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Inefficiency in Rice Production and Land Use: A panel study of Japanese rice farmers (Revised)

OGAWA Kazuo
Kansai Gaidai University

Research Institute of Economy, Trade & Industry, IAA
The Research Institute of Economy, Trade and Industry
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Inefficiency in Rice Production and Land Use: A panel study of Japanese rice farmers*

OGAWA Kazuo
College of Foreign Studies
Kansai Gaidai University

Abstract

In this study, an empirical analysis was conducted on the behavior of Japanese rice producers from the standpoint of efficiency in production by using the panel data of the *Rice Production Cost Statistics* by the Ministry of Agriculture, Forestry and Fisheries. The stochastic frontier production function, which comprises four production factors (land, labor, capital stock, and materials), was estimated and the inefficiency indices of production were calculated. Based on this information, the efficient and inefficient rice producers were identified, and the factor demand behavior and characteristics of the land use for rice production were compared. It was found that production-inefficient rice producers did not make any adjustments in employment in the short or long run, even if there was a change in the wages. The certified farmers, who are supposed to play a leading role in enhancing efficiency of agricultural operations, tend to lower the land utilization rate of rice production; moreover, the more production-efficient the certified farmers are, the larger the effects of such activities, which is the opposite of what was intended by policymakers.

JEL Classification Number: Q12, Q15, Q18
Keywords: stochastic frontier production function, productivity, factor demand, land use, rice production adjustment

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1. Introduction

Japan's consumption for rice is decreasing as a secular trend. The annual per capita consumption of rice peaked in 1962, and has exhibited a consistent tendency to decline since that time. Japanese consumed 118 kg per capita on an average in 1962, but this figure had decreased to only 55 kg per capita as of 2014. In addition, domestic consumption exhibited a tendency to decrease. Figure 1 shows the production of and consumption for rice as a staple food from 2004 to 2014. Almost every year, production exceeded consumption, and excess supply has continued.

Given chronic oversupply of rice, the Japanese government has been promoting a shift of crops from production of the staple food, rice, to soybeans and grains, and in addition, a change of crops to the so-called "new demand rice," which is mainly rice used as animal feed. The "Basic Plan on Food, Agriculture and Rural Areas" issued in 2015 also called for the provision of the support required for achieving an expansion of the production of rice for animal feed and other such uses.[1]

However, even with the shift from rice as a staple food to other crops, if the farmers in charge of producing rice as a staple food are inefficient producers, it would be costlier to produce rice. In fact, it is evident that, from an international perspective, the operation scale of rice cultivation in Japan is small, and its productivity is low. Figure 2 compares the harvests for rice paddy per 10 a (unit of area, 100a = 1ha) in three countries, Australia, the United States, and Japan. In 1980, the harvests of Australia and the United States were approximately 500 kg per 10 a, while that of Japan was 412 kg per 10 a; but in 2014, the figures were 1,092 kg and 849 kg per 10 a for Australia and the United States, respectively, whereas the harvest for Japan was only 536 kg per 10 a. For rigorous evaluation about the switching policy from rice as a staple food to other crops, it is important to fully grasp the behavioral characteristics of rice producers from the viewpoint of efficiency.

The purpose of this study is to use the panel data from the Rice Production Cost Statistics by the Ministry of Agriculture, Forestry and Fisheries and undertake an empirical analysis of the efficiency in production by the rice-producing farm households. Specifically, the stochastic frontier production function, which comprises four production factors (land, labor, capital stock, and materials), is estimated, and the inefficiency indices

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[1] For example, there are direct subsidies paid to farmers for utilization of paddy fields for producing crops such as grains, soybeans, rice for feed, rice for rice flour, etc.

of production are calculated. Based on the information, the efficient and inefficient rice producers are identified, and the factor demand behavior is compared.[2]

Moreover, from the standpoint of exploitation of agricultural land, a comparative analysis of efficient and inefficient rice producers is conducted concerning the factors that determine the land utilization rate of rice. The land utilization rate of rice production is defined as the proportion of the planted area (*sakuzuke menseki*) of rice to the operated area (*keiei menseki*) for rice.[3] Land utilization for rice production has depended heavily on rice production adjustment (*seisan chosei*) policies.[4] Our analysis can clarify the differences in the responses to such policies by the efficient and inefficient producers. In addition, our analysis can provide quantitatively useful information for formulating policies to achieve efficient arable land utilization.

Now we preview our main findings. First, the inefficiency indices of production were measured from the stochastic frontier production function, and it was found that the estimated inefficiency was robust, irrespective of the type of production function or the probability distribution of the assumed inefficiency.

Based on the median of the measured inefficiency indices, the producers were divided into efficient and inefficient rice producer groups, and we found that the inefficient rice producers had the following characteristics:

1) The number of parcels (a ‘parcel’ refers to a gathering or complex consisting of several neighboring plots) is large
2) The income per 10 a is low, and the loan outstanding per 10 a is large
3) The land and labor productivity are low
4) Majority of the farmers own farms with small plots (*kukaku*), and few farmers own farms with relatively large-scale plots

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[2] The stochastic frontier production function, which models the production function by taking into consideration that producers deviate from the production frontier is an econometric model that was independently developed by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977).

[3] Note that fields and pasture are not included in defining the land utilization rate of rice production.

[4] The purpose of production adjustment policy of rice is to prevent the fall of rice price and secure income for rice farmers when the rice consumption has decreased relative to rice production. The policy measure was initially an allocation of set-aside area to each prefecture, but it was switched in 2004 to an allocation of production target quotas of rice to each prefecture. This production adjustment policy was abolished in 2018.

5) Land utilization rate of rice production is low.

In addition, a comparison between the behavior of inefficient and efficient rice producers with respect to the dynamic factor demand revealed that the inefficient rice producers do not respond to a change in wages.

Finally, an analysis was conducted on the determinants of the planted area for rice production. It was found that the higher the proportion of small plots, the more likely that the producer would reduce land utilization rate of planting rice; and these effects were larger for the efficient producer. In addition, it was observed that certified farmers reduced the land utilization rate of rice production, and the extent of this reduction was larger for efficient producers. That is, the more efficient a certified farmer was, the more likely it was that the operated area of rice was left fallow. If this situation continues, the productivity of rice production may decline further in the future. Therefore, it is necessary to design an agricultural system that has incentives for efficient rice producers to expand rice planting.

This study is organized as follows. The next section describes the data set used for the analysis. In section 3, a model for estimating the inefficiency of production is formulated, and the estimated results thereof are indicated. In section 4, the characteristics of the efficient and inefficient producers, based on the efficiency indices, are compared. In section 5, the dynamic and static factor demand function is estimated, and the differences in factor demand behavior between the efficient and the inefficient rice producers is examined. Section 6 shows the results of an econometric analysis of the determinants of land utilization of rice production. Section 7 concludes this study.

2. Data Set and their Characteristics

The data employed in the analysis is the panel data of 2008 to 2013 from the Rice Production Cost Statistics (*Kome Seisanhi Chosa Tokei*) by the Ministry of Agriculture, Forestry and Fisheries. The sample farmers are farm households that sold at least 600 kg of unpolished rice (*genmai*), from the total agricultural management entities (*nogyo keiei tai*) based on the 2010 World Agricultural and Forestry Census. The total number of observations from the panel data used is 5,542. There are 1,950 unique farmers in the panel data set. There are 320 farmers that stay only for one year, 752 farmers that stay for two years, 321 farmers that stay for three years, 326 farmers that stay for four years, 25 farmers that stay for five years and 206 farmers that stay for the whole 6 years in the panel.[5] Our data set is an unbalanced panel data. Now an explanation is in order on the procedure of data construction.

The output (Y) is the quantity of rice produced as the staple product (*syu sanbutsu*) for sale and home use. The labor input (N) is the working time spent on rice production, and it includes both family labor and hired labor used for rice production. The land (L) is the planted area of rice. The capital stock (K) is calculated by deflating the nominal capital stock of four types by the corresponding price indices, and by summing up them. We use the deflators in the *Agricultural Price Index* reported by the Ministry of Agriculture, Forestry and Fisheries. The materials (M) were calculated by dividing the expenditure on five types of materials by the corresponding deflators in the Agricultural Price Index and summing up them.

The prices corresponding to the output and four production factors were prepared as follows. The output price (p) was calculated by dividing the sales of the rice produced as the staple product for sales and home use by the quantity. The wage rate (w) was calculated by dividing the family labor cost and the hired labor cost by total working hours of family labor and hired labor. The rental price of capital (p_K) was calculated by dividing the nominal rentals and depreciation allowances for agricultural machinery by the real capital stock obtained above. The materials price (p_M) was calculated by dividing the nominal expenditure on materials by the real amount.

Table 1 shows the descriptive statistics of the rice production, the four production factor inputs, productivity, land utilization rate of rice production and plots area distribution. The means of rice production, land, capital stock, and materials input were all twice the medians, and exhibited a right-skewed distribution. The means and medians of land productivity and labor productivity were roughly the same, although the mean of capital productivity greatly exceeded the median. The land utilization rate of rice production is about 75%, and the remaining portion is used either for switching to other crops or is left fallow. With regard to the plots area distribution, plots from 10 a to 30 a account for 54% on average. In addition, the median is zero for the plots more than 30 a, and these plots are owned by some large-scale rice farmers.

3. Identification and Estimation of Inefficiency in Production

We estimated the stochastic frontier production function, which comprises four production factors (land, labor, capital stock, and materials), and calculated inefficiency indices of production for individual rice producer. The index of inefficiency was

[5] Appendix table A-1 shows the number of observations of rice producers by prefecture.

calculated under two production functions, the Cobb-Douglas production function and translog production function and the two distribution functions, truncated normal and half-normal for the probability density functions of inefficiency.[6]

The stochastic frontier production function is specified as

$$\ln Y_{it} = f(lnN_{it}, lnK_{it}, lnL_{it}, lnM_{it}) - u_i + v_{it} \quad (1)$$

where Y_{it} : output in year t

N_{it} : labor input in year t

K_{it} : capital stock in year t

L_{it} : planted area for rice in year t

M_{it} : material input in year t

u_i : random variable representing inefficiency, $u_i \geq 0$

v_{it}: disturbance term

i is an index of rice producer

When the production function is the Cobb-Douglas type, it is written as

$$f(lnN_{it}, lnK_{it}, lnL_{it}, lnM_{it}) = \alpha_N lnN_{it} + \alpha_K lnK_{it} + \alpha_L lnL_{it} + \alpha_M lnM_{it} \quad (2)$$

When the production function is the translog type, it is written as

$$\begin{aligned} f(lnN_{it}, lnK_{it}, lnL_{it}, lnM_{it}) &= \alpha_N lnN_{it} + \alpha_K lnK_{it} + \alpha_L lnL_{it} + \alpha_M lnM_{it} \\ &+\alpha_{NN}(lnN_{it})^2 + \alpha_{NK}(lnN_{it})(lnK_{it}) + \alpha_{NL}(lnN_{it})(lnL_{it}) + \alpha_{NM}(lnN_{it})(lnM_{it}) \\ &+\alpha_{KK}(lnK_{it})^2 + \alpha_{KL}(lnK_{it})(lnL_{it}) + \alpha_{KM}(lnK_{it})(lnM_{it}) \\ &+\alpha_{LL}(lnL_{it})^2 + \alpha_{LM}(lnL_{it})(lnM_{it}) + \alpha_{MM}(lnM_{it})^2 \quad (3) \end{aligned}$$

When u_i is distributed as truncated normal, the density function is written as

$$\mathrm{h}(u_i) = \frac{exp\left\{-\frac{1}{2}(u_i-\mu)^2/\sigma_u^2\right\}}{\sqrt{2\pi}\sigma_u\left[1-\Phi\left({}^{-\mu}/_{\sigma_u}\right)\right]} \quad u_i \geq 0 \quad (4)$$

where $\Phi(\quad)$: cumulative standard normal density function

[6] Pitt and Lee (1981) is an empirical study of the stochastic frontier production function that assumes a half-normal distribution for the probability distribution of inefficiency. Battess and Coeli (1988) generalized the probability distribution function for inefficiency to a truncated normal distribution and estimated the stochastic frontier production function.

When u_i is distributed as half-normal, $\mu = 0$ in eq.(4). We assume that the disturbance term (v_{it}) is i.i.d. normal as $N(0, \sigma_v^2)$.

We also estimate the within estimator model that treats the u_i as fixed.[7] In estimation, the year dummies and regional dummies that classify Japan's 47 prefectures into 10 regions (Hokkaido, Tohoku, south Kanto, north Kanto and Koshin, Hokuriku, Tokai, Kinki, Chugoku, Shikoku, and Kyushu) were added to the explanatory variables.[8] Table 2 shows the results of the stochastic frontier production function estimated by the maximum likelihood method and the fixed model.[9] First, let us examine the estimation results when half-normal is assumed in the probability distribution of inefficiency. Significantly positive values are obtained for all of the coefficient estimates of the Cobb-Douglas production function (column 1 of Table 2). The elasticity of labor, capital stock, land, and materials is 0.0143, 0.0048, 0.9400, and 0.0563, respectively.[10] The total elasticity is 1.0154, which indicates increasing returns to scale.[11, 12] On the other hand, the estimation results of the translog production function are not entirely satisfactory since many of the coefficient estimates are not significant due to multicollinearity (column 2 of Table 2).

Next, we examine the estimation results when truncated normal is assumed for the probability distribution of inefficiency. All of the coefficient estimates of the Cobb-Douglas production function are significantly positive, and the elasticity of labor, capital

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[7] See Schmidt and Sickles (1984) for the fixed-effect model of inefficiency.

[8] When the model with dummy variables corresponding to the individual prefectures was estimated, convergence was not attained. Therefore, we use the regional dummies instead.

[9] Unobservable soil quality or shocks of pest insect might affect the production of rice as well as the quantity of factor inputs, which leads to endogeneity problem in estimating production function or factor demand function. Considering endogeneity in estimating the stochastic frontier production function is an important agenda for the future research.

[10] The obtained elasticity estimates are close to the values in Saito et al. (2010), which estimated the Cobb-Douglas production function with the microdata of the Agriculture and Forestry Census. The estimated elasticities of labor, capital stock, and land obtained by them are 0.0523–0.0678, 0.0214–0.0291, and 0.9571–1.0556, respectively. In their estimation, the amount of materials input has not been controlled as an explanatory variable.

[11] When the null hypothesis of constant returns to scale was tested by a Wald statistics, it was rejected at the 1% level.

[12] Kako (1979), Hayami and Kawagoe (1989), and Saito et al. (2010) have reported that increased returns to scale are prevalent in Japan's rice production.

stock, land, and materials is 0.0142, 0.0048, 0.9401, and 0.0563, respectively. These estimates are roughly the same as those obtained when half-normal was assumed for the probability distribution of inefficiency (column 3 of Table 2). In addition, the total elasticity is 1.0154, and it indicates increasing returns to scale. The estimate of the inefficiency parameter μ of truncated normal distribution is 0.0190, but it is not statistically significant, and no major difference is observed between the estimation results when truncated normal is assumed for the probability distribution of inefficiency and the estimation results when half-normal is assumed. As for the estimation results of the translog production function, many of the coefficient estimates are not significant due to multicollinearity (column 4 of Table 2).

Now we show the estimation results of the within estimator model. The coefficient estimates of the Cobb-Douglas production function are significantly positive except for capital stock. The elasticity of labor, land, and materials is 0.0360, 0.9281 and 0.0490, respectively, but the elasticity of capital is negative, although it is not significant. (column 5 of Table 2). As for the estimation results of the translog production function, many of the coefficient estimates are not significant due to multicollinearity (column 6 of Table 2).

We can measure the index of inefficiency with the method of Jondrow et al. (1982) for individual rice producers based on the coefficient estimates of the production function as:

$$\mathrm{E}[u_i \mid \varepsilon_{it}] \quad \text{where } \varepsilon_{it} \equiv v_{it} - u_i \tag{5}$$

When the estimation is conducted by combining the two production functions and the three assumptions related to the probability distribution of inefficiency, six inefficiency indices are calculated. Table 3 shows the descriptive statistics of inefficiency indices that are calculated from the respective coefficient estimates of the Cobb-Douglas production function and translog production function. Given the probability distribution of efficiency, the means, medians, and standard deviations of the two inefficiency indices calculated under the different specifications of production functions are roughly the same magnitude. In addition, the correlation coefficient as well as the Spearman rank correlation coefficient of the two inefficiency indices is above 0.99 for all cases.[13]

[13] The p-value of the null hypothesis that the correlation coefficient is zero is 0.00 for all cases.

We also calculate the correlation coefficient of the inefficiency indices across three different stochastic structures of the inefficiencies when the production function is specified as the Cobb-Douglas type. The correlation coefficients as well as the Spearman rank correlation coefficients are shown in Table 4. The correlation coefficients exceed 0.7 for all pairs of inefficiencies, irrespective of the type of the correlation coefficients. We find that the inefficiency indices are also robust with respect to the stochastic structure underlying the inefficiencies.

In the above-mentioned model, it was assumed that the inefficiency of individual producers is time-invariant. Battess and Coeli (1992) relaxed this assumption and conducted estimation based on the alternative specification of the inefficiency term, wherein the inefficiency changes with time.

$$u_{it} = exp\{-\eta(t - T_i)\}u_i \qquad (6)$$

where u_i : random variable distributed as truncated normal, $u_i \geq 0$

T_i: last year for i-th producer in the panel data set

The estimation results of equation (6) are shown in Appendix Table A-2. The estimate of η is positive at 0.0009 in the case of the Cobb-Douglas production function, and 0.0016 in the case of the translog production function; however, neither of them is statistically significant.

Based on the above results, we conclude that the inefficiency indices of production are time-invariant, and the probability distribution can be depicted well by half-normal. In addition, it was found that the inefficiency indices do not depend on the specification of the production function. Therefore, in the subsequent analysis, half-normal will be assumed for the probability distribution of inefficiency, and we will assume the Cobb-Douglas production function, wherein stable parameters are obtained.[14]

4. Comparison of Characteristics between Efficient and Inefficient Rice Producers

Based on the median of the inefficiency indices of the stochastic frontier production function estimated in the preceding section, the rice producers are divided into an efficient producer group and an inefficient producer group, and the characteristics of their behaviors are examined.

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[14] The analysis in the subsequent sections is almost entirely unaffected even if we use the inefficiency indices that are obtained under the assumption of the Cobb-Douglas production function and truncated normal distribution.

Specifically we compare the behavioral characteristics of the efficient and inefficient rice farmers based on the following 16 items:

1) The number of parcels
2) The area planted with rice
3) The income per 10 a [15]
4) The outstanding loan balance per 10 a
5) Land productivity
6) Capital productivity
7) Labor productivity
8) Land utilization rate of rice production
9) Proportion of family labor hours aged over 65
10) Proportion of non-readjusted plots (*miseiri kukaku*) or plots less than 10 a
11) Proportion of plots from 10 a to 20 a
12) Proportion of plots from 20 a to 30 a
13) Proportion of plots from 30 a to 50 a
14) Proportion of plots more than 50 a
15) Proportion of certified farmers
16) Price per kg of the harvested rice

Some explanation is in order on some of the above variables. A parcel refers to a gathering or complex consisting of several neighboring plots. It has been argued that the larger the number of parcels, the more the agricultural land is fragmented, the higher the rise in production costs, and the more the inefficiency.[16] Items 10 to 14 provide useful information on the relationship between efficiency of production and the plot size. Based on this distributional information, we can examine whether the share of small plots is large in the case of inefficient producers, and whether the proportion of relatively large-scale plots is large in the case of efficient producers.

The certified farmer system certifies plans for improving agricultural management drafted by farmers to attain targets for efficient and stable farm management in basic plans prepared by municipal governments to meet their respective conditions under the

[15] Income is defined as follows: gross agricultural income + family labor cost - agricultural expenditures (all expenses necessary for farming) – interest payment – paid rent for land.

[16] Kawasaki (2010) has shown that a large number of parcels lead to inefficiency in rice production by employing the panel data of Rice Production Cost Statistics.

Agricultural Management Framework Reinforcement Act. [17] For certified farmers, or those whose plans have been certified, various measures are primarily implemented, including low interest financing from the Super L loan system and other programs, measures to facilitate farmland consolidation and infrastructure improvement efforts to support business farmers

However, the costs of becoming a certified farmer cannot be overlooked. In addition to various burdensome official procedures, cooperation in production adjustment for rice was a requirement at the stage of applying to become a certified farmer prior to 2009. It is particularly likely that the latter factor acted as a constraining condition on certified farmers on the utilization of the operated area for rice production. This will be examined in details in section 6.

Table 5 shows the t-statistics to test the mean equality of the 16 items described above between the efficient and inefficient producer groups.[18] The characteristics of the inefficient producers can be summarized from this table as follows:

1) The number of parcels is large
2) The income per 10 a is low, and the outstanding loan balance per 10 a is large
3) The land and labor productivity are low
4) The proportion of land used for rice production is low
5) The proportion of non-readjusted plots or plots less than 20 a is large, and the proportion of relatively large-scale plots more than 30 a is small
6) The proportion of working hours by family members aged over 65 is low
7) The proportion of certified farmers is high

There are no statistically significant differences between inefficient and efficient producers as far as the area planted with rice is concerned. However, the small plots less than 20 a is large for inefficient producers, while the proportion of relatively large-scale plots more than 30 a is large for efficient producers. Moreover, the number of parcels is

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[17] This description about certified farmers is taken from Ministry of Agriculture, Forestry and Fisheries (2018).

[18] One might argue that the calculated inefficiency measure might be regressed on the 16 items of farmer's attributes as explanatory variables. I do not take this regression approach since we cannot exploit the time-varying information of farmer's attributes fully in regressing *time-invariant* inefficiency measure on the farmer's attributes. In fact we fail to obtain significant coefficient estimates of many explanatory variables.

larger in the case of inefficient producers. This difference in plot size for rice production and degree of agricultural land fragmentation may result in the differences in productivity. In Figure 3, the histograms of land productivity for efficient and inefficient producers are compared.

No one will disagree that the characteristics mentioned in 1 to 5 describe the behavior of inefficient rice farmers quite well. However, the sixth characteristics that the share of working hours by old family members is low seems to contradict with conventional wisdom. It might suggest that labor input by older family members are complemented by more efficient ways of producing rice for efficient producers. The seventh characteristic, wherein the proportion of certified farmers is higher for inefficient producers, is also the opposite of the intention of certified farmer system. This issue will be examined further in section 6, which conducts an econometric analysis of the determinants of the utilization rate of operated land for rice production. [19]

5. Inefficiency in Production and Factor Demand

This section analyzes the relationship between the inefficiency of rice production and the inefficiency of factor demand in rice production by examining the static and dynamic factor demand behavior by rice producers.

Estimation of the static factor demand function

Firstly, when there is inefficiency in production, it is easy to see its effects on static factor demand, using a simple theoretical model. We assume that the production function is expressed as:

$$\mathrm{Y} = \mathrm{F}(K, N, M, \bar{L})e^{-u} \quad (7)$$

where Y is the output, *K*, *N*, *M*, and *L* are the input amounts of capital stock, labor, materials, and land, respectively, and u is the non-negative variable indicating inefficiency. In this section the input of land used for rice production is taken as given. It is assumed that utilization decision of operated area for rice production is determined in

[19] Some may argue that efficient rice producers have increased production efficiency by producing rice of lower quality. We cannot deny this possibility since the price per kg of the rice harvested by inefficient producers is significantly higher than that by efficient producers. We need more detailed information on the rice cultivar of individual farmers for further discussions on this issue.

the previous year by taking account of set-aside fallow land. We will examine the factors to determine the land utilization rate of rice production in the sext section.

The necessary conditions of profit maximization are expressed as follows:

$$\frac{\partial F}{\partial K}e^{-u}=\frac{p_K}{p},\ \ \frac{\partial F}{\partial N}e^{-u}=\frac{w}{p}\ ,\ \ \frac{\partial F}{\partial M}e^{-u}=\frac{p_M}{p} \qquad (8)$$

where p_K, w, p_M ,and p are the rental price of capital, wage rate, material price, and output price, respectively. From equation (8), the factor demand function is derived as a function of the real factor prices, the planted area of rice, and the inefficiency index.

$$\begin{aligned} K^* &= g_K\left(\frac{p_K}{p},\frac{w}{p},\frac{p_M}{p},\bar{L},u\right)\\ N^* &= g_N\left(\frac{p_K}{p},\frac{w}{p},\frac{p_M}{p},\bar{L},u\right) \qquad (9)\\ M^* &= g_M\left(\frac{p_K}{p},\frac{w}{p},\frac{p_M}{p},\bar{L},u\right)\end{aligned}$$

It can be shown that the inefficiency in factor demand is *positively* correlated with the inefficiency in production function when the second partial derivative with respect to different production factors is positive or $\frac{\partial^2 Y}{\partial x_i \partial x_j}>0$ (x_i: factor input, $i\neq j$).[20] To examine this proposition empirically, the logarithmic linear factor demand function, which takes inefficiency into consideration, is estimated. The estimation equation is specified as follows: [21]

$$\begin{aligned} lnK_{it} &= \beta_{0K}+\beta_{1K}ln\left(\frac{p_K}{p}\right)_{it}+\beta_{2K}ln\left(\frac{w}{p}\right)_{it}+\beta_{3K}ln\left(\frac{p_M}{p}\right)_{it}+\beta_{4K}ln\overline{L_{it}}-u_{K,i}+v_{K,it}\\ lnN_{it} &= \beta_{0N}+\beta_{1N}ln\left(\frac{p_K}{p}\right)_{it}+\beta_{2N}ln\left(\frac{w}{p}\right)_{it}+\beta_{3N}ln\left(\frac{p_M}{p}\right)_{it}+\beta_{4N}ln\overline{L_{it}}-u_{N,i}+v_{N,it} \qquad (10)\\ lnM_{it} &= \beta_{0M}+\beta_{1M}ln\left(\frac{p_K}{p}\right)_{it}+\beta_{2M}ln\left(\frac{w}{p}\right)_{it}+\beta_{3M}ln\left(\frac{p_M}{p}\right)_{it}+\beta_{4M}ln\overline{L_{it}}-u_{M,i}+v_{M,it}\end{aligned}$$

[20] This condition is satisfied in the Cobb-Douglas production function.

[21] In calculating the real factor prices, we use the output price in the *previous* year since the output price of the current year is not available in making decision of the current factor inputs. See the Data Appendix for the procedure to construct the factor prices.

where $u_{K,i}, u_{N,i}, u_{M,i}$: time-invariant stochastic inefficiency term corresponding to capital stock, labor and material $u_{K,i} > 0, u_{N,i} > 0, u_{M,i} > 0$

$v_{K,it}, v_{N,it}, v_{M,it}$: disturbance term corresponding to capital stock, labor and material

By calculating the correlation coefficient between the estimated inefficiency index of factor demand from equation (10), and the inefficiency index of production, which was obtained by estimating the stochastic frontier production function, it is possible to test the validity of the above proposition.

Table 6 shows the estimation results of equation (10) under the assumption that the probability distribution of inefficiency is half-normal and that the error term is distributed as i.i.d. normal. The descriptive statistics of the inefficiency indices in the three-factor demand functions are shown in Table 7. Positive correlation of 0.2928, 0.1660, and 0.1694 were observed for the correlation coefficients of production inefficiency and inefficiency in capital, labor, and materials, respectively, which supports our proposition above. The rank correlation coefficient exhibits an even higher value. Spearman's rank correlation coefficients between the inefficiency of production and the factor demand functions of capital, labor, and materials are 0.3105, 0.2003, and 0.1891, respectively. It is evident that the production-inefficient farmers tend to be also inefficient in factor demand decisions.

<u>Estimation of the dynamic factor demand function</u>

The factor demand function estimated above is a static model, but if the factor demand is less than the optimal level, it is interesting to compare the dynamic processes of adjusting factor demand between the efficient and the inefficient rice producers. Accordingly, the following dynamic factor demand function is estimated for the efficient and inefficient producer groups:

$$lnK_{it} = \gamma_{0K} + \gamma_{1K} ln\left(\frac{p_K}{p}\right)_{it} + \gamma_{2K} ln\left(\frac{w}{p}\right)_{it} + \gamma_{3K} ln\left(\frac{p_M}{p}\right)_{it} + \gamma_{4K} ln\overline{L_{it}} + \gamma_{5K} lnK_{i,t-1} + v_{K,it}$$

$$lnN_{it} = \gamma_{0N} + \gamma_{1N} ln\left(\frac{p_K}{p}\right)_{it} + \gamma_{2N} ln\left(\frac{w}{p}\right)_{it} + \gamma_{3N} ln\left(\frac{p_M}{p}\right)_{it} + \gamma_{4N} ln\overline{L_{it}} + \gamma_{5N} lnN_{i,t-1} + v_{N,it}$$

$$lnM_{it} = \gamma_{0M} + \gamma_{1M} ln\left(\frac{p_K}{p}\right)_{it} + \gamma_{2M} ln\left(\frac{w}{p}\right)_{it} + \gamma_{3M} ln\left(\frac{p_M}{p}\right)_{it} + \gamma_{4M} ln\overline{L_{it}}$$
$$+\gamma_{5M} lnM_{i,t-1} + v_{M,it} \quad (11)$$

The explanatory variables are the factor input level of the previous year, the real factor prices of the current period, the planted area of rice and the year dummies. In equation (11), the adjustment speed of factor demand is estimated as 1 - γ_{5j} ($j = K, N, M$). The producers are divided into efficient and inefficient producer groups based on the efficiency index in production and then the system GMM estimator is applied to equation (11) for each of the groups. Table 8 shows the estimation results.

A large difference in dynamic factor demand behavior was observed between the labor demand of the production-efficient and the production-inefficient producer groups. The response of labor input to a change in wage is significantly positive for the production-efficient producers, but it is not significant for the production-inefficient producers. The short run (long run) wage elasticity of production-efficient producers is -0.3684 (-0.4294), while the short run (long run) wage elasticity of production-inefficient producers is only -0.0353 (-0.0408), which is not significant. Why is the labor input of production-inefficient producers so inelastic to a change in wage rate?

To answer this question, it is important to know where the variations of wage rate come from. On average nearly 94 % of labor input is family labor and the wage rate of family labor is imputed from the wage data for business establishments with five to 29 workers in the construction, manufacturing and transportation/ postal industries in *the Monthly Labor Survey* conducted by the Ministry of Health, Labor and Welfare. This imputed wage rate is available for four age brackets: below 65 years old, 65-70 years old, 70-75 years old and above 75 years old. Therefore the age composition of family labor plays a vital role in calculating the wage rate of total family labor. To illustrate this point, the distribution of the hourly wage rate of total family labor is calculated for Tohoku district in 2008. The minimum wage rate is 932 yen per hour and the maximum wage is 1575 yen per hour. The range is 643 yen. The mean is 1342.9 yen per hour and the standard deviation is 142.9 yen. We compare this *intra*-regional variations of wage rate with the *inter*-regional variations of wage rate. In 2008 the minimum average wage rate is 1342.9 yen per hour in Tohoku district and the maximum average wage rate is 1634.5 yen per hour in Tokai district. The range is 291.6 yen, far smaller than the intra-regional range. Lastly, we calculate the inter-temporal variations of wage rate. For Tohoku district, the minimum average wage rate is 1321.0 yen in 2011 and the maximum average wage rate is 1342.9 yen in 2008. The range is only 21.9 yen. To sum up, the intra-regional variations are larger than any other variations.

Therefore it is likely that a rise in wage rate of family labor might reflect a change in wage distribution across age brackets, which will lead to a decrease in family labor input with relatively higher wage rate. Low sensitivity of labor input to wage rate might reflect the difference in labor productivity between production-efficient producers and production-inefficient producers. The labor productivity of the production-inefficient farmers is lower than that of the production-efficient farmers, as was seen in Table 5. Further investigation shows that the difference in labor productivity is due to that in the output level of rice and there is no statistical difference in labor inputs between the production-inefficient and the production-efficient farmers.[22] It implies that the optimal labor inputs should be less than the current level for the production-inefficient farmers and thus the production-inefficient farmers hoard redundant labor inputs for some reasons. Therefore the labor inputs of production-inefficient farmers will not respond to a change in wage rate. [23]

6. Determinants of Land Utilization Rate of Rice Production

The preceding section analyzed the efficiency of rice production when the factor demand other than land is adjusted. This section examines the land use for rice production. The rice farmers have operated land for rice. Note that the operated land for rice does not include fields or pasture. Some of the operated land is used for paddy rice planting, some for other crops, ant the rest left fallow. This section conducts an econometric analysis of the extent to which rice producers allocate their operated land to paddy rice planting by dividing the producers into efficient and inefficient groups. The farmers' decision to use their operated land for rice production might be affected by the government policies on rice production adjustment. When efficient rice producers stop rice planting, rice production may end up in the hands of inefficient producers. Then it would be costlier to

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[22] The average rice output is 24.0 ton and 19.8 ton for the production-efficient producer and production-inefficient producer, respectively.

[23] One might argue that low sensitivity of labor input to wage rate for production-inefficient producers is due to the age composition of family labor. When production-inefficient farmers consist mostly of retired elderly, the labor input is inelastic to a change in wage rate since it is more likely that they do not consider the wages as opportunity cost. However, this argument is not supported by the data since the proportion of family labor aged over 65 is *higher* for the production-efficient producers, as was seen in Table 5.

produce rice. Therefore, analyzing how rice farmers make decisions of the operated land utilization for rice planting from the standpoint of efficiency may have important policy implications.

We assume that the proportion of operated land of rice used for rice production is determined by the economic circumstances of rice producers in the previous year. The estimated equation is specified as follows:

$$\left(\frac{L}{TL}\right)_{it} = a_0 + a_1\left(\frac{Y}{L}\right)_{i,t-1} + a_2 FRG_{i,t-1} + a_3 GROUP_{i,t-1} + a_4 DEBT_{i,t-1}$$
$$+ a_5 HOBAVS_{i,t-1} + a_6 HOBAS_{i,t-1} + a_7 HOBAM_{i,t-1} + a_8 HOBAL_{i,t-1}$$
$$+ a_9 LIC_{i,t-1} + \mu_i + v_{it} \qquad (12)$$

where L_{it}: planted area of rice

TL_{it} : operated area of rice

Y_{it}: rice output

$FRG_{i,t}$: number of parcels

$GROUP_{i,t}$: dummy variable that takes 1 when a producer participates group farming organization and 0 otherwise

$DEBT_{i,t}$: outstanding loan balance per 10 a

$HOBAVS_{i,t}$: proportion of non-readjusted plots or plots less than 10 a

$HOBAS_{i,t}$: proportion of plots from 10 a to 20 a

$HOBAM_{i,t}$: proportion of plots from 20 a to 30 a

$HOBAL_{i,t}$: proportion of plots from 30 a to 50 a

$LIC_{i,t-1}$: dummy variable that takes 1 for certified farmers and 0 otherwise

μ_i : producer-specific effect

v_{it} : disturbance term

The determinants of land utilization for rice production can be divided into three groups. The first group is associated with the performance of producers in the previous year. Outstanding loan balance and the land productivity fall under this group. The second is related to the attributes of the paddy fields held by producers. The number of parcels and the area distribution of plots fall under this group. The dummy variable of the participation in group farming organizations (*nogyo seisan soshiki*) and the dummy variable of certified farmers fall under the third group, organizational form of rice producers.

The producers were divided into production-efficient and production-inefficient producer groups based on the efficiency indices of production, and equation (12) was estimated for these groups. The estimation method is a random-effect model that is compatible with the estimation methods adopted in the preceding sections. Table 9 shows the estimation results.

As for the effects of the performance of producers on the land utilization for rice production, it was observed that if the land productivity was higher for production-inefficient producers in the previous year, then the proportion of planted area of rice increased.

In terms of the attributes of the paddy fields, there is a tendency for planted area of rice production to be reduced more by producers that have a great deal of paddy fields in small plots. In particular, these effects are larger for production-efficient producers. The effect of the proportion of small plots less than 10 a on land utilization for rice production is largest; these effects gradually decline as the size of plots gets larger. The effect of the proportion of small plots on land utilization for rice production is much smaller for production-inefficient producers. Consequently, more production-efficient rice producers tend to leave the operated land of rice in small plots hallow or use it for growing other crops, and thus the operated area used for rice production will be concentrated in relatively large-scale plots.

Among the variables related to the organization form of rice producers, being a certified farmer significantly reduces the planted area for rice production. This result is consistent with the findings of Saito and Ohashi (2015), who showed that certified farmers tend to switch to crops other than rice. Our results confirm their findings and further show that the more production-efficient a certified farmer is, the larger this effect will be. If a certified farmer was production-efficient in the previous year, he will reduce land utilization rate of rice production by 6.0%, while the extent of the reduction by production-inefficient certified farmers is only 3.2%. The negative effect of being certified farmer on land utilization for rice production may reflect the fact that cooperation in production adjustment for rice was a requirement at the stage of applying for certified farmers prior to 2009. However, our findings suggest that productivity of rice production will decline further as the production-efficient certified farmers reduce the planting area for rice more. This is the opposite of what was intended by policymakers.

7. Concluding Remarks

This study conducts an empirical analysis on the behavior of Japanese rice producers from the viewpoint of efficiency of production by using the panel data of the

Rice Production Cost Statistics by the Ministry of Agriculture, Forestry and Fisheries. The stochastic frontier production function, which comprises four production factors (land, labor, capital stock, and materials), was estimated, and the inefficiency indices of production were calculated. This information was used in identifying the production-efficient and production-inefficient rice producers. Then the factor demand and the characteristics of the land utilization for rice production were compared between the production-efficient and production-inefficient rice producers. With regard to factor demand, we found that production-inefficient rice producers do not make any adjustments in employment in the short or long run even if there is a change in the wages. We also found that production-efficient rice producers who hold a large amount of small plots aim at increasing productivity by reducing the land utilization for rice production. Moreover, these effects are greater for production-efficient certified farmers.

In a situation wherein the rice consumption is decreasing steadily, the government has promoted the policy of switching from cultivation of rice as a staple food to other crops to resolve chronic oversupply of rice. For the successful implementation of the policy on adjusting the production of rice, the production-efficient producers should engage in the production of rice to improve productivity, while the production-inefficient producers should switch rapidly from cultivation of rice as a staple food to rice for feed and other crops. However, in reality the production-efficient certified farmers tend to promote a shift from rice production. If this trend continues, there might be a further decline in the productivity of rice production. In order to avoid such a situation, it is imperative to design an agricultural system that gives incentives to efficient rice producers to expand rice cultivation, and inefficient producers to withdraw from rice cultivation and switch to other crops.

Based upon the estimated stochastic frontier production function, a simulation exercise was conducted to evaluate a shift of rice production from the inefficient farmers to the efficient farmers. The total number of farm households planting rice was 943,236 in 2015 (2015 Census of Agriculture and Forestry). We assume that 5% of farm households, which are production-inefficient in paddy-rice production, cease rice production and it is substituted by 5% of farm households, which are production-efficient in paddy-rice production. Note that the total planted area for rice production remains unchanged since there is no statistical difference of the planted are for rice production between production-efficient farmers and production-inefficient farmers, as was seen in Table 5. We also showed that the land productivity of production-efficient farmers is statistically higher than that of production-inefficient farmers. Based on the difference in land productivity between production-efficient farmers and production-inefficient farmers, we can calculate the change in total output of rice resulting from the reallocation of rice production from production-inefficient farmers to production-efficient farmers. We find that the rice output increases by 162,880 tons, which is 2.2% of the total output of paddy rice in 2015. This simulation exercise demonstrates that reallocation of rice production from production-inefficient farmers to production-efficient farmers leads to large gain in rice output.

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Data Appendix

In this appendix we describe the sources and the methods of constructing the variables used in this study. The data are mainly from the Rice Production Cost Statistics (*Kome Seisanhi Chosa Tokei*) by the Ministry of Agriculture, Forestry and Fisheries.

Y: output is the quantity of rice that was produced as the staple product (*syu sanbutsu*) for sale and home use. (unit: kg)

N: labor input is the working time spent on rice production. It includes both family labor and hired labor used for rice production. The working hours of family labor are the sum of those in age brackets below 65, between 65-70, between 70-75 and above 75. (unit: hours)

L: land is the planted area of rice (*sakuduke menseki*) (unit: a).

K: capital stock is calculated by deflating the nominal stock of buildings and structures, land improvement facilities (*tochi kairyo setsubi*), automobiles, agricultural machinery, and tools in the fixed capital by the corresponding price indices, and by summing up them. The 2015-price deflators corresponding to the respective items are buildings and materials, automobiles and related fees, and agricultural machinery and tools (comprehensive). The data source of price deflators is the *Agricultural Price Index* reported by the Ministry of Agriculture, Forestry and Fisheries.

M: materials were calculated by dividing the expenditure on five types of materials (seed and seedling costs, fertilizer costs, agricultural chemical costs, light, heat and power costs, and various other materials costs) by the deflators in the *Agricultural Price Index* corresponding to each of these five items, and summing up them.

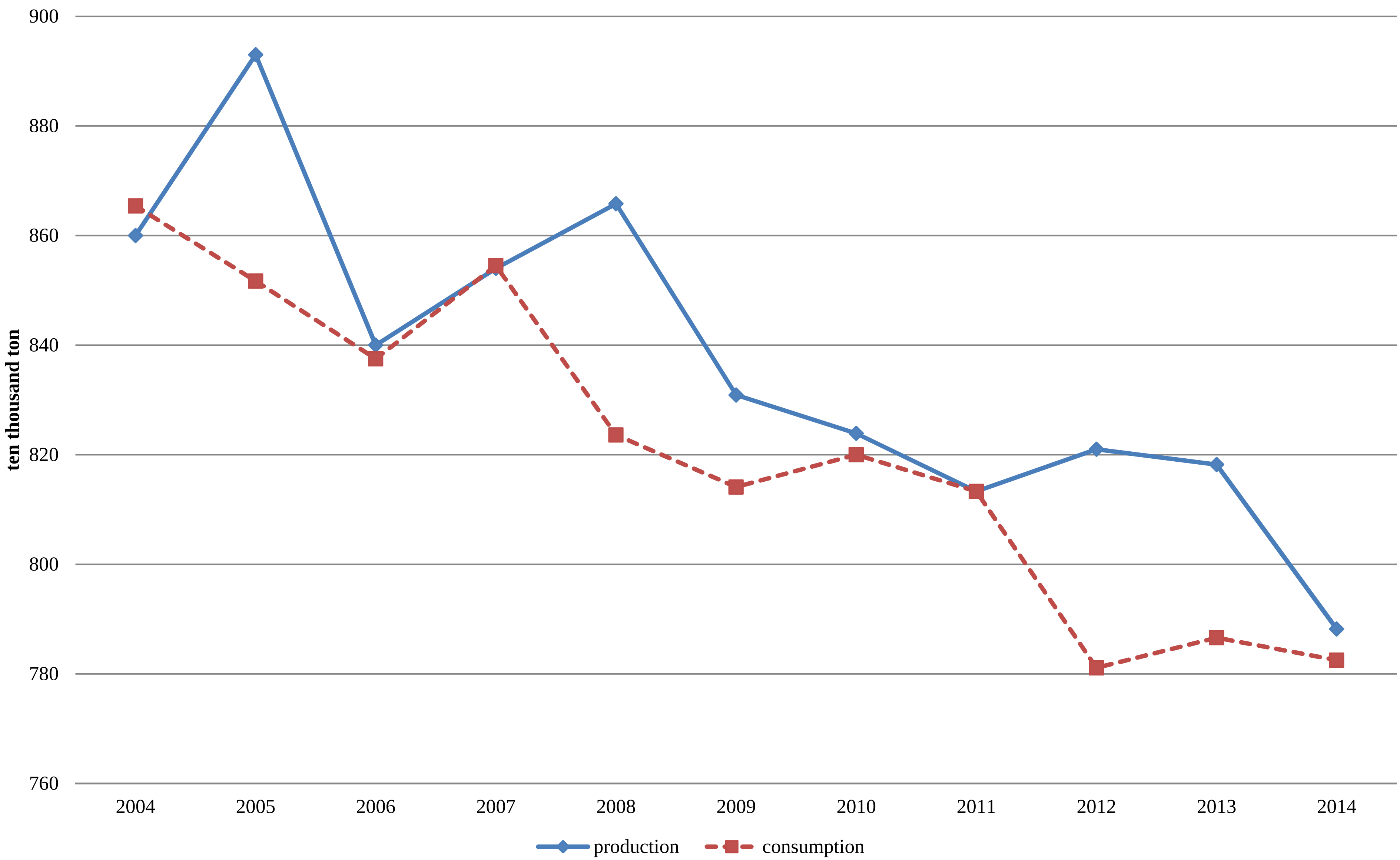
p: output price was calculated by dividing the nominal sales of the rice produced as the staple product for sales and home use by the output quantity of rice.

w: wage rate was calculated as follows. First, the family labor cost is calculated by multiplying the working hours of family labor in the four age brackets defined above by the respective hourly imputed wage rate. The hourly imputed wage rate is based on wage data for business establishments with five to 29 workers in the construction, manufacturing and transportation/ postal industries in *the Monthly Labor Survey* by the Ministry of Health, Labor and Welfare. The hired labor cost is also calculated by multiplying the working hours of hired labor by the hourly wage rate. Then, total labor cost, defined as the sum of the family labor cost and the hired labor cost, is divided by total working hours of family labor and hired labor to obtain the wage rate.

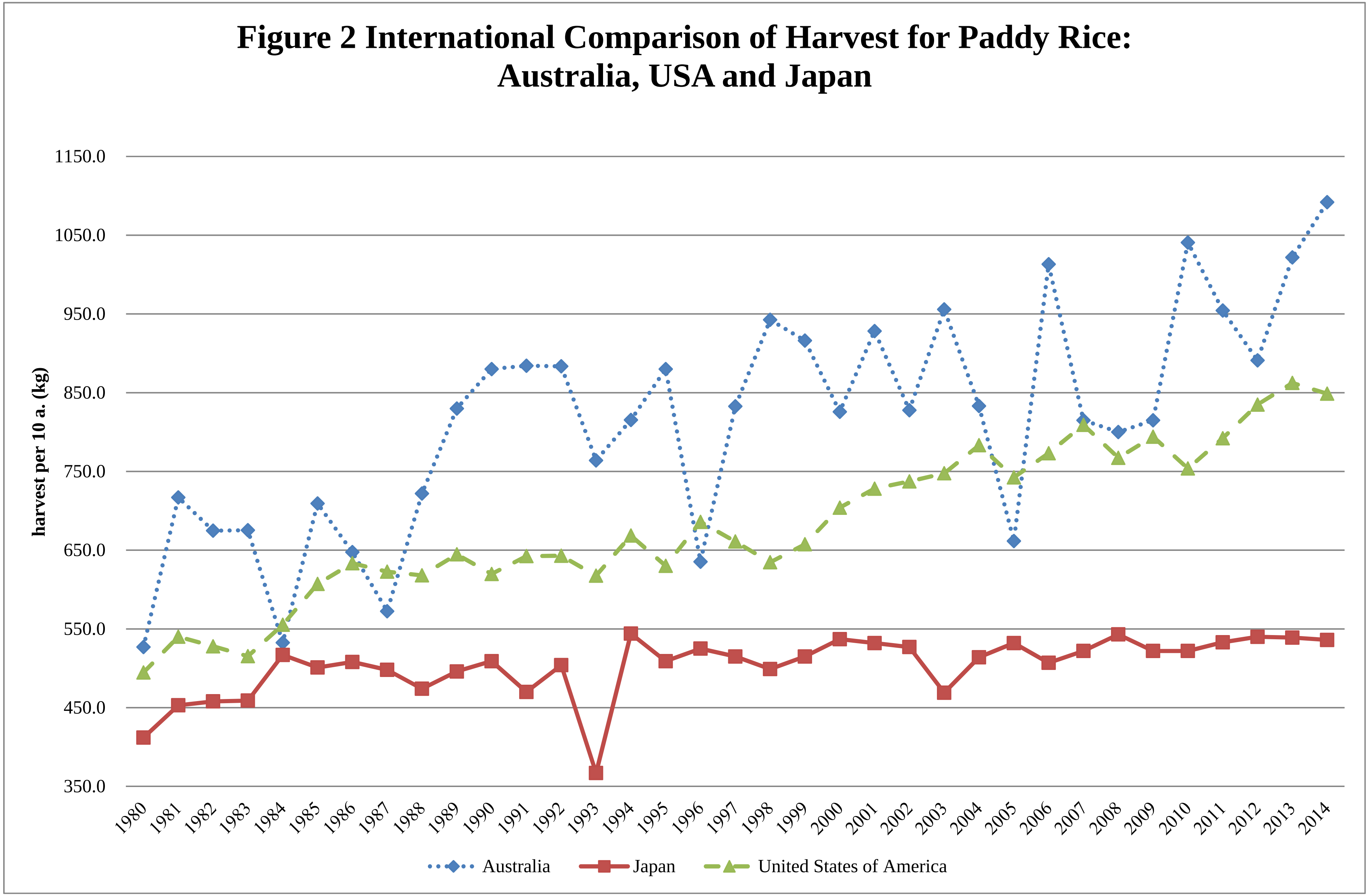
p_K: rental price of capital was calculated by summing up the land improvement and water conservancy fees; the rent and fees; the depreciation costs for buildings, automobiles, agricultural machinery, tools, and production management; paid interest; imputed interest on the farmers' own capital and the self-supplied portion out of the building, automobile, agricultural machinery and tool costs; then, dividing the total sum by the capital stock.

p_M: materials price was calculated by dividing the nominal expenditure on the five items of materials calculated above by the corresponding real amount.

Figure 1　Production and Consumption of Rice as a Staple Food



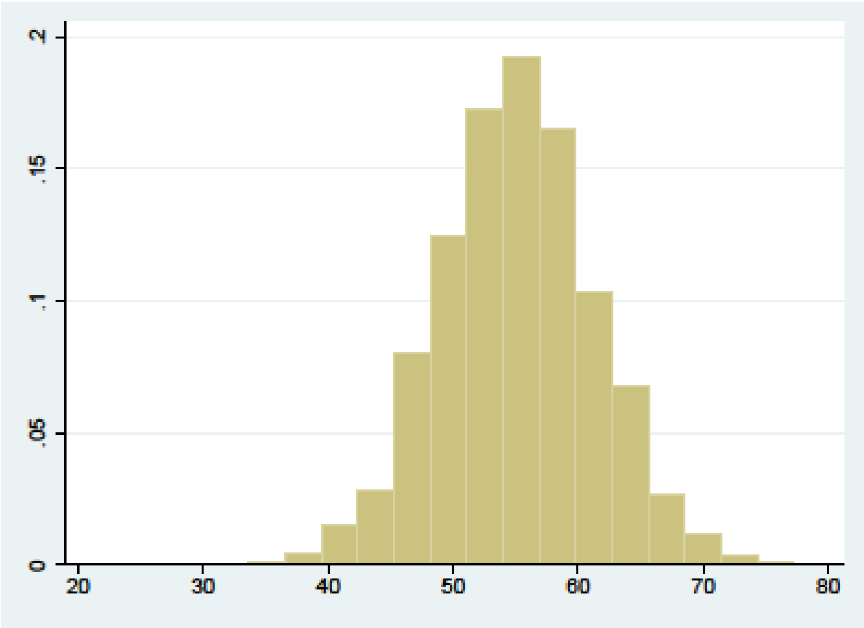
Source: Ministry of Agriculture, Forestry and Fisheries, *Situations about Rice, Basic Principles on Demand and Supply of Rice and Price Stabilization*



Source:Food and Agriculture of the United Nations, FAOSTAT. Ministry of Agriculture, Forestry and Fisheries, Statistical Yearbook。

Figure 3 Histogram of Land Productivity

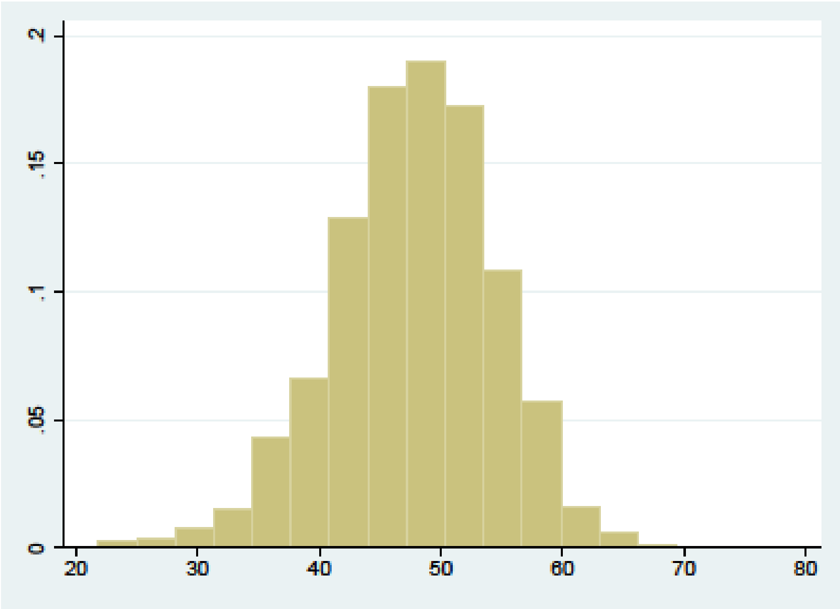
(a) Efficient Rice Producer



kg/a

mean = 55.57kg

(b) Inefficient Rice Producers



kg/a

mean =47.27kg

Table 1 Descriptive Statistics of Major Variables

	mean	median	standard deviation
Rice production (kg)	21893	10305	31023
Planted area for rice production (a)	416.1	199.0	578.7
Labor input (hours)	816.4	515.0	914.8
Capital stock (ten thousand yen) 1)	421.9	207.0	618.6
Material input (ten thousand yen) 2)	107.6	52.6	148.9
Land productivity (kg/a)	51.4	51.7	7.4
Labor productivity (kg/hour)	23.5	21.0	12.8
Capital productivity (kg/ten thousand yen)	275.5	57.1	4669.7
Land utilization rate of rice production (%)	74.2	75.6	18.2
Proportion of non-readjusted plots (*miseiri kukaku*) or plots less than 10 a (%)	17.4	5.1	26.8
Proportion of plots from 10a to 20 a (%)	27.0	18.6	28.2
Proportion of plots from 20 a to 30 a (%)	27.0	18.6	29.0
Proportion of plots from 30 a to 50 a (%)	18.6	0.0	25.7
Proportion of plots more than 50 a (%)	10.0	0.0	23.3

Notes: 1), 2) real values in 2015 price

Source: Ministry of Agriculture, Forestry and Fisheries, Rice Production Cost Statistics

Table 2 Estimation Results of Stochastic Frontier Production Function

	(1)	(2)	(3)	(4)	(5)	(6)
	haf-normal		truncated-normal		fixed-effect model	
lnN	0.0143 **	-0.0942	0.0142 **	-0.0939	0.0360 **	0.2845
	(2.24)	(-0.51)	(2.23)	(-0.57)	(2.08)	(0.95)
lnK	0.0048 **	-0.1619 ***	0.0048 **	-0.1615 ***	-0.0001	-0.1543 *
	(2.30)	(-2.72)	(2.31)	(-2.75)	(-0.05)	(-1.84)
lnL	0.9400 ***	1.0339 **	0.9401 ***	1.0313 ***	0.9281 ***	0.9798 **
	(101.93)	(2.55)	(102.40)	(3.56)	(40.48)	(2.10)
lnM	0.0563 ***	0.3212	0.0563 ***	0.3232	0.0490 ***	0.0048
	(5.87)	(0.64)	(5.88)	(0.93)	(2.96)	(0.01)
$(\ln N)^2$		0.0045		0.0046		-0.0006
		(0.50)		(0.50)		(-0.03)
(lnN)(lnK)		0.0046		0.0047		-0.0006
		(0.99)		(1.02)		(-0.10)
(lnN)(lnL)		-0.0056		-0.0056		0.0414
		(-0.26)		(-0.29)		(1.02)
(lnN)(lnM)		0.0015		0.0013		-0.0338
		(0.07)		(0.07)		(-0.96)
$(\ln K)^2$		0.0005		0.0005		-0.0005
		(0.53)		(0.52)		(-0.62)
(lnK)(lnM)		0.0168 ***		0.0168 ***		0.0185 *
		(2.56)		(2.59)		(1.91)
(lnK)(lnL)		-0.0178 ***		-0.0179 ***		-0.0134
		(-2.72)		(-2.76)		(-1.35)
$(\ln L)^2$		0.0100		0.0098		-0.0112
		(0.45)		(0.56)		(-0.36)
(lnL)(lnM)		0.0069		0.0073		-0.0001
		(0.14)		(0.20)		(-0.00)
$(\ln M)^2$		-0.0211		-0.0212		-0.0006
		(-0.66)		(-0.96)		(-0.024)
Constant term	3.5593 ***	3.0949	3.5603 ***	3.0870 **	3.4783 ***	3.9935 *
	(43.65)	(1.53)	(43.62)	(2.16)	(22.44)	(1.69)
μ			0.0190	0.0155		
			(0.27)	(0.21)		
σ_u	0.1788	0.1778	0.0298	0.0299		
σ_v	0.0926	0.0926	0.0086	0.0086	0.0921	0.0922
Number of observations	5407	5407	5407	5407	5062	5062

Notes: The coefficient estimates of year dummies and regional dummies are suppressed.

The values in parhenthesis are t-values based on heteroskedasticity-robust standard errors.

*,**, *** significant at 10%, 5% and 1% level, respectively

N: labor input K: capital stock L: planted area of rice M: material input

μ: mean of truncated normal distribution σ_u: standard deviation of inefficieny distribution

σ_v: standard deviation of disturbance distribution

Table 3

Comparison of Production Inefficiency Indices

production function	probability distribution of inefficiency	mean	median	standard deviation
Cobb-Douglas	Half-normal	0.1176	0.0909	0.0869
Translog	Half-normal	0.1169	0.0904	0.0865
Cobb-Douglas	Truncated normal	0.1461	0.1254	0.0983
Translog	Truncated normal	0.1449	0.1233	0.0979
Cobb-Douglas	Fixed-effect	0.3314	0.3149	0.1323
Translog	Fixed-effect	0.3284	0.3136	0.1323

Table 4 Correlation Coefficients of Inefficiency Indices
When the Production Function Is the Cobb-Douglas Type

(1) correlation coefficients

	truncated-normal	half normal
half normal	0.8754 (0.00)	-
fixed-effect model	0.8900 (0.00)	0.7797 (0.00)

(2) Spearman rank correlation coefficients

	truncated-normal	half normal
half normal	0.9215 (0.00)	-
fixed-effect model	0.8796 (0.00)	0.7969 (0.00)

Notes: The values in parenthesis are p-values of the null hypothesis that the correlation coefficient is zero.

Table 5 Comparison of Characteristics between Efficient and Inefficient Rice Producers

	inefficient producers	efficient producers	t-test of the mean equility
Number of parcels	4.55	4.25	2.94*** (0.00)
Planted area for rice production (a)	410.3	421.9	-0.95 (0.46)
Income per 10 a (yen)	13049.6	24682.7	-9.66*** (0.00)
Outstanding loan balance per 10 a (yen)	15433.2	12128.7	3.18*** (0.00)
Land productivity (kg/a)	47.27	55.57	-49.7*** (0.00)
Labor productivity (kg/hour)	21.72	25.24	-10.27** (0.00)
Capital productivity (kg/ten thousand yen)	192.3	359.6	-1.24 (0.22)
Land utilization rate of rice production (%)	73.1	75.3	-4.52*** (0.00)
Proportion of family labor hours aged over 65 (%)	39.61	46.27	-5.73*** (0.00)
Proportion of non-readjusted plots or plots less than 10 a (%)	19.32	15.52	5.24*** (0.00)
Proportion of plots from 10 a to 20 a (%)	29.49	24.56	6.47*** (0.00)
Proportion of plots from 20 a to 30 a (%)	26.11	27.96	-2.36** (0.02)
Proportion of plots from 30 a to 50 a (%)	17.06	20.05	-4.32*** (0.00)
Proportion of plots more than 50 a (%)	8.03	11.91	-6.19*** (0.00)
Proportion of certified farmers (%)	48.95	45.60	2.47** (0.01)
Price of the harvested rice per kg (yen)	219.7	216.0	3.78*** (0.00)

Notes: *, **, *** significant at 10%, 5%, 1% level, respectively

The values in parenthesis are p-values of the null hypothesis that there is no difference in mean.

Income = gross agricultural income + family labor cost - agricultural expenditures (all expenses necessary for farming) – interest payment – paid rent for land

Table 6 Estimation Results of Static Factor Demand Function with Inefficiency

	lnK		lnN		lnM	
$\ln(p_K/p)$	-1.1662	**	-0.0334	***	-0.0232	***
	(-140.61)		(-5.33)		(-4.85)	
$\ln(w/p)$	0.0801		-0.4396	***	-0.1004	***
	(1.08)		(-9.07)		(-2.65)	
$\ln(p_M/p)$	1.0955	***	0.4096	***	0.0143	
	(11.84)		(7.13)		(0.30)	
lnL	0.6522	***	0.6853	***	0.8988	***
	(72.47)		(99.38)		(201.78)	
Constant term	10.4165	***	6.2854	***	8.9777	***
	(16.64)		(15.79)		(28.06)	
σ_u	0.7794		0.7848		0.4100	
σ_v	0.2454		0.1151		0.1165	
Number of observations	3460		3460		3460	

Notes: The coefficient estimates of year dummies and regional dummies are suppressed.
The values in parenthesis are t-values based on heteroskedasticity-robust standard errors.
*,**, *** significant at 10%, 5% and 1% level, respectively
K: capital stock N: labor input M: material input L:land
p_K: rental price of capital w: wage rate p_M: material price p: output price
σ_u: standard deviation of inefficieny distribution
σ_v: standard deviation of disturbance distribution

Table 7 Inefficient Indices of Production and Factor Demand

(1) Mean, Median and Standard Deviation

	mean	median	standard deviation
lnY	0.1066	0.0798	0.0842
lnK	0.3923	0.3231	0.2920
lnN	0.4068	0.3536	0.2981
lnM	0.2068	0.1699	0.1554

(2) Correlation Coefficient

	lnY	lnK	lnN
lnK	0.2928		
	(0.00)		
lnN	0.1660	0.2451	
	(0.00)	(0.00)	
lnM	0.1694	0.3410	0.4729
	(0.00)	(0.00)	(0.00)

(3) Spearman Rank Correlation Coefficient

	lnY	lnK	lnN
lnK	0.3105		
	(0.00)		
lnN	0.2003	0.3150	
	(0.00)	(0.00)	
lnM	0.1891	0.3921	0.5098
	(0.00)	(0.00)	(0.00)

Notes: Y: rice output K: capital stock N: labor input M: material input L:land
The values in parethesis are p-values of the null hypothesis that there is no correlation.

Table 8 Estimation Results of Dynamic Factor Demand Function

(1) Production-Efficient Rice Producers

	lnK		lnN		lnM	
$\ln(p_K/p)$	-1.0792	***	-0.0296		0.0132	
	(-17.18)		(-1.62)		(1.08)	
ln(w/p)	0.0260		-0.3684	***	0.0818	
	(0.12)		(-2.60)		(0.76)	
$\ln(p_M/p)$	0.9651	***	0.4423	**	-0.0735	
	(4.10)		(2.41)		(-0.59)	
lnL	0.6339	***	0.8415	***	0.9826	***
	(9.55)		(20.17)		(35.06)	
lagged dependent variable	0.2892	***	0.1421	**	0.0724	*
	(4.67)		(2.23)		(1.80)	
Constant term	5.5396	***	3.8015	***	6.5804	***
	(3.32)		(3.16)		(5.73)	
Test statistics of serial correlation	0.4234		-1.0907		0.1801	
	(0.67)		(0.28)		(0.86)	
Number of observations	1521		1522		1522	

(2) Production-Inefficient Rice Producers

	lnK		lnN		lnM	
$\ln(p_K/p)$	-1.1135	***	-0.0268	**	0.0225	*
	(-30.48)		(-2.00)		(1.70)	
ln(w/p)	0.2409		-0.0353		0.1186	
	(1.32)		(-0.40)		(1.15)	
$\ln(p_M/p)$	0.9385	***	0.0725		-0.1949	*
	(4.62)		(0.72)		(-1.69)	
lnL	0.5482	***	0.7681	***	0.8736	***
	(9.90)		(15.08)		(34.38)	
lagged dependent variable	0.2646	***	0.1338	*	0.0596	
	(6.18)		(1.69)		(1.51)	
Constant term	5.4681	***	1.6217	*	6.6518	***
	(3.54)		(1.81)		(6.95)	
Test statistics of serial correlation	-1.0407		-1.0402		-0.2021	
	(0.30)		(0.30)		(0.84)	
Number of observations	1938		1938		1938	

Notes: The coefficient estimates of year dummies are suppressed.

The values in parenthesis are t-values based on heteroskedasticity-robust standard errors.

*,**, *** significant at 10%, 5% and 1% level, respectively

The values in parenthesis of test statistics of serial correlation are p-values of the null hypothesis that first-differenced errors have zero correlation.

K: capital stock N: labor input M: material input L:land

p_K: rental price of capital w: wage rate p_M: material price p: output price

Table 9 Estimation Results of the Determinants of Land Utilization for Rice Production

Explanatory variables	production-efficient rice producer		production-inefficient rice producer	
Land productivity	0.0005		0.0008	*
	(0.69)		(1.75)	
Number of parcels	0.0026	*	0.0020	**
	(1.81)		(2.01)	
Dummy for participation in group farming organization	-0.0230	*	-0.0361	***
	(-1.64)		(-2.80)	
Outstanding loan balance	0.0190		0.0073	
	(1.33)		(1.03)	
Proportion of non-readjusted plots or plots less than 10 a	-0.1038	***	-0.0626	**
	(-3.45)		(-2.09)	
Proportion of plots from 10 a to 20 a	-0.0685	**	-0.0251	
	(-2.45)		(-0.88)	
Proportion of plots from 20 a to 30 a	-0.0810	***	-0.0128	
	(-3.01)		(-0.46)	
Proportion of plots from 30 a to 50 a	-0.0335		-0.0268	
	(-1.16)		(-0.93)	
Dummy for certified farmers	-0.0600	***	-0.0323	***
	(-5.13)		(-3.02)	
Constant term	0.7875	***	0.6465	***
	(15.75)		(17.34)	
Determinants of coefficient	0.1554		0.1173	
Number of observations	1544		1955	

Notes: The coefficient estimates of year dummies and regional dummies are suppressed.

The values in parenthesis are t-values based on heteroskedasticity-robust standard errors.

*,**, *** significant at 10%, 5% and 1% level, respectively

Appendix Tables

Table A-1 Sample Distribution by Prefecture

region	prefecture	number of observations	number of observations by region
Hokkaido	Hokkaido	543	543
Tohoku	Aomori	190	1507
	Iwate	195	
	Miyagi	255	
	Akita	338	
	Yamagata	261	
	Fukushima	268	
North Kanto & Koshin	Ibaraki	234	632
	Tochigi	242	
	Gunma	48	
	Yamanashi	10	
	Nagano	98	
South Kanto	Saitama	110	320
	Chiba	202	
	Tokyo	0	
	Kanagawa	8	
Hokuriku	Niigata	402	685
	Toyama	114	
	Ishikawa	83	
	Fukui	86	
Tokai	Gifu	51	297
	Shizuoka	46	
	Aichi	88	
	Mie	112	
Kinki	Shiga	114	325
	Kyoto	46	
	Osaka	14	
	Hyogo	112	
	Nara	19	
	Wakayama	20	
Cyugoku	Tottori	37	340
	Shimane	60	
	Okayama	112	
	Hiroshima	66	
	Yamaguchi	65	
Shikoku	Tokushima	54	226
	Kagawa	64	
	Ehime	63	
	Kochi	45	
Kyusyu	Fukuoka	141	577
	Saga	88	
	Nagasaki	44	
	Kumamoto	130	
	Oita	76	
	Miyazaki	52	
	Kagoshima	46	
	Okinaawa	0	
	total	5452	5452

Source: Ministry of Agriculture, Forestry and Fisheries, Rice Production Cost Statistics

Table A-2

Estimation Results of Stochastic Frontier Production Function with Time-Varying Inefficiency

	(1)		(2)	
lnN	0.0142	**	-0.0941	
	(2.23)		(-0.57)	
lnK	0.0048	**	-0.1613	***
	(2.29)		(-2.75)	
lnL	0.9401	***	1.0297	***
	(102.45)		(3.56)	
lnM	0.0563	***	0.3252	
	(5.88)		(0.94)	
$(\ln N)^2$			0.0045	
			(0.50)	
(lnN)(lnK)			0.0047	
			(1.02)	
(lnN)(lnL)			-0.0055	
			(-0.29)	
(lnN)(lnM)			0.0013	
			(0.07)	
$(\ln K)^2$			0.0005	
			(0.52)	
(lnK)(lnM)			0.0167	***
			(2.59)	
(lnK)(lnL)			-0.0179	***
			(-2.76)	
$(\ln L)^2$			0.0097	
			(0.56)	
(lnL)(lnM)			0.0075	
			(0.21)	
$(\ln M)^2$			-0.0213	
			(-0.96)	
Constant term	3.5605	***	3.0773	**
	(43.72)		(2.15)	
μ	0.0184		0.0145	
	(0.25)		(0.19)	
η	0.0009		0.0016	
	(0.07)		(0.12)	
σ_u	0.0299		0.0301	
σ_v	0.0086		0.0086	
Number of observations	5407		5407	

Notes: The coefficient estimates of year dummies and regional dummies are suppressed.

The values in parenthesis are t-values based on heteroskedasticity-robust standard errors.

*,**, *** significant at 10%, 5% and 1% level, respectively

N: labor input K: capital stock L: planted area for rice M: material input

μ: mean of truncated normal distribution η: time coefficient of inefficiency

σ_u: standard deviation of inefficieny distribution

σ_v: standard deviation of disturbance distribution