Comparing Technical and Allocative Efficiency between Family Farms and Agricultural Corporations: Evidence From Japan's Rice Sector*

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Is an agricultural corporation more efficient than a traditional family farm? This study attempts to answer this question by examining the technical efficiency and allocative efficiency of family farms and agricultural corporations. To do so, it applies the stochastic production frontier method in panel data built on the family farms and agricultural corporations in the Japanese rice sector and focuses on comparing the technical efficiency and allocative efficiency between the two production forms of the same operation scale. The results reveal that family farms have a significant advantage over agricultural corporations in technical efficiency at each level of operation scale. In both production forms, as the operation scale increases, the technical efficiency rises accordingly. However, such disparity in technical efficiency diminishes between the two production forms as their operating land scales increase. In contrast, the allocative efficiency of different factors differs between family farms and agricultural corporations at different land scales. Overall, family farms show superiority in the allocative efficiency of labor, and agricultural corporations exhibit superiority in the allocative efficiency of agricultural capital. Last, the decomposition of the total productivity progress(TFP) reveals that family farms have positive TFP change which is mainly contributed by a positive and large allocative component, while agricultural corporations undergo negative TFP change by virtue of its negative and large allocative component. Moreover, the results intimate that technical progress and technical efficiency improvement are faster in agricultural corporations than in family farms.

Keywords: Agricultural corporation; Family farm; Technical inefficiency; Allocative inefficiency
JEL Codes: D10, D22, D24, Q10

Introduction

What is a corporation? Simply speaking, a corporation is a production organization set up and operated by contracts. What is a family? A family is a unit held together and organized by blood or affection. It is widely believed and proven that a corporation is more efficient than a household or an individual in industrial production. That is why large factories inevitably replaced family workshops following the first Industrial Revolution. However, does this hold true in agricultural production? Is an agricultural corporation more efficient than a traditional family farm? To date, there is no definitive conclusion.

By 2013, there were more than 570 million farms worldwide, most of which were small and family-operated. Family farms manage about 75% of the world's agricultural land (Lowder et al. 2016). In other words, family farms remain the dominant form of agricultural production worldwide. The broad existence of family farms must have its rationale. First of all, the vulnerability and susceptibility of the agricultural production process makes it difficult to both supervise and assess the labor effort input involved in that process. That is to say, family members, who are connected by blood or affection and share in the core profits of agricultural production, are thought to be more trustworthy than the mere employed. Secondly, agriculture depends heavily on land relative to other industries, and with arable land usually owned or used by independent and dispersed farm households, it is highly challenging to concentrate land to achieve a large business scale in agriculture (Egaitsu and Suzuki 2015). This is more true in the regions whose agricultural sector mainly consists of peasant households, such as Asian or African areas. Thirdly, it is more difficult to concentrate capital in the agricultural sector. That is, the peculiar nature of some agriculture's productive process is incompatible with the requirements of capitalist production and unattractive for capitalist penetration (Mann and Dickinson 1978). Those theories explain the dominance of family farms in agriculture worldwide, namely, why it is difficult to develop agricultural corporations, yet fall short in providing evidence that family farmers are superior to agricultural corporations in production efficiency.

Peasant households had long been considered backward and inefficient until Schultz (1967) proposed his famous hypothesis that peasant households are poor but efficient. What has followed is years of debate on the efficiency of peasant households and a wave of empirical work designed to test his theory (e.g., Adams 1986; Lipion 1968; Popkin 1980). Recently, researchers in this field

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are more interested in examining and comparing the production efficiency of family farms with different-sized operations and testing the hypothesis of the inverse farm size-productivity relationship, which states that small farms are more productive than larger farms (Carletto et al. 2013; Charnes et al. 1978; Chayanov 1991; Cornia 1985; Kagin et al.2016; Larson et al. 2014; Sen 1962; Schultz 1980). Thus far, the issue of production efficiency of family farms has been systematically and elaborately examined. However, rare studies refer to the comparison of production efficiency between family farms and agricultural corporations. Hence, we have neither evidence nor conclusion on which form of agricultural production holds the advantage in production efficiency.

The research question fuelling this study is whether agricultural corporations have an advantage over family farms in production efficiency. The key hypothesis put forward is that agricultural corporations are more efficient than family farms in production efficiency. This advantage, if it in fact exists, may stem from the fact that the former is established and operated by contract, while the latter is maintained and operated by blood relations. This implies the former is more adept in flexibly adjusting the input of production factors, thus making its production efficiency higher than the latter. More importantly, taken together with the finding from the existing literature that operation size has an extremely significant effect on production efficiency (Fujie and Senda 2022; Perdomo et al. 2022), this study focuses on estimating and comparing production efficiency between family farms and agricultural corporations of the same operation size to verify whether agricultural corporations are superior to family farms in production efficiency.

Concretely, this study builds a quantitative framework for measuring the technical and allocative efficiency (inefficiency) of agricultural production in family farms and agricultural corporations, respectively, via estimating the stochastic production frontier functions. An economic entity's production process may exhibit technical inefficiency, allocative inefficiency, or both. Technical inefficiency is defined as the unsuccessful minimization of input usage to produce given outputs or the unsuccessful maximization of outputs using given inputs. Allocative inefficiency is described as the failure to combine inputs in optimal proportions to minimize the production costs, namely, failure to equate the marginal rate of technical substitution (MRTS) between any two inputs to the ratio of corresponding input prices (Atkinson and Cornwell 1994; Farrell 1957; Kopp and Diewert 1982; Zhang et al. 2019). Obviously, the former inefficiency is price-independent, and the latter is price-related.

Table1 Composition of Agricultural Management Entities in Japan (thousand, %)

Year	Number of Agricultural Management Entities				% of Corporation
	Total	Individual	Organization		
			Total	Corporation	
2005	2009.4	1981.3	28.1	13.9	0.69
2006	1935.8	−	−	−	−
2007	1867.0	−	−	−	−
2008	1804.1	−	−	−	−
2009	1753.2	−	−	−	−
2010	1679.1	1648.1	31.0	17.1	1.02
2011	1617.6	1586.1	31.5	−	−
2012	1563.9	1532.7	31.2	17.8	1.14
2013	1514.1	1482.4	31.7	18.2	1.20
2014	1471.2	1439.1	32.1	18.9	1.28
2015	1377.3	1344.3	33.0	22.8	1.66
2016	1318.4	1284.4	34.0	23.8	1.81
2017	1258.0	1223.1	34.9	24.8	1.97
2018	1220.5	1185.0	35.5	25.5	2.09
2019	1188.8	1152.8	36.0	26.1	2.20
2020	1075.7	1037.3	38.4	30.7	2.85
2021	1030.9	991.4	39.5	31.6	3.07

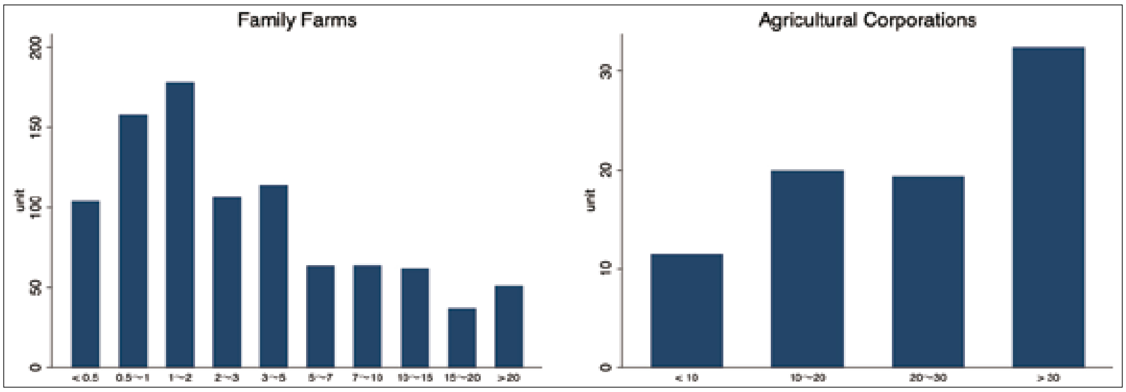
Source: The data are from the database of the Ministry of Agriculture, Forestry, and Fisheries of Japan.

The methodologies are as follows. In the first step, the stochastic production frontier models are applied to estimate the technical inefficiency of family farms and agricultural corporations, respectively. In the second step, the respective allocative inefficiencies of family farms and agricultural corporations are measured using the estimated results of the stochastic production frontier model and the first-order conditions for cost minimization. Last, to examine changes in the technology and efficiency of family farms and agricultural corporations, it decomposes the TFP for each.

To facilitate the quantitative analysis, a rich set of data on Japanese family farms and agricultural corporations is compiled. In Japan, decreasing birthrate and aging population are becoming problematic for its agriculture. The number of peasant households in Japan has plummeted from 1.98 million in 2005 to 0.99 million in 2021, while the average age of agricultural workers has soared to 62.3 years. In such context, a countermeasure put forward by the Japanese government is to vigorously develop agricultural production corporations.[1] The number of agricultural corporations in Japan has more than doubled from 13.9 thousand in 2005 to 31.6 thousand in 2021 (See Table 1).

Figure 1 displays the average number of single rice farming family farms and single rice farming agricultural corporations at each level of land size from 2004 to 2016.[2] Japan’s Statistical Survey on Farm Management and Economy divides family farms into ten grades and agricultural corporations into four grades according to their operating land scale, as shown in Figure 1. The operating land scale of the majority of rice family farms is under 2 hectares, while that of most rice farming agricultural corporations is above 10 hectares. As mentioned above, it is crucial to compare family farms and agricultural corporations of the same operation size on the grounds that even though we can empirically prove that agricultural corporations produce rice more (or less) efficiently than family farms, it is hard to say whether and to what extent the gulf between them is due to the difference in operation form or merely the variation in operating land scale. To address this problem, we split family farms and agricultural corporations into four groups according to their operating land scale and compare the technical and allocative efficiency between the two forms of agricultural production within each group.

Figure1 Distribution of Rice Family Farms and Rice Agricultural Corporations in Land Size



In a series of quantitative analyses, our empirical results show that family farms hold a significant advantage over agricultural corporations in technical efficiency at each level of operation scale. In terms of allocative efficiency, family farms present superiority in the allocative efficiency of labor, and agricultural corporations enjoy superiority in the allocative efficiency of agricultural capital. Those findings strongly reject our hypothesis that agricultural corporations are superior to family farms in production efficiency. Furthermore, decomposition of the TFP shows that family farms have positive TFP change which is mainly contributed by a positive and large allocative component, while agricultural corporations undergo negative TFP change by virtue of its negative and large allocative component.

This study enriches the existing literature on agricultural production efficiency analysis by including agricultural corporations in the analytical framework. It is the first attempt to evaluate technical and allocative efficiency between family farms and agricultural corporations. It reveals that agricultural corporations do not retain an advantage over traditional family farms in production efficiency, but the disparity between the two forms of agricultural production diminishes as their operation size increases. These findings have rich policy implications for developing new agricultural production forms. Exploring further methods of increasing the production

[1] Agricultural corporations are defined as operating entities that engage in agriculture and are registered as legal persons in Japan. That is to say, the process of setting up, managing, and disbanding or abolishing agricultural corporations must satisfy the conditions of legal persons (enterprise counting and taxing system, etc.). Refer to Appendix A for the classification of Japan’s agricultural corporations.

[2] Single rice farming entities refer to family farms and agricultural corporations in which more than 80 percent of their total agricultural sales is rice.

efficiency of agricultural corporations should be a component of new strategy of agricultural modernization.

The rest of this article is organized as follows. Section 2 describes the methodology of evaluating the technical and allocative efficiency and decomposing the TFP growth. Section 3 introduces the data adopted in this study and groups the research objects. Section 4 reports the empirical results. Section 5 draws the conclusion.

Methodology

Measurement of Technical Efficiency

The present study identifies and compares the technical and allocative efficiency between family farms and agricultural corporations by estimating a stochastic production frontier model. Stochastic frontier models have been widely applied in the analyses of the efficiency of agricultural production (Aigner et al. 1977; Battese and Coelli 1992; Battese and Coelli 1995; Meeusen and Julien 1977; Perdomo et al. 2022; Zhang et al. 2019).

An agricultural management entity is technically inefficient when it operates beneath its stochastic production frontier. Thus, the production technology of an agricultural corporation can be characterized by a production function of the form

$$y = a_0 \prod_{i=1}^{n} x_i^{a_i} e^{v-u}, \qquad (1)$$

where y is the agricultural output of the agricultural management entities, the x_i are the inputs to the production process, a_0 and a_i are parameters, v is a random error term that captures random variation in output due to factors outside the control, which is distributed as $N(0, \sigma_v^2)$, and u is a non-negative disturbance and reflects technical inefficiency, which is distributed as $N^+(0, \sigma_u^2)$.

The log-linear form of this production function can be written as

$$\ln y = \ln a_0 + \sum_{i=1}^{n} a_i \ln x_i + v - u. \qquad (2)$$

Obviously, $\ln y$ is bounded from above by the stochastic production frontier

$$\ln a_0 + \sum_{i=1}^{n} a_i \ln x_i + v, \qquad (3)$$

with technical efficiency relative to the frontier given by u percent.

The log-linear form of this production defined in Equation 2 is used to estimate technical efficiency. In fact, besides the production system approach, a form of stochastic cost frontier is also widely used to identify and measure technical and allocative efficiencies (Kumbhakar 1997; Mosheim and Lovell 2009). However, Kumbhakar and Wang (2006) point out that the estimates of a cost frontier function can be easily biased without the cost of allocative inefficiency included explicitly. Here, we do not adopt the form of a cost system approach mainly for another reason. To make the comparison of technical efficiency between family farms and agricultural corporations meaningful, we must put them at the same production or cost frontier. However, this condition cannot be satisfied in the estimation of cost frontier because family farms and agricultural corporations do not encounter the same factor markets. In other words, they face systematically different prices of production factors. This point is of great importance. Simply speaking, an agricultural corporation might be identified as being more technically efficient in the estimates of the cost frontier model, but such technical efficiency is due to lower prices of input factors rather than less quantity of input factors. Intuitively, in terms of technical efficiency, we only want to observe which production form can use less input to produce the same output or which can produce more output using the same amount of input. Therefore, the production system approach is better suited to such an objective.

Measurement of Allocative Efficiency

As stated previously, allocative inefficiency is defined as the degree of failure to combine inputs in optimal proportions to minimize the production costs, namely, failure to equate the marginal rate of technical substitution between any two inputs to the ratio of corresponding input prices. Thus, by adding the first-order conditions for cost minimization into the production function defined as Equation 1, we will have

$$\frac{f_j}{f_1} = \frac{p_j}{p_1} e^{\xi_j}, \qquad (4)$$

where f_j represents the first derivation of the production function for input j, p_j is the price for input j, and ξ_j is interpreted as the allocative inefficiency for the input pair $(j,1)$. x_1 is the numeraire. The sign ξ_j shows whether input j is over- or underused relative to numeraire input 1. A positive sign means input j is underused relative to input 1, while a negative sign means input j is overused relative to input 1.

Equation 4 can also be rewritten as

$$\frac{\partial \text{In} y}{\partial \text{In} x_j} \div \frac{\partial \text{In} y}{\partial \text{In} x_1} \equiv \frac{s_j}{s_1} = \frac{p_j \cdot x_j}{p_1 \cdot x_1} e^{\xi j} = \frac{a_j}{a_1}, \qquad (5)$$

where s_j is cost share of input j, which is defined as $s_j = p_j \cdot x_j / c$ and $c = \sum_j p_j \cdot x_j$. Taking logs for Equation 5 yields

$$\ln(a_j/a_1) - \ln(p_j/p_1) - \ln x_j + \ln x_1 = \xi_j. \qquad (6)$$

Due to the linear homogeneity in input prices, only relative inefficiency can be estimated using Equation 6. In the following analysis, we choose land as the numeraire to estimate relative allocative inefficiency.[3]

[3] The estimation results will not be affected by choice of the input used as the numeraire. Thus, the choice of determining the numeraire can be arbitrary (Kumbhakar, et al. 2015; Khataza et al. 2019).

TFP Decomposition

To examine the technical and efficiency changes, this study decomposes the TFP growth in family farms and agricultural corporations, respectively. There are various approaches used to decompose TFP, including parametric estimation of production or cost functions, non-parametric indices, exact index numbers, and non-parametric methods using linear programmings (Bauer 1990; Kalirajan et al. 1996; Kumbhakar, et al. 2015). Following the above method of estimating technical and allocative efficiency, we use the parametric estimation of the production function to decompose the TFP. The production function has been defined as Equation 1. And TFP change, which measures the productivity change, can be expressed in the form of

$$\dot{TFP} = \dot{y} - \sum_j s_j \dot{x}_j . \qquad (7)$$

Differentiating Equation 1 totally and combing it with Equation 7, we will have

$$\dot{TFP} = TC - \frac{\partial u}{\partial t} + \sum_j \left(\frac{f_j x_j}{f} - s_j \right) \dot{x}_j = (RTS - 1) \sum_j \lambda_j \dot{x}_j + TC + TEC + \sum_j (\lambda_j - s_j) \dot{x}_j , \qquad (8)$$

where $TC = \frac{\partial \ln f(\cdot)}{\partial t}$, is the measure of technical change; $TEC = -\frac{\partial u}{\partial t}$, is the measure of technical efficiency change; and $RTS = \sum_j \frac{\partial \ln y(\cdot)}{\partial \ln x_j} = \sum_j \frac{\partial \ln f(\cdot)}{\partial \ln x_j} = \sum_j f_j(\cdot) x_j \equiv \sum_j \epsilon_j$, is the measure of returns to scale. ϵ_j is the input elasticity defined as the production frontier. $\lambda_j = f_j x_j / \sum_k f_k x_k = \epsilon_j / RTS$.

In this way, we can decompose *TFP* into scale components, $(RTS - 1) \sum_j \lambda_j \dot{x}_j$, technical progress, *TC*, technical efficiency change, *TEC*, and change in allocative efficiency, $\sum_j (\lambda_j - s_j) \dot{x}_j$.

Table2 Description of Variables and Data Sources

Variable	Unit	Description	Source
Output			
Rice Output	kg	Annual gross rice output per household/corporation	Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Input			
Labor Input	hour	Labor hours input in rice production per household/corporation consisting of hours input of family members and employed workers	Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Agricultural Fixed Assets	1000 yen	Fixed assets relative to rice production owned by per household/corporation	Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Cultivated Land	hectare	Area of land sown with rice per household/corporation consisting of owned land and rented land	Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Other Costs	1000 yen	Costs consisting of expenses in seedlings, fertilizer, agricultural chemicals, relative materials and fuel, and power	Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Price Index			
Price Index of Fixed Assets	100	Price index of agricultural implements (2015=100)	Statistical Survey on Prices in Agriculture (Statistics code: 00500204)
Price Index of Other Costs	100	Price index of other materials for agricultural production (2015=100)	Statistical Survey on Prices in Agriculture (Statistics code: 00500204)
Factor Price			
Labor Wage	yen/hour	Average wage weighted by household labor input and employment labor input	Calculated from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Rate of Interest	%	Interest rate of borrowing	Calculated from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Land Rent	yen/10ha	Average land rent weighted by owned land and rented land	Calculated from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Others			
Ratio of Employed Labor	%	Percentage of hours input of employed labor in total hours input	Calculated from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201)
Ratio of Borrowed Land	%	Percentage of borrowed land area in the total cultivated land area	Calculated from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201)

Data and Grouping

Data

This study adopts the aggregate data from the Statistical Survey on Farm Management and Economy (Statistics code: 00500201) conducted by the Ministry of Agriculture, Forestry, and Fisheries of Japan. This survey is conducted on and summarizes family farmers and agricultural corporations of different sizes. Japan's Statistical Survey on Farm Management and Economy divides family farms into ten grades and agricultural corporations into four grades according to their operating land scale, as shown in Figure 1. It reports the averages of various inputs and outputs of family farms and agricultural corporations on different operating land sizes each year. Considering production techniques and outputs vary greatly across different agricultural product sectors, we choose single rice farming entities, the family farms and agricultural corporations in which more than 80 percent of their total agricultural sales is rice, as research objects. Our observation period spanned 2004 to 2016, thus this study adopts a panel data set with 14 observations for 13 years.

Table 2 describes each of the variables used in the estimation and its data sources. To estimate the stochastic production frontier model, we choose gross rice output (in kgs) as the output variable. For input variables, we select labor input (in hours), agricultural fixed assets (in thousand Japanese yen), the area of arable land (in hectares), and other costs (in thousand Japanese yen), which consists of expenses in seedlings, fertilizer, agricultural chemicals, various relative materials and fuel, and power. Note that labor input includes both family labor input and hired labor input, and land input combines owned land and rented land. Agricultural fixed assets and other costs are deflated to the prices of 2015. The relevant data on the price index are from the Statistical Survey on Prices in Agriculture (Statistics code: 00500204) published by the Ministry of Agriculture, Forestry and Fisheries of Japan. Labor wage is calculated by dividing total labor cost by labor hours. Land rent is calculated by dividing the total cost of land rent by the area of borrowed land. Agricultural capital price is calculated by dividing debt interest by total debt.[4]

Grouping

It is well-known that land size plays a crucial role in assessing and explaining the performance of family farms (Chayanov 1991; Hall and LeVeen 1978; Helfand and Levine 2004; Henneberry et al. 1991; Khataza et al. 2019; Mottaleb and Mohanty 2015; Weersink and Tauer 1991; Wolf and Sumner 2001). To eliminate the effect of land size on assessing economic efficiency and to obtain as accurate as possible comparison results of production efficiency between family farms and agricultural corporations, we split family farms and agricultural corporations into four groups according to their operating land scale. As shown in Table 3, we classify family farms whose operating land scale is under 7 hectares as group one and classify family farms between 7 and 10 hectares and agricultural corporations under 10 hectares as group two. Note there is neither subdivision for the agricultural corporations under 10 hectares nor a group one, as the average operating land scale of agricultural corporations under 10 hectares is over 7 hectares. Thus, we classify agricultural corporations under 10 hectares separately from family farms under 7 hectares. The family farms and agricultural corporations between 10 and 20 hectares are classified as group three, and family farms and agricultural corporations above 20 as group four. In such a way, the operating scale of family farms and agricultural corporations differs little within each group. Hence, in the following analysis, we will be intent on comparing the technical and allocative efficiency of family farms and agricultural corporations within each group.

Table3　Division of Operating Land Size

Form	Hectare	Group
Family Farms	<0.5	1
	0.5-1	
	1-2	
	2-3	
	3-5	
	5-7	
	7-10	2
	10-15	3
	15-20	
	>20	4
Agricultural Corporations	<10	2
	10-20	3
	20-30	4
	>30	

The summaries and comparison of variables between family farms and agricultural corporations within each group are reported in Table 4. Variations in the quantity of each input factor are insignificant between family farms and agricultural corporations within each group, suggesting our division is reasonable. Also prominent is that within each group the amount of labor input hours, agricultural fixed assets, cultivated land, and others

[4] The database of Management Statistics by Farming Type does not cover the relative data for calculating the input prices for single rice farming family farms. Hence, we use the database of Agricultural Production Costs, which also belongs to the Statistical Survey on Farm Management and Economy (Statistics code: 00500201), to calculate the input prices for single rice farming family farms.

expended in rice production by agricultural corporations is higher than that of family farms. But in terms of output levels, agricultural corporations do not always produce more rice than family farms. Only in group four (above 20 ha) is the average rice output of agricultural corporations greater than that of family farms. This might forebode that our hypothesis that agricultural corporations are more efficient than family farmers in agricultural production may be challenged.

It is worth mentioning the difference in factor prices paid by agricultural corporations and family farmers in each group. In group two (7-10 ha) and group three (10-20 ha), the average labor wage of family farms is higher than that of agricultural corporations. The situation in group four (above 20 ha) is the opposite. In all groups, the average interest rate (capital price) and land rent of agricultural corporations are lower than those of family farms. This implies that compared with traditional family farms, agricultural corporations tend to have more market power in the factors market and thus can obtain production factors at a lower price, especially in the capital and land rent markets.

Table4 Intra-group Comparison of Mean Values of Variables

	< 7 ha	7-10 ha		10-20 ha		>20 ha	
	Family Farms	Family Farms	Corporations	Family Farms	Corporations	Family Farms	Corporations
Rice Output	12714	42840	34929	76932	68911	137323	173230
Labor Input	642	1752	1927	2631	3287	4131	6768
Agricultural Fixed Assets	2496	6538	10572	11441	13391	20294	23127
Cultivated Land	313	1044	1226	1802	2044	3139	4591
Other Costs	687	2209	2802	3820	4165	7036	10092
Labor Wage	1417	1489	1183	1538	1260	1512	1686
Rate of Interest	3.87	3.61	0.45	3.48	0.80	3.42	0.74
Land Rent	16136	17772	11034	16992	12354	16976	13507
Ratio of Employed Labor	6.01	8.95	18.68	13.34	26.01	23.49	36.79
Ratio of Borrowed Land	22.96	52.06	87.32	52.98	97.72	62.47	94.39

Results

Estimates of Technical Efficiency

First of all, we estimated the production frontier aggregately for family farms and agricultural corporations. The parametric estimates for the frontier production function appear in Table 5. Model 1 shows the results with family farms and corporations estimated aggregately. For reference, we also estimate their production frontier separately and report the estimation results. Models 2 and 3 include the results with family farms and corporations estimated separately. All the estimated coefficients are statistically significant in the three models except capital, whose coefficient is insignificant in Model 1 and Model 3. The estimated coefficient of ln capital is negative in Model 3. This is mainly because agricultural capital is over-invested to some extent in agricultural corporations, and thus as capital inputs increase, output first rises and then falls. That is, rice output and capital inputs show an inverted U-shaped relationship in agricultural corporations. For that reason, we add the square of the ln Capital into Model 3 and re-estimate the stochastic frontier production of agricultural corporations, shown in Model 4.

The return to scale is 0.772, 0.759, 0.902, and 1.05 in the four models, respectively. According to the results of the Wald test, the former two are significantly less than 1, but the last two are not markedly different from 1. The estimated parameter σ_u is much greater than that of σ_v, suggesting deviations from the production frontier are primarily due to technical inefficiency. The null hypothesis that there does not exist an inefficiency component is rejected, thus justifying the use of the stochastic frontier approach.

Table5　Parametric Estimates of the Stochastic Frontier Production Function

	Aggregated Model 1	Family Farms Model 2	Corporations Model 3	Corporations Model 4
ln Labor	0.154***	0.127*	0.120*	0.120*
	(0.045)	(0.070)	(0.064)	(0.065)
ln Capital	0.021	0.110***	−0.037	0.133
	(0.022)	(0.037)	(0.032)	(0.560)
ln Land	0.300***	0.215**	0.502***	0.483***
	(0.079)	(0.104)	(0.130)	(0.147)
ln Others	0.297***	0.308***	0.317***	0.320***
	(0.065)	(0.078)	(0.123)	(0.125)
ln Capital * ln Capital	−	−	−	−0.009
	−	−	−	(0.029)
sigma u	0.434	0.493	0.176	0.183
sigma v	0.043	0.040	0.047	0.047
Observations	182	130	52	52

Note. Models 1-4 use Modified-LSDV time-varying fixed-effect estimators. Standard errors are reported in parentheses. Significant levels are * 0.10, ** 0.05, *** 0.01

In Model 1, the estimated coefficients of ln Labor, ln Capital, and ln Land are 0.154, 0.021, and 0.300, respectively. In Model 2, the estimated coefficients of ln Labor, ln Capital, and ln Land are 0.127, 0.110, and 0.215, respectively. In Model 3, they are 0.120, -0.037, 0.502, and 0.317, respectively. After including the square of the ln Capital, the coefficient of ln Capital becomes 0.133, while minor deviations are observed in the other coefficients. These results echo those of the existing literature. Ajibefun et al. (2002) estimated the translog stochastic frontier production function of Japanese rice farms for 1984-1994. According to their estimation results, the coefficients of ln Labor, ln Capital, and ln Land are 0.191, 0.210, and 0.163, respectively. Considering their chosen study period, the estimates appear to reflect the situation of family farms. Hence, in comparing their results with ours from Model 2, we can see that the coefficient of ln Capital is smaller than theirs by almost twice, and variations in the other coefficients are minimal.

Table6　Technical Efficiency

Group	Aggregated		Separated		DEA	
	Family Farms	Corporations	Family Farms	Corporations	Family Farms	Corporations
<7 ha	0.446	−	0.433	−	0.890	−
7-10 ha	0.707	0.504	0.712	0.640	0.899	0.657
10-20 ha	0.847	0.689	0.855	0.818	0.930	0.758
>20 ha	0.988	0.922	1.000	0.982	0.958	0.900
Average	0.607	0.759	0.602	0.856	0.906	0.804

Table 6 summarizes the technical efficiency estimated from the stochastic frontier models. The first and the second columns are estimated from Model 1. The third column comes from Model 2, and the fourth column is derived from Model. 4. For comparison, the efficiency scores from the Data Envelopment Method (DEA) are included in the last columns.[5]

Let us view the estimated technical efficiency from the stochastic frontier production function. There are some interesting findings. First, technical efficiency is higher in family farms than in agricultural corporations, whether estimated aggregately or separately. For example, according to the estimation results from aggregated estimation, the average technical efficiency of family farms is 0.446 in farm sizes below 7 hectares (group one). It means that family farms in this group, on average, produce around half

[5]The method of DEA refers to Appendix B. For related literature, refer to Liu et al. (2015), Mao and Koo (1997), and Sarac et al. (2022).

of their maximum potential output due to technical inefficiency. In farm sizes between 7-10 hectares (group two), technical efficiency is 0.707 in family farms and 0.504 in agricultural corporations. In group three, between 10-20 hectares in size, it is 0.847 in family farms and 0.689 in agricultural corporations. In farm sizes above 20 hectares (group four), technical efficiency is 0.988 in family farms and 0.922 in agricultural corporations. Second, the disparity in technical efficiency between the two production forms diminishes as farm size increases. According to the results from the aggregated estimation, the gap in technical efficiency between the two is 0.20 in group two (7-10 ha), 0.16 in group three (10-20 ha), and 0.07 in group four (above 20 ha). As for the results from the separated estimation, the gap in technical efficiency between the two is 0.07, 0.04, and 0.02 in the three groups, respectively, displaying the same law. Lastly, technical efficiency rises with farm size increases, whether in family farms or agricultural corporations. In other words, the larger the entity's land scale is, the larger its technical efficiency is. This rule applies to family farms and agricultural corporations.

The findings from the DEA method are comparable, except that the relative level of technical efficiency in agricultural corporations is much lower. For example, based on parametric estimation of the frontier production function, the technical efficiency of agricultural corporations between 7-10 hectares is larger than that of family farms below 7 hectares. However, based on the DEA method, the technical efficiencies of agricultural corporations sized between 7-10 hectares and 10-20 hectares are smaller than that of family farms below 7 hectares.

In short, our results confirm that family farms are more technically efficient than agricultural corporations at the same level of operating land scale. However, Fujie and Senda (2022) adopt DEA to estimate and compare the production efficiency between family farms and agricultural corporations in the Japanese rice sector. They argue there is no significant difference in efficiency between corporate farms and family farms on average. But they also point out that the efficiency of family management significantly exceeds the efficiency of corporate management at the medium- and large-scale operations, confirming the superiority of family farms in the medium- and large-scale groups. However, they use agricultural gross income rather than rice output as the output variable in estimates, which involves the effect of the rice sale price. The same problem arises in Dong (2022)'s study, whose results show that agricultural corporations exhibit higher production efficiency than family farms in Japanese agriculture. Taking into account the effect of the rice sale price difference between the two production forms, we have reason to believe our estimates and results are more reliable and reflect the reality of agriculture in Japan.

Moreover, importantly, our estimations show that rice production's technical efficiency rises as farm size increases. This finding seems incongruous with the hypothesis of the inverse farm size-productivity relationship, which depicts that small farms are more productive than larger farms and has been widely discussed and verified in existing literature (Carletto et al. 2013; Charnes et al. 1978; Chayanov 1991; Cornia 1985; Kagin et al. 2016; Larson et al. 2014; Schultz 1967; Sen 1962). However, there are two notable differences between those studies and our findings. Firstly, productivity is not equal to production efficiency. Many measurements have been used to represent productivity, and the most often used is the net value or net weight of output per unit of cultivated land (Carletto et al. 2013; Kagin et al. 2016; Muyanga and Jayne 2019). Secondly, those studies supporting the inverse farm size-productivity relationship mainly examine smallholder farms between zero and 10 hectares or so. However, division is crucial in verifying such a relationship. Muyanga and Jayne (2019)'s study examined farms in Kenya with a broader range of farm sizes (≤ 5ha, 5-20ha, >20ha) and detected a U-shaped relationship between farm size and farm productivity. Specifically, they found that the inverse relationship hypothesis holds true on farms between zero and 3 hectares, the relationship between farm size and productivity is relatively flat between 3 and 5 hectares, and a strong positive relationship between farm size and productivity emerges within the 5 to 7 hectare range of farm sizes. Hence, we can see how much the distribution and grouping of samples affect the verifying results of the hypothesis.

How about the relationship between land productivity and farm size for the two forms in our study? Figure 2 shows the relationship between land productivity and farm size. Unlike the hypothesis of the inverse farm size-productivity relationship, the relationship between land productivity and farm size is more like an inverse U-shape in both family farms and agricultural corporations. That is to say, land productivity first increases and then decreases as farm size expands. And similarly, land productivity is greater in family farms than in agricultural corporations at a similar farm size. This is quite interesting.

Estimates of Allocative Efficiency

In the following analysis, we mainly use the estimated results of the stochastic frontier production function from Model 1 to examine the allocative efficiency of family farms and agricultural corporations. There is no relative data for calculating the prices of seedlings, fertilizer, and others for agricultural corporations in the statistics of such a period. Hence, we only consider the three inputs of labor, capital, and land when estimating allocative efficiency in this section. The prices of the three input factors are summarized in Table 4. Note that for both family farms and agricultural corporations, the wage of family labor and the rent of self-owned land are included when calculating the input prices.

Table7　Allocative Inefficiency

Group	*ξlabor*		*ξcapital*	
	Family Farms	Corporations	Family Farms	Corporations
<7 ha	−1.419	−	−3.039	−
7-10 ha	−1.090	−1.302	−2.488	−0.940
10-20 ha	−1.025	−1.307	−2.507	−1.370
>20 ha	−0.899	−1.384	−2.487	−0.844
Average	−1.250	−1.344	−2.822	−0.999

An estimation of allocative inefficiency is reported in Table 7.[6] With land as the numeraire, we find that labor and capital are overused in both family farms and agricultural corporations. This phenomenon is mainly due to a serious shortage of arable land in Japan and thus the high relative price of arable land to labor and capital, shown in Table 4. Both family farms and agricultural corporations try to fully utilize farmland by devoting more resources to other factors in production.

In terms of labor, the absolute value of family farms is less than that of agricultural corporations, suggesting the allocative inefficiency of labor is larger in agricultural corporations. Namely, the overuse of labor is more serious in agricultural corporations. As farm size increases, allocative inefficiency improves in family farms. This is because as operating land size expands, the ratio of employed labor used in family farms increases, shown in Table 4. Apparently, a family farm with a high ratio of employed labor can adjust labor input more elastically, such as responding to labor wage change, than a family farm full of family labor. Nevertheless, such a rule is not applicable to agricultural corporations. Even though the ratio of employed labor in agricultural corporations also rises as their operating land size expands, the allocative inefficiency of labor in agricultural corporations rises rather than decreases as operating land size expands. This difference between the two production types is probably due to the fact that employment contracts in family farms are usually for a short period, while employment contracts in agricultural corporations are usually for a long period, which results in family farms performing better in adjusting labor input when responding to the change in labor wage than agricultural corporations do on average. It is important to note that the allocative inefficiency is highest in family farms below 7 hectares, suggesting the biggest challenge for an agricultural management entity full of family labor is adjusting relative labor input in response to changes in labor wage. Our findings further the existing conclusion on the advantages of family farms in using labor. For example, Kostov et al.（2019）verified the superiority of family farms relative to agricultural corporations in the organizational efficiency of family labor by examining family and corporate farms of EU Member States. However, our results document that the superiority of family farms might be more embodied in the distribution of family labor and employed labor according to labor wage. The situation is reversed when it comes to capital. The allocative inefficiency of capital is larger in family farms, as the overuse of capital is much more severe in family farms. Over-investment in the Japanese rice sector has been elaborated on and proven in existing literature（e.g., Hara and Hitoshi 2008）. The disparity of allocative inefficiency of capital between family farms and agricultural corporations is mainly due to the distinguished ability to acquire loans from financial institutions and invest in agricultural capital. Exactly, agricultural corporations are more likely to obtain low-interest loans than family farms. Their lending interest rate is much lower than family farms, as shown in Table 6. It implies that agricultural corporations can obtain more credit when increased agricultural capital is required. They need not invest in precautionary agricultural capital since they can obtain credit more easily than family farms. Therefore, agricultural corporations have a higher ability to adjust agricultural capital in response to changes in capital price.

TFP Decomposition

By applying the data into Equation 8, we can decompose and compare TFP for family farms and agricultural corporations, respectively.[7] Changes in inputs and RTS of family farms and agricultural corporations are reported in Table 8. Labor input

[6]The values of the coefficients of ln Labor, ln Capital, and ln Land used to estimate the allocative inefficiency are 0.15, 0.12, and 0.30. The value of the coefficient of ln Capital adopts the mean value of the coefficient of ln Capital from Model 2 and that from Model 4, considering the estimated value is far smaller in Model 1.

[7]Considering the data of separate prices of fertilizer for the two entity types are unavailable, we also only consider the three inputs of labor, capital, and land in decomposing TFP, similar in the estimates of allocative efficiency. The reestimation of the translog stochastic frontier production function for TFP decomposition is reported in Appendix C.

and agricultural capital used per management entity declined in family farms from 2004 to 2016. The situation in agricultural corporations is basically the same, except that labor input increases in agricultural corporations below 20 hectares. Regarding land, the area of arable land used increases in family farms below 20 hectares but declines in those above 20 hectares. The situation in agricultural corporations is the opposite. The area of arable land used declines in agricultural corporations below 20 hectares but increases in those above 20 hectares. These findings confirm our conclusion on allocative efficiency above. Namely, labor and capital are both overused relative to land in family farms and agricultural corporations. Thus, both family farms and agricultural corporations tend to reduce these two factors' input and expand the area of arable land.

Table8　Changes in Inputs and RTS (%, unit)

		Family Farms	Corporations
< 7 ha	% Growth of Labor	−0.52	−
	% Growth of Capital	−3.11	−
	% Growth of Land	0.84	−
	RTS	1.22	−
7-10 ha	% Growth of Labor	−1.27	0.87
	% Growth of Capital	−2.21	−1.49
	% Growth of Land	1.77	−0.43
	RTS	1.10	1.11
10-20 ha	% Growth of Labor	−0.27	0.15
	% Growth of Capital	−2.54	−3.21
	% Growth of Land	1.31	−1.06
	RTS	1.08	1.01
>20 ha	% Growth of Labor	−0.18	−1.17
	% Growth of Capital	−3.74	−3.95
	% Growth of Land	−0.09	0.41
	RTS	1.04	0.91
Average	% Growth of Labor	−0.51	−0.33
	% Growth of Capital	−2.97	−3.15
	% Growth of Land	0.93	−0.16
	RTS	1.16	0.98

Table9　Decomposition of TFP (%)

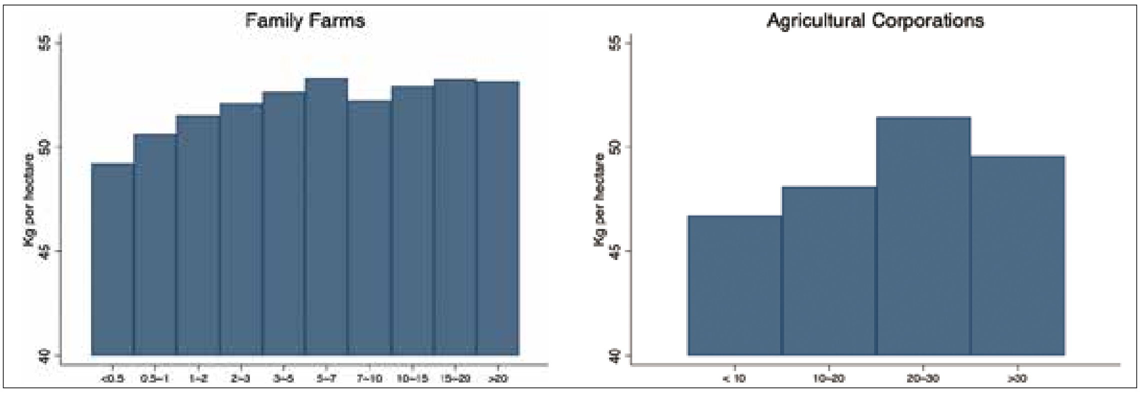
		Family Farms	Corporations
< 7 ha	TFP	1.19	−
	Scale	−0.13	−
	TC	−0.55	−
	TEC	0.23	−
	Allocative	1.73	−
7-10 ha	TFP	0.04	−15.98
	Scale	−0.23	−1.80
	TC	−0.08	0.01
	TEC	−0.01	−0.34
	Allocative	0.37	−13.85
10-20 ha	TFP	−0.37	−8.63
	Scale	−0.21	−0.39
	TC	0.13	0.20
	TEC	0.69	0.81
	Allocative	−0.97	−9.24
>20 ha	TFP	0.60	−5.05
	Scale	−0.18	0.66
	TC	0.34	0.42
	TEC	0.51	1.27
	Allocative	−0.07	−7.40
Average	TFP	0.69	−8.68
	Scale	−0.16	−0.22
	TC	−0.28	0.26
	TEC	0.33	0.75
	Allocative	0.85	−9.47

Table 8 shows that RTS is greater than 1 (increasing return to scale) except in agricultural corporations above 20 hectares. This finding seems contradictory to what we found in Table 5. Such inconsistency is mainly due to the fact that we only consider labor, capital, and land in decomposing TFP and exclude other factors. However, we can see that RTS decreases as farm size increases. It declines from 1.22 in farm size below 7 hectares (group 1) to 1.04 for those above 20 hectares (group 4) in family farms. In agricultural corporations, it declines from 1.11 to 0.91. These data are in line with our expectations.

On the basis of Table 8, we decompose TFP for family farms and agricultural corporations, respectively. The results of the decomposition of TFP are summarized in Table 9. The scale component is -0.16 in family farms and -0.22 in agricultural corporations on average. Recall Table 8, the negative scale component is mainly driven by the declining input. Technical change is, on average, -0.28 in family farms and 0.26 in agricultural corporations, suggesting technical progress is faster in agricultural corporations than in family farms. In addition, as farm size increases, technical progress becomes faster accordingly, regardless of the type.

Technical efficiency change, TEC, is 0.33 in family farms and 0.75 in agricultural corporations. It reveals that even though family farms show a larger technical efficiency than agricultural corporations, as concluded in Section 4.1, the improvement in technical efficiency is more rapid in the latter. As to allocative efficiency, the previous analysis reveals that family farms show superiority in the allocative efficiency of labor, and agricultural corporations show superiority in the allocative efficiency of agricultural capital. However, the change in allocative efficiency is positive in family farms but negative in agricultural corporations. This phenomenon might be due to the fact that the average prices of most input factors are higher in family farms than in agricultural corporations, as shown in Table 4. Therefore, family farms are sensitive to changes in input prices and are incentivized to improve their allocative efficiency. Furthermore, the allocative efficiency component is the largest contributor to each TFP of family farms and agricultural corporations. Hence, this drives TFP positively in family farms but negatively in agricultural corporations. Besides, it is important to note that TFP increases in agricultural corporations as farm size increases, which also suggests that the larger the agricultural corporation is, the better it is. Importantly, our findings from TFP decomposition deepen our understanding of the relationship between TFP change and operation size by involving agricultural corporations. Much existing literature confirms that the driving factors behind the TFP growth of family farms of different operation sizes are different (Rahmatullah and Kuroda 2005; Fan and Chan- Kang 2005; Hu 1995; Kuroda 1989). Our findings reveal this rule is also applicable to agricultural corporations.

Figure2　Farm Size and Land Productivity



Conclusions

This study attempts to answer the question of whether an agricultural corporation is more efficient than a traditional family farm, a subject which is both important and forward-looking. As an extension and development of the existing theory on the production efficiency of family farms, this study provides crucial evidence for assessing and comparing production efficiency between traditional family farms and agricultural corporations systematically.

Our analysis found that family farms have a significant advantage over agricultural corporations in technical efficiency at each level of operation scale. It reveals that the family farm can utilize input factors to maximize output more efficiently than agricultural corporations in rice production. Moreover, the results show that larger operation scale is accompanied by higher technical efficiency in both family farms and agricultural corporations. The disparity in technical efficiency between the two forms diminishes as farm size increases. This implies that once farm size becomes large enough and exceeds a certain degree, the advantage of family farms may vanish. Those findings differ from the existing studies (Dong 2022; Fujie and Senda 2022), which argue that there is no significant difference in technical efficiency between the two production forms or that agricultural corporations are superior to traditional family farms in technical efficiency. Unlike recent studies, we chose rice output weight as the output variable to eliminate the effect of rice sale prices on the measurement of technical efficiency and adopted the stochastic production frontier method, which is more flexible and adaptable in form than the DEA method. Hence, our estimation results are more reasonable and credible.

The findings in allocative efficiency are more complicated. In fact, allocative efficiency varies from family farms to agricultural corporations, as well as across different input factors and across land scales. Overall, family farms exhibit superiority in the allocative efficiency of labor, and agricultural corporations show superiority in the allocative efficiency of agricultural capital. Both labor and capital relative to land are overused in family farms and agricultural corporations. This can be put down to the severe shortage of agricultural land in Japan, which makes the relative of land much higher than the prices of other inputs.

On the basis of the analysis of technical and allocative efficiency, we decomposed TFP to examine the changes in TFP and in each of its components. Overall, family farms have positive TFP change, which is mainly contributed by a positive and large allocative component. In contrast, agricultural corporations experience negative TFP change which is largely driven by its negative and large allocative component. Separately, technical progress and efficiency improvement are faster in agricultural corporations than in family farms. By contrast, family farms are superior to agricultural corporations in scale effect and allocative efficiency improvement.

Reviewing what we have learned thus far, we can draw a conclusion and discuss the reasons behind it. Firstly, overall, family farms are more technically efficient than agricultural corporations at the same level of operation land scale. There are two possible explanations as to why this is the case. For one, we have seen that prices of most input factors, mainly referring to labor and land, are higher for family farms than for agricultural corporations. That makes family farms use input factors more carefully and sparingly. For another, the ratio of employed labor and the ratio of borrowed land are both lower in family farms relative to agricultural corporations of the same operation size. This makes agricultural production more stable in family farms and makes it easier to plan various inputs during the production process and, thus, more possible to maximize agricultural output. More than that, we also see that as farm size increases, the disparity in technical efficiency between the two forms narrows. A probable reason is that as farm size increases, the ratios of employed labor and borrowed land rise in family farms, therefore, diminishing their advantage in technical efficiency.

Secondly, the superiority of family farms and agricultural corporations in allocative efficiency varies across input factors. Simply speaking, family farms are better at utilizing labor, while agricultural corporations are better at utilizing capital. A likely explanation is that employment in family farms is more flexible than in agricultural corporations and that agricultural corporations have better access to credit. Lastly, family farms perform better in improving allocative efficiency, and agricultural corporations are better equipped to improve technical efficiency and progress. This reveals traditional family farms are more sensitive to changes in the prices of input than agricultural corporations, and the latter has a stronger ability for technical innovation. Hence, our hypothesis that agricultural corporations are more efficient than family farms in production efficiency is mostly rejected in this study.

The work provides some interesting insight and suggestions for developing agricultural production entities. First, we have proven that, on average, family farms are superior to agricultural corporations in technical efficiency. That being so, the replacement of family farms with agricultural corporations will generate net welfare loss unless we can reverse this problem. Accordingly, future studies must figure out which factors result in lower technical efficiency in agricultural corporations. Secondly, irrespective of the analysis of technical and allocative efficiency or the analysis of decomposing TFP, the golden rule shown is that the larger an agricultural corporation is, the better it is. In other words, the superiority of agricultural corporations is primarily embodied when their scales are large enough. Hence, the key is to develop agricultural corporations of large land scale.

Finally, we would like to address the limitations of this study. Although we have proven that traditional family farms exceed agricultural corporations in production efficiency, we must respect the rapid rise of agricultural corporations in Japan, as explained in the introduction. Our findings do not attempt to provide reasons for this movement in Japanese agriculture. Rather, the theme requires more in-depth examination via future studies. A reasonable argument is that agricultural corporations have a remarkable advantage over traditional family farms in maintaining higher rice sale prices and lower input factors prices. However, this supposition needs further systematic verification and discussion, which we plan to undertake as a follow-up.

＜References＞

Adams, J.（1986）. “Peasant rationality: individuals, groups, cultures”. World Development 14（2）, 273-282.

Aigner, D., Lovell, C.A. K., and Schmidt, P.（1977）. “Formulation and estimation of stochastic frontier production function models”. Journal of Econometrics 6（1）, 21-37.

Ajibefun, I. A., Kada, R., and Battese, G. E.（2002）. “Technical efficiency and technological change in Japanese rice industry: a stochastic frontier analysis”. In: Acharya, S.S. et al.（eds）, Sustainable Agriculture, Poverty and Food Security: Agenda for Asian Economies. Rawat Publications, Jaipur and New Delhi, 214-225.

Atkinson, S. E. and Cornwell, C.（1994）. “Parametric estimation of technical and allocative inefficiency with panel data”. International Economic Review, 231-243.

Battese, G. E. and Coelli , T. J.（1992）. “Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India”. Journal of Productivity Analysis 3（1）, 153-169.

Battese, G. E. and Coelli , T. J.（1995）. “A model for technical inefficiency effects in a stochastic frontier production function for panel data”. Empirical Economics 20（2）, 325-332.

Bauer, P. W.（1990）. “Decomposing TFP growth in the presence of cost inefficiency, nonconstant returns to scale, and technological progress”. Journal of Productivity Analysis 1（4）, 287-299.

Carletto, C., Savastano, S., and Zezza, A.（2013）. “Fact or artifact: the impact of measurement errors on the farm size-productivity relationship”. Journal of Development Economics 103, 254-261.

Charnes, A., Cooper, W. W., and Rhodes, E.（1978）. “Measuring the efficiency of decision making units”. European Journal of Operational Research 2（6）, 429-444.

Chayanov, A. V［1926］（1991）. The Theory of Peasant Co-Operatives. OH: Ohio State University Press.

Cornia, G. A.（1985）. “Farm size, land yields and the agricultural production function: an analysis for fifteen developing countries”. World Development 13（4）, 513-534.

Dong, Q.（2022）. “A comparison of production efficiency between peasant households and agricultural corporations in Japanese agriculture: 2004-2018（In Japanese）”. The Agricultural Economics Society of Japan, 2022 Annual Meeting, Conference Paper.

Egaitsu, F. and Suzuki, N.（2015）. Agricultural Economics（In Japanese）. Vol. 4. Tokyo: Iwanami Shoten.

Fan, S. and Connie C.（2005）. “Is small beautiful? Farm size, productivity, and poverty in Asian agriculture”. Agricultural economics 32, 135-146.

Farrell, M. J.（1957）. “The measurement of productive efficiency”. Journal of the Royal Statistical Society: Series A（General）120（3）, 253-281.

Fujie, T. and Senda T.（2022）. “Are corporate farms more efficient than family farms?: evidence from single rice farming（In Japanese）”. The Agricultural Economics Society of Japan, 2022 Annual Meeting, Conference Paper.

Hall, B. F. and LeVeen , E. P.（1978）. “Farm size and economic efficiency: the case of California”. American Journal of Agricultural Economics 60（4）, 589-600.

Hara, K. and Hitoshi K.（2008）. “Allocative efficiency and overinvestment in rice crop”. Agricultural Economic Papers of Kobe University 40, 17-21.

Helfand, S. M. and Levine, E. S.（2004）. “Farm size and the determinants of productive efficiency in the Brazilian Center-west”. Agricultural Economics 31（2-3）, 241-249.

Henneberry, S. R., Tweeten, L., and Nainggolan, K.（1991）. “An analysis of US aggregate output response by farm size”. Agricultural Economics 5（1）, 1-19.

Hu, B.（1995）. “The determinants of changes in total factor productivity of Japanese agriculture, 1960-90”. Journal of Rural Problems 31（3）, 103-111.

Kagin, J., Taylor, J. E., and Yunez-Naude, A.（2016）. “Inverse productivity or inverse efficiency? evidence from Mexico”. The Journal of Development Studies 52（3）, 396-411.

Kalirajan, K. P., Obwona, M. B., and Zhao, S.（1996）. “A decomposition of total factor productivity growth: the case of Chinese agricultural growth before and after reforms”. American Journal of Agricultural Economics 78（2）, 331-338.

Khataza, R. R. B., Hailu, A., Doole, G. J., Kragt, M. E., and Alene, A. D.（2019）. “Examining the relationship between farm size and productive efficiency: a Bayesian directional distance function approach”. Agricultural Economics 50（2）, 237-246.

Kopp, R. J. and Diewert, W. E.（1982）. “The decomposition of frontier cost function deviations into measures of technical and allocative efficiency”. Journal of Econometrics 19（2-3）, 319-331.

Kostov, P., Davidova, S., and Bailey, A.（2019）. “Comparative efficiency of family and corporate farms: does family labour matter?” Journal of Agricultural Economics 70（1）, 101-115.

Kumbhakar, S. C.（1997）. “Modeling allocative inefficiency in a translog cost function and cost share equations: an exact relationship”. Journal of Econometrics 76（1-2）, 351-356.

Kumbhakar, S. C., Wang, H. J., Horncastle, A. P.（2015）. A Practitioner’s Guide to Stochastic Frontier Analysis Using Stata. Cambridge University Press.

Kumbhakar, S. C. and Wang, H. J.（2006）. “Pitfalls in the estimation of a cost function that ignores allocative inefficiency: a Monte Carlo analysis”. Journal of Econometrics 134（2）, 317-340.

Kuroda, Y.（1989）. “Impacts of economies of scale and technological change on agricultural productivity in Japan”. Journal of The Japanese and International Economies 3（2）, 145-173.

Larson, D. F., Otsuka, K., Matsumoto, T., and Kilic, T.（2014）. “Should African rural development strategies depend on smallholder farms? an exploration of the inverse-productivity hypothesis”. Agricultural Economics 45（3）, 355-367.

Lipion, M.（1968）. “The theory of the optimising peasant”. The Journal of Development Studies 4（3）, 327-351.

Liu, S., Zhang, P. , He, X., and Li, J.（2015）. “Efficiency change in North-East China agricultural sector: a DEA approach”. Agricultural Economics 61（11）, 522-532.

Lowder, S. K., Skoet, J., and Raney, T. (2016). “The number, size, and distribution of farms, smallholder farms, and family farms worldwide”. World Development 87, 16-29.

Mann, S. A. and Dickinson, J. M. (1978). “Obstacles to the development of a capitalist agriculture”. The Journal of Peasant Studies 5 (4), 466-481.

Mao, W. N. and Koo, W. W. (1997). “Productivity growth, technological progress, and efficiency change in Chinese agriculture after rural economic reforms: a DEA approach”. China Economic Review 8 (2), 157-174.

Meeusen, W. and van Den Broeck, J. (1977). “Efficiency estimation from Cobb-Douglas production functions with composed error”. International Economic Review, 435-444.

Mosheim, R. and Lovell C. A. K. (2009). “Scale economies and inefficiency of US dairy farms”. American Journal of Agricultural Economics 91 (3), 777-794.

Mottaleb, K. A. and Mohanty, S. (2015). “Farm size and profitability of rice farming under rising input costs”. Journal of Land Use Science 10 (3), 243-255.

Muyanga, M. and Jayne, T. S. (2019). “Revisiting the farm size-productivity relationship based on a relatively wide range of farm sizes: evidence from Kenya”. American Journal of Agricultural Economics 101 (4), 1140-1163.

Perdomo Calvo, J. A., Arteche, J., and Ansuategi, A. (2022). “Returns to scale and technical efficiency in Colombian coffee production: implications for Colombia’s agricultural and land policies”. Studies in Agricultural Economics 124 (3), 104-112.

Popkin, S. (1980). “The rational peasant”. Theory and Society 9 (3), 411-471.

Rahmatullah, A B M. and Kuroda, Y. (2005). “Causality between capital investment and productivity in Japanese agriculture, 1957-97”. The Japanese Journal of Rural Economics 7, 78-87.

Sarac, S. B., Atici, K. B., and Ulucan, A. (2022). “Elasticity measurement on multiple levels of DEA frontiers: an application to agriculture”. Journal of Productivity Analysis 57 (3), 313-324.

Schultz, T. W. (1967). Transforming Traditional Agriculture. Yale University Press.

Schultz, T. W. (1980). “Nobel lecture: The economics of being poor”. Journal of Political Economy 88 (4), 639-651.

Sen, A. K. (1962). “An aspect of Indian agriculture”. Economic Weekly 14 (4-6), 243-246.

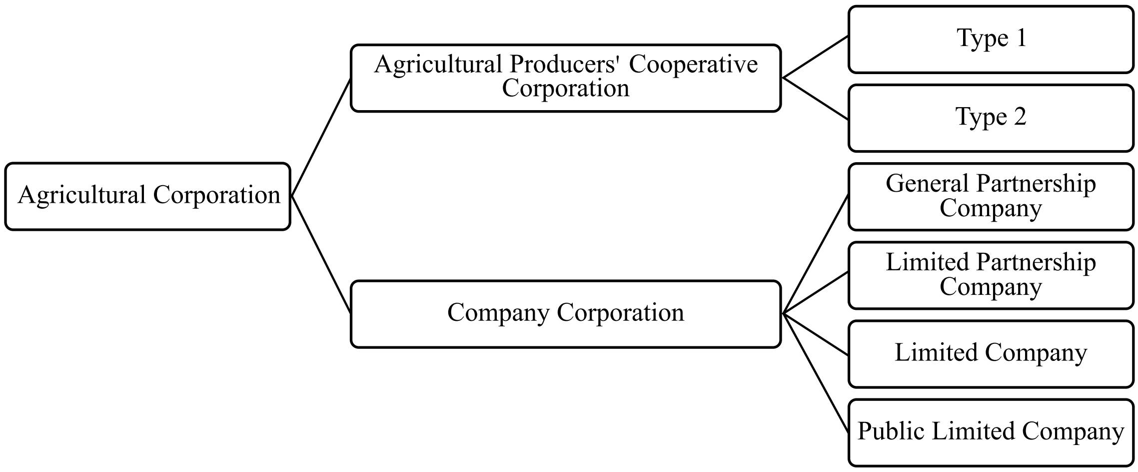
Weersink, A. and Tauer, L. W. (1991). “Causality between dairy farm size and productivity”. American Journal of Agricultural Economics 73 (4), 1138-1145.

Wolf, C. A. and Sumner D. A. (2001). “Are farm size distributions bimodal? evidence from kernel density estimates of dairy farm size distributions”. American Journal of Agricultural Economics 83 (1), 77-88.

Zhang, X., Yu, X., Tian, X., Geng, X., and Zhou, Y. (2019). “Farm size, inefficiency, and rice production cost in China”. Journal of Productivity Analysis 52 (1), 57-68.

＜Appendix＞

A. Types of Agricultural Corporations in Japan



B. DEA Method

Data Envelopment Analysis (DEA) was initially proposed by Charnes (1978) measuring to assess the operational efficiency of the decision-making unit (DMU) in public programs in order to improve the planning and control of these activities. This method is widely used in measuring operational efficiency and technical change in many fields, including agriculture.

In this method, the efficiency of any DMU is obtained as the maximum ratio of weighted outputs to weighted inputs subject to the condition that the similar ratios for each DMU be no more than unity. In more precise form, it can be expressed as:

$$\max_{v,u}\theta = \frac{u_1 y_{1i} + u_2 y_{2i} + \cdots + u_m y_{mi}}{v_1 x_{1i} + v_2 x_{2i} + \cdots + v_n x_{ni}} \quad \text{(B-1)}$$

subject to

$$\frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_m y_{mj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_n x_{nj}} \leq 1 \, (j = 1, \cdots, t) \quad \text{(B-2)}$$

$$u_p \geq 0 \, (p = 1, \cdots, m) \quad \text{(B-3)}$$

$$v_q \geq 0 \, (q = 1, \cdots, n) \quad \text{(B-4)}$$

where y_{pi} and x_{qi} are the known outputs and inputs of the ith DMU, p denotes the category of outputs, and q denotes the category of inputs. u_p and v_q are the variable weights of each output and input, which are called virtual multipliers and are to be determined by the solution to this problem. θ_i is the measured efficiency for the ith DMU.

The output-oriented DEA model is used with the variable returns to scale (VRS). The output variable is gross rice output (in kgs), and the input variables are labor input in agricultural production activity (in hours), the area of cultivated land (in hectares), and agricultural fixed assets (in 10 thousand Japanese yen). The agricultural fixed assets are deflated to 2015 prices.

C. Reestimation of Production Function for TFP Decomposition

Table C-1 Estimates of Parameters of the Translog Stochastic Frontier Production Functions

	Coefficient
ln Labor	2.969 (19.114)
ln Capital	−4.604 (18.261)
ln Land	−3.886** (1.701)
ln Labor * ln Labor	−3.891*** (0.641)
ln Capital * ln Capital	−0.585*** (0.144)
ln Land * ln Land	−2.673*** (0.677)
ln Labor * ln Capital	0.406** (0.206)
ln Labor * ln Land	2.888*** (0.650)
ln Capital * ln Land	0.186 (0.236)
Year	−0.035 (0.026)
Year * Year	0.000 (0.000)
Year * ln Labor	0.001 (0.009)
Year * ln Capital	0.003 (0.009)
Year * ln Land	0.000 (0.000)
sigma u	0.265
sigma v	0.038
lambda	6.933

Note. Model uses random-effects time-varying inefficiency effects model estimators. Standard errors are reported in parentheses. Significant levels are * 0.10, ** 0.05, and *** 0.01.