dividing the total farm-households through their land-scale. They found that there was a difference among classes. In our future study, we will try to capture the difference of productivity growth, technical change and technical efficiency change between large-scale and small-scale farm-households.

1) The stochastic frontier analysis (SFA) is a parametric method (i. e., we assign an assump tion on the distribution of technical inefficiencies) but DEA uses a nonparametric method. Owing to this fact, the estimation of technical inefficiencies by SFA is less sensitive to the measurement error than that of DEA. However, it is also true that assigning assumptions in the stochastic frontier analysis is strict. Therefore, each method has both advantages and disadvantages. Hence, we want to complement the disadvantages of each method by using both methods. These two concepts are, in a sense, near to the concept of X-efficiency which measures by the distance between the cost mini-

mization point and the real value point in monopoly and oligopoly markets.

2) Kuroda used a translog type production function by using the dual approach of cost function and cost share type. In this paper, we estimated only the production function. Owing to the multi-collineality problem, estimating the translog production function is very difficult for obtaining a good result. In this kind of analysis, many studies use the Cobb-Douglas production function. Therefore, we follow them and used the Cobb-Douglas production function.

3) In some previous studies (e.g., Kondo and Yamamoto [19]), they used the input-orientation method for getting the Malmquist TFP index. However, as constant return to scale is assumed in our analysis, output-orientation and input-orientation methods are the same. Therefore, we used the output-orientation method in this paper.

4) Owing to the data restriction, we use only fertilizer as a current input. Although we may have a slight bias by this restriction, it will be negligible.

5) This computer program software can be obtained from the web-page : 〈http ://www.uq.edu.au/economics/cepa/Center〉 offered by The Center for Efficiency and Productivity Analysis in the School of Economics at the University of Queensland, Australia.

6) This computer program software also can be obtained from the web-page : 〈http ://www.uq.edu.au/economics/cepa/Center〉 offered by The Center for Efficiency and Productivity Analysis in the School of Economics at the University of Queensland

7) The value of each region is obtained from calculating the geometric mean of all prefectures in each region.

8) From 1976 to 1980, Hokkaido, Miyagi, Akita, Yamagata, Gunma, Tokyo, Kanagawa, Toyama, Aichi and Miyazaki were innovative prefectures in Japan. From 1981 to 1985, Hokkaido, Miyagi, Akita, Gunma, Kanagawa, Niigata, Yamanashi, Shiga, Miyazaki shifted the Japanese grand frontier. From 1986 to 1990, Hokkaido, Akita, Kanagawa, Niigata, Toyama, Shizuoka, Shiga and Miyazaki were innovative in Japanese agriculture.

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