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A Nonparametric Approach to Measuring Cost Efficiency of Dairy Farms in Japan

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Abstract

The purpose of this paper is to analyze the cost efficiency of dairy farms in Japan. The overall cost efficiency measure is decomposed of two components: (1) the weak cost efficiency measure; (2) the scale efficiency measure. Linear programming techniques were used in calculating the efficiency measures (cost and scale) for a random sample of dairy farms in Japan in 1989. The study demonstrates that an overall cost inefficiency is not due to the scale inefficiency, but rather to a weak cost inefficiency.

Ⅰ. Introduction

The purpose of this paper is to estimate cost efficiency of a cross-section of dairy farms in Japan and to investigate the relationship between overall cost efficiency and farm characteristics. The empirical analysis of cost efficiency is based on the deterministic nonparametric approach of Färe and Grosskopf (1985)[1)].

There is a marked difference between dairy farming in Hokkaido, Japan's northernmost island, and dairy farming in the rest of Japan[2,3,4)]. Dairy farmers in Hokkaido currently produce more than 40% of Japan's milk (43% in 1998). In Hokkaido, the price of farmland is, on average, cheaper than in the rest of Japan. The low cost of farmland is due to a lower demand on land resources and remote location. On-farm fodder production is the basis of dairy farming in Hokkaido.

During the past three decades herd size on Hokkaido dairy farms has increased and there have been significant biological and mechanical improvements which means they are now at a level comparable to EU countries[5)]. Even though

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there has been progress, the average production costs of milk are still high from an international perspective. The reduction of production costs and international imports of dairy products are of a primary concern for Hokkaido dairy farmers. Therefore, measuring cost efficiency can provide useful insights into reducing production costs.

In developed countries many of the parametric frontier production functions have been estimated for dairy farms[6,7,8,9]. Battese (1992) discussed that an estimated parametric frontier production function can be used to determine efficiency[10]. Weersink, Turvey, and Godah (1990) and Jaforullah and Whiteman (1999) employed the nonparametric approach to examine the efficiency of dairy farms[11,12]. These efficiency studies employed the production side approach, whereas we have chosen to employ a cost side nonparametric approach. One advantage of the cost side nonparametric approach is the ease of acquiring data. Usually, it is difficult for researchers to obtain information on farm-specific data for inputs and input prices. If all farms faced the same input price, our efficiency measures would not require farm-specific data on inputs and input prices; they would only require farm-specific data on output and total costs that are usually easy to obtain.

The next section contains the theoretical framework of the model followed by the discussion of the data. The empirical results will be presented, including a correlation analysis of factors related to variations in cost efficiencies among the sample farms. The final section is summary and concluding remarks.

II. Methodology

Linear programming models developed by Färe and Grosskopf (1985) are used to calculate cost efficiency measures for each farm[1].

From the duality theory, we know that the properties of technology may be analyzed from the primal (input/output) side, or deduced from the dual or cost side. This dual method affords researchers a wider range of choice in terms of data requirements when calculating efficiencies. This approach can be used to calculate overall efficiency when information on inputs and input prices is not known, as long as all farms face the same input prices. In this paper, this dual approach is used to calculate the measures of cost efficiency.

Let us start with the most restrictive cost frontier that exhibits constant returns to scale (CRS). For the cost approach, suppose that a farm's output is given for each farm. Moreover, assume that the total cost of producing the output for each farm is given and that each farm faces the same input price vector.

The measure of overall cost efficiency defined in this study can be considered as the ratio of the potential or efficient cost using CRS technology to actual cost. The measure of cost efficiency (K) can be calculated by solving the following LP problem[1)]:

$$K = \min \lambda \qquad (1)$$

subject to

$$zM \geqq u_i$$
$$zC \leqq \lambda C_i$$
$$z \in R_+^k$$

where

$u_i = (u_i)$: ith farm's vector of output (1×1)
$M = (u_1 \cdots u_i \cdots u^k)^t$: the matrix of output $(k \times 1)$
$C = (c_1 \cdots c_i \cdots c^k)^t$: the matrix of total cost $(k \times 1)$
$z = (z_1 \cdots\cdots\cdots z^k)$: the intensity vector $(1 \times k)$
t : the notation of transpose vector (matrix)

In Fig. 1, four observations are labeled A', B', C' and P'. The cost frontier obtained from (1) is given by the ray O'H' and the c-axis. Only observation B' is efficient relative to this frontier. The measure of overall cost efficiency (K) applied to observation P' is given by the ratio OR'c/OP'c.

Next, we construct the less restrictive cost frontier that satisfies variable returns to scale (VRS). The measure of weak cost efficiency is equal to the ratio of the potential or efficient cost under the VRS technology to actual cost. The

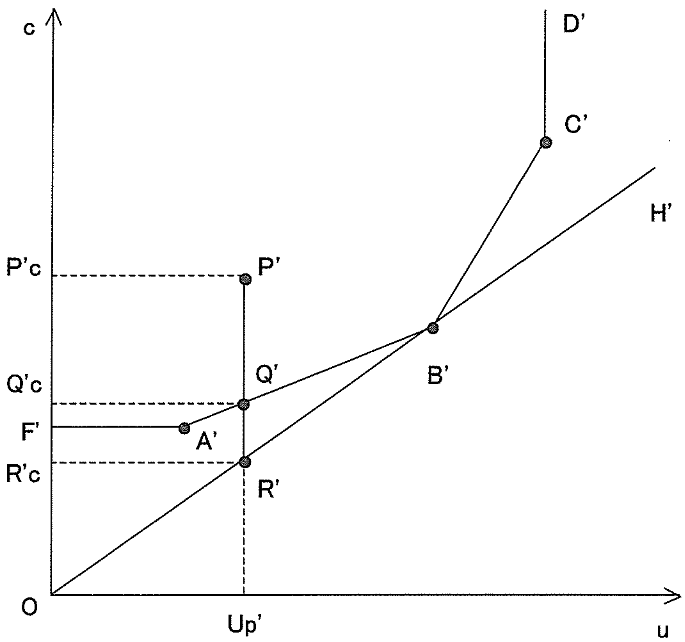

Fig. 1. Cost frontiers and efficiencies

measure of weak cost efficiency (W) can be calculated by solving the following LP problem[1]:

$$W = \min \lambda \tag{2}$$

subject to

$$zM \geqq u_i$$
$$zC \leqq \lambda C_i$$
$$\sum z_i = 1$$
$$z \in R^k_+$$

Afriat (1972) has shown that restricting the intensity vector to a sum of one permits decreasing, constant and increasing returns to scale[13].

In Fig. 1, the cost frontier obtained from (2) is given by the F'A'B'C'D' and the c-axis above F'. Here, observations A', B' and C' are all efficient. The measure of weak cost efficiency (W) applied to observation P' is given by the ratio OQ'c/OP'c.

Finally, a measure of scale efficiency (S) can now be defined as follows,

$$S = K/W \tag{3}$$

In terms of Fig. 1, the scale efficiency of observation P' is thus OR'c/OQ'c. Clearly, $0 < S \ll 1$. $S=1$ is called scale efficient if and only if the farm belongs to the CRS frontier given by the constraints in (1).

In sum, the measure of overall cost efficiency applied to observation P' is decomposed into as follows,

$$\underset{(OR'c/OP'c)}{K} = \underset{(OQ'c/OP'c)}{W} \times \underset{(OR'c/OQ'c)}{S} \tag{4}$$

Therefore, the overall cost efficiency is the product of weak cost efficiency and scale efficiency. Inefficiency is evident for an individual farm if the measure of each of the three efficiencies (K, W or S) is less than one.

To calculate the efficiency measures from the sample of farms used in this study, individual linear programming was run for each of the measures described in (1) and (2). Since 239 farms were examined, the results of the analysis are based on 478 linear programming solutions. The data and results of the analysis are presented in the following section.

III. Data

The data used to estimate the various efficiency measures were obtained from Survey on Production Costs of Milk, published by the Ministry of Agriculture, Forestry and Fisheries (MAF) of Japan in 1989. Of course, it is desirable to use the most recent data available, but the 1989 data was used in the study due to the unavailability of more recent information. In Japan there are few price variations found among farms at the one year cross-section so it is reasonable to assume that all farms in 1989 faced the same input prices as the sampled farms. The major data was used to compute the average production costs for the formula for pricing raw milk for dairy products. To achieve this objective, data on physical costs and farm characteristics were collected for a random sample of 239 farms.

Table 1 Summary statistics of Hokkaido dairy farms, 1989

Ⅰ) Production costs of milk (per farm)[1] (Raw milk per 100kg production cost, converted to a milk fat content of 3.5%; Unit=Yen/100kg)	
Reproduction (insemination)	126
Commercial feed	1596
Forage crops, grazing and mowing	2153
Bedding	85
Light, heat, water, material and fuel	148
Veterinary and medicine	166
Charges and fees	69
Dairy cattle (Depreciation)	521
Building	157
Agricultural implements	314
Labor	1689
Total costs	7025
Ⅱ) Management Characteristics (per farm)[1]	
Number of milking cows (cow／farm)	33.6
Milk production per cow (kg／cow)	7172
Working hours per milk production (hour／100kg)	1.71
Working hours per cow (hours／cow)	122.6
Cultivated land for forage crops per cow (a／cow)	72.3
Compound feed per cow (kg／cow)	1705
Ⅲ) Prices (Farmgate price)[2]	
Compound feed Price (Yen／kg)	49.6
Milk Price (Yen／kg)	77.2

Sources:
[1] Survey on production costs of milk, MAFF
[2] Commodity price indices in rural areas, MAFF

The milk output for these farms was measured in kg of 3.5% fat content milk. Eleven input costs (reproduction (insemination); commercial feed; forage crops, grazing and mowing; bedding; light, heat, water, material and fuel; veterinary and medicine; charges and fees; dairy cattle (depreciation); building; agricultural implements; labor) are used. Their average values are listed in Table 1, along with those for management characteristics and farmgate prices of compound feed and milk.

IV. Empirical results

A. Cost efficiency measures

The cost efficiency for each of the 239 Hokkaido dairy farms in the sample were determined by solving the series of two linear programming problems. The linear programming models derive the efficiency of each farm by comparing its observed costs and produced output relative to all other farms.

Table 2 includes the means and coefficients of variations of the three measures of cost efficiency of the sample as a whole, as well as by milk output size. Looking first at the sample as a whole, the overall cost efficiency (K) of farms in our sample is, on average, approximately 0.71. Recall that a value of

Table 2 Average cost efficiency of Hokkaido dairy farms by milk output class, 1989

	Cost Efficiency Measures		
Milk Output Class	K (overall)	W (weak)	S (scale)
Total	0.7053 (0.164)	0.7338 (0.143)	0.9591 (0.061)
0 - 99t	0.5325 (0.151)	0.6337 (0.167)	0.8446 (0.091)
100t - 199t	0.6877 (0.127)	0.7188 (0.126)	0.9567 (0.016)
200t - 299t	0.7222 (0.111)	0.7322 (0.110)	0.9862 (0.005)
300 - 400t	0.7760 (0.122)	0.7810 (0.121)	0.9936 (0.006)
≧ 400t	0.8006 (0.087)	0.8431 (0.105)	0.9522 (0.043)

Figures in the parentheses are coefficients of variations.

unity represents cost efficient production; i.e. actual cost is equal to minimum potential cost (as defined by the best practice in the sample). Thus, for our sample, on average, the farm costs could have been 29% less had they all been operating with overall cost efficiency.

The next question is; what is the major cause of this inefficiency? Recall that the product of weak cost efficiency and scale efficiency is overall cost efficiency. Turning to the component measures (W and S), the average level of weak cost efficiency is lower than the average level of scale efficiency (0.74 versus 0.96). Thus, the major loss in overall cost efficiency, on average, is due to weak cost efficiency (W). This general pattern is also confirmed by the milk output size classification.

Table 2 indicates the average level of overall cost efficiency (K) and weak cost efficiency (W) increase with milk output size. Table 2 also shows that the variability in overall cost efficiency (K) and weak cost efficiency (W) are inversely related to milk output size. A possible explanation for this result may be the existence of more homogeneous management practices and the use of technology on larger farms[11,14].

B. Correlation between cost efficiency and farm characteristics

The final set of results concern the correlation between overall cost efficiency and farm characteristics. As the causality between cost efficiency and farm characteristics is generally unknown, correlation analysis was used in this study.

The Pearson Correlation Coefficient estimates between overall cost efficiency and farm characteristics are shown in Table 3. A positive (negative) sign on the correlation coefficient indicates that a change in that variable has a positive (negative) relationship with overall cost efficiency.

Generally, attention is often given to farm size in the agricultural policy debate. Table 3 suggests that there is a positive relationship between herd size and overall cost efficiency. This finding is statistically significant to a 1% level. Overall cost efficiency is found to increase with herd size, confirming previous results by milk output size classification (Table 2).

Management characteristics and farm technology are also related to overall

Table 3 Pearson correlation coefficient between overall cost efficiency and farm characteristics of Hokkaido dairy farms, 1989

Variable name	Herd size (cows)	Milk production per cow (kg/cow)	Milk fat percentage (%)	Age of Manger (years old)	Share of Farm produced feed (%)	Farm income per cow (Yen／cow)	Milk production per working hours (kg／hour)
Pearson correlation coefficient	0.5055*	0.6076*	0.0695	-0.1656	-0.3192*	0.8219*	0.7111*

* indicates significance of 0.01 probability level.

cost efficiency. Milk production per cow, which is a function of the genetic technology of the cow and feed level and feed quality, has an expected positive relation with the correlation coefficient. Table 3 suggests that there is a positive relationship between milk production per cow and overall cost efficiency. This finding is statistically significant to a 1% level.

Table 3 suggests that there is no relationship between the milk fat percentage and overall cost efficiency. This finding contrasts with that of Weersink, Turvey, and Godah (1990) belief that the percentage of milk butterfat variable was related to managerial ability and found that an increase in butterfat had the largest positive impact on overall technical efficiency for Ontario dairy farms[11].

The estimated correlation coefficient of the variable used with a proxy of farming experience indicated that there was a negative but weak relationship between age of a farm manager and overall cost efficiency. This finding is not statistically significant to a 1% level. A possible explanation for the estimated result in this study is that beginning farmers are more knowledgeable about recent technological advances, such as computer information technology, than their older counterparts[11].

Table 3 suggests that there is a negative relationship between the share of farm produced feed and overall cost efficiency. This finding is statistically significant to a 1% level. This finding also contrasts with that of Weersink, Turvey, and Godah (1990) who expected that feed could be grown on the farm more cheaply and have higher quality than purchased feed[11]. They found that an increase in the proportion of total feed purchased lowered overall technical efficiency for Ontario dairy farms.

Farm income per cow and milk production per working hour were selected as proxies of profitability and labor productivity in milk production, respectively. Correlation coefficients between these variables and overall cost efficiencies are statistically significant to a 1% level with the expected positive signs, implying that high profitability and high labor productivity are strongly related to greater efficiency.

V. Conclusion

The purpose of this paper is to estimate cost efficiency of a cross-section of dairy farms in Japan and to investigate the relationship between overall cost efficiency and farm characteristics. The overall cost efficiency measure has two components[1]: (1) the weak cost efficiency measure; (2) the scale efficiency measure. The primary advantage of cost side nonparametric approach is the ease of acquiring data. Usually, researchers find data acquisition difficult for farm-specific data on inputs and input prices. If all farms faced the same input prices, our efficiency measures would not require farm-specific data on inputs and input prices; they would only require farm-specific data on output and total costs that are usually easy to obtain. Linear programming was used in calculating the efficiency measures for the sample of Hokkaido dairy farms during the year 1989.

The average farm operates at 71% efficiency, indicating that substantial improvements in cost efficiency are possible.

The correlation results indicate that higher cost efficiency is associated with larger herd size, higher milk production per cow, higher income per cow, higher milk production per working hour and a lower share of farm produced feed.

The major lack of overall cost efficiency is not due to improper scale of operation (scale inefficiency) but due to improper cost allocation (weak cost inefficiency). The policy implications of the above findings suggest that improvements in planning and control of farm management for a given business size are better strategies than the expansion of business size in order to reduce production costs for Hokkaido dairy farms.

A disadvantage of the nonparametric approach is its sensitivity to outliers. Incorporation of stochastic elements into the model would relax the assumption that the entire deviation of a farm from the frontier is due to inefficiency[15].

Overall cost efficiency also can be decomposed into technical efficiency and allocative efficiency[16]. The role of technical efficiency and allocative efficiency has been omitted from this analysis but can be examined readily with nonparametric methodology, once farm-specific data on inputs and input prices are available.

The data set used in this study is old, but when more recent data becomes available, the usefulness of cost efficiency estimates will be increased further.

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