Technical Efficiency of Melon Farms under the Marketing Strategy of Agricultural Cooperatives

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Abstract: The purpose of this paper is to measure the technical efficiency of farms on the basis of data envelopment analysis (DEA) and to present an analytical method of farm diagnosis using measurements obtained for melon farms in Japan. The paper first describes the objectives of melon farms operating under the marketing strategy of agricultural cooperatives and explains DEA, which measures the technical efficiency of such farms. It then uses this analytical method to measure technical efficiency for each farm and demonstrates how technical efficiency is dependent not only on the management performance of production of melons and other crops but also on the number of full-time farm workers. In addition, the effect of management performance on technical efficiency is analysed quantitatively for each size group of full-time farm workers. The paper also illustrates how DEA can be used for farm diagnosis when the management performance of inefficient melon farms is compared with that of efficient farms. DEA is able to indicate some efficient farms as the optimum solution that should be treated as the model for the improved management of inefficient farms. Data are drawn from a sample of 91 melon farms in Choshi, Chiba Prefecture.

Introduction

Fruit have tended to be in a state of overproduction in Japan since 1980, due to factors that include a slump in demand, the conversion from rice cultivation to other crops, and an increase in yield. The oversupply situation of melons had begun to ease, thanks to an increase in the disposable income of consumers and high price elasticity, but recently the dramatic increase in supply has resulted in a levelling-off of the price received by producers. As a result, melon producers in different producing areas have now started to compete strongly with one another in order to achieve higher prices.

Agricultural cooperatives in melon-growing regions sell most of the fruit and vegetables produced under their control to wholesalers on behalf of producers. In the case of melons, the cooperatives devise a marketing strategy to maximize the total income of melon producers and advise growers to produce and market according to this strategy. The melon marketing strategy of agricultural cooperatives calls for the regular supply to wholesale markets of a large volume of melons that are of the quality and size required to meet buyers' expectations. Consequently, producers are subject to the constraints of the marketing strategy of agricultural cooperatives and must set a farm management goal of maximizing farm income while determining the timing of melon cultivation and the marketing of superior quality produce.

Melon farms are typically mixed farms that also produce other crops, such as rice and vegetables, so that other crops compete with melon production in the use of farm resources. Income from melon production in mixed farms must be maximized subject to the constraints of increasing income from other crops while giving due regard to the competitive relationship with these crops.

Melon farms have multiple goals in that they are subject to both the marketing strategy of agricultural cooperatives and the constraints of the production of other crops. As a result, the technical efficiency of melon farms must be judged in accordance with standards that comprehensively satisfy the multiple output indices for representing differing characteristics. These types of judgement standards are particularly useful for agricultural cooperatives in farming regions that manage agriculture for the region while seeking to improve the efficiency of individual farmers.

The objective of this paper is to indicate an appropriate management diagnosis method for this situation, using data obtained from the measurement of technical efficiency on the basis of data envelopment analysis (DEA), by focusing on the objective of melon farms, which is to maximize multiple outputs under the marketing strategy of agricultural cooperatives. Agricultural cooperatives will be able to apply this analytical method to various farming types, including melon growing, to support farmers' decision making.

The paper looks specifically at farms under the control of the Choshi Agricultural Cooperative in Chiba Prefecture that produce the *Ams* type of melon. This cooperative grades the melons strictly by size and quality to distinguish them from those grown in other areas, and also promotes melon cultivation under plastic to extend the shipment period to the market, which at present is concentrated in July. The data analysed consist of records for 1988 obtained from 91 farms for which this cooperative ships the melons.

Estimation of Technical Efficiency Based on DEA

The traditional concept of technical efficiency can be applied to farms only when they aim at a single goal (Farrell, 1957; and Timmer, 1970) and cannot be measured when the farm seeks to satisfy multiple goals. Banker, Charnes, and Cooper developed the DEA method that measures the technical efficiency of the decision-making unit when there are multiple outputs and inputs (Banker, 1984; and Banker, Charnes, and Cooper, 1984). Their analytical methods are explained here using the example of melon farms in Choshi.

Mixed farms whose melon-marketing strategy is planned by agricultural cooperatives allocate their cultivated lands between planted areas of melon (X_1) and planted areas of other crops (X_2), use these inputs and the labour of full-time farm workers (X_3), and adopt the behaviour that maximizes the total outputs of melons (Y_1), the total outputs of other crops (Y_2), the percentage of high quality quantity of total marketed melons (Y_3), and the percentage of early quantity of total marketed melons (Y_4).

Capital goods are not included in the inputs described above. It is assumed that capital goods are in proportion to each of the outputs. Under this assumption, which approximately expresses the actual situation, the effects of other inputs on each of the melon outputs are not dependent on the inputs of capital goods. The behaviour of melon farms according to this assumption can be formulated as the fractional programming of maximizing h_{j0} in objective function (1), subject to the constraints of (2), (3), and (4):

$$(1)\quad h_{j0} = \frac{\sum_{r=1}^{4} u_r Y_{rj0}}{\sum_{i=1}^{3} v_i X_{ij0}}$$

$$(2)\quad \frac{\sum_{r=1}^{4} u_r Y_{rj}}{\sum_{i=1}^{3} v_i X_{ij}} \leq 1 \quad (j=1,\ 2,\ \ldots,\ 91)$$

$$(3)\quad u_r > 0\ (r=1,\ 2,\ 3,\ 4)$$

$$(4)\quad v_i > 0\ (i=1,\ 2,\ 3)$$

The fractional programming is converted into linear programming which maximizes (5), subject to the constraints of (6), (7), (3), and (4):

$$(5)\quad Z_{j0} = \sum_{r=1}^{4} u_r Y_{rj0}$$

$$(6)\quad \sum_{i=1}^{3} v_i X_{ij0} = 1$$

(7) $\sum_{r=1}^{4} u_r Y_{rj} - \sum_{i=1}^{3} v_i X_{ij} \leq 0 \quad (j=1, 2, ..., 91)$

If the optimum solution Z_{j0}^* of the linear programming is (u_r^*, v_i^*), it equals the optimum solution of fractional programming h_{j0}^* and represents technical efficiency. Consequently, farming is most efficient when $Z_{j0}^* = 1$ and is inefficient the closer Z_{j0}^* is to 0.

Measurement of Technical Efficiency in Melon Farms

Measures of the technical efficiency of the 91 melon farms can be obtained from the optimum objective function of the linear programming described in the previous section. The second column of Table 1 shows the level of technical efficiency of the 91 farms. This is shown as an average of 0.81, centred on the range 0.7–0.8 and 1.0 but covering a wide distribution from 0.5 to 1.0.

Table 1—Choshi Melon Farms Measured in Terms of Technical Efficiency

	Total	Number of Full-Time Workers		
		1	2	3 or more
Number of samples	91	28	34	29
Grouped by measure of technical efficiency		*Percent*		
0.5–0.6	8.8	3.6	–	3.4
0.6–0.7	17.6	3.6	–	10.4
0.7–0.8	26.4	28.6	8.8	10.4
0.8–0.9	13.2	10.7	17.7	27.6
0.9–1.0	7.7	10.7	14.7	3.4
1.0	26.4	42.8	58.8	44.8
Average	0.8076	0.8802	0.9442	0.8727
Standard deviation	0.1503	0.1312	0.0870	0.1411

Notes: Based on total sample farms in Choshi. Number of full-time workers based on farms grouped by full-time workers.

The technical efficiency of farms is affected by management performance in production of melons and other crops and by the number of full-time farm workers. If technical efficiency T is represented as a dependent variable, the high quality of total marketed melons as Q percent, the total quantity of early melons marketed as E percent, melon yield per are as M kg, the yield of other crops per are as P ¥1,000, and the number of full-time workers N as independent variables, the multiple regression equation is computed as follows (figures in parentheses represent t-values):

$$(8) \quad T = \underset{(4.0790)}{0.0029Q} + \underset{(5.2914)}{0.0042E} + \underset{(4.5465)}{0.0249M} + \underset{(2.6640)}{0.0008P} - \underset{(-2.2651)}{0.0311N} + 0.4032 \qquad R^2 = 0.5491$$

The coefficient of determination is 0.55, which is not at all large, but all the regression coefficients are significant at the 5-percent level. The effect of the independent variables on the measures of technical efficiency in terms of elasticity coefficients is greatest in the "melon yield per are" category (0.30) and smallest in the "percentage of early melons marketed" category (0.06).

Of particular interest is the fact that the higher the number of full-time workers, the lower the level of technical efficiency. There are two reasons for this. One is that on melon farms, as the number of full-time workers increases, the number of part-time workers falls or remains unchanged. Nor does the ratio of fixed equipment increase. The second reason is that the percentages of high quality and early crop melons in total melons marketed obtained to measure technical efficiency do not increase in proportion to the number of full-time workers.

The measurements of technical efficiency for full-time workers are shown in Table 1 (Cols. 3–5). In all groups, the number of efficient farms with a technical efficiency of 1.0 is increasing and the number of inefficient farms with a technical efficiency of 0.7 or less is decreasing. This is due not to measurement in terms of absolute efficiency on farms but to measurement in terms of relative efficiency within each group. This indicates that differences in technical efficiency are small among farms in the group comprising two full-time workers and large in the groups comprising one or three-or-more full-time workers. The results of measurements of the multiple regression equations, which make technical efficiency a dependent variable and (excluding the number of full-time workers) make other factors independent variables, are shown in Table 2 in order to clarify the factors determining technical efficiency in terms of number of full-time workers.

Table 2—Regression Relationships between the Measure of Technical Efficiency and Its Factors

Number of Full-Time Workers	Linear Regression Coefficients (t-values)				R^2
	Q	E	M	P	
1	0.0048** (3.6690)	0.0033* (2.5977)	0.0072** (3.1201)	0.0005 (1.0696)	0.6217
2	0.0027** (3.6888)	0.0016 (1.7016)	−0.0012 (−1.0025)	0.0006 (2.0098)	0.3967
3 or more	0.0015 (1.1730)	0.0038** (3.0455)	0.0028 (1.6225)	0.0016* (2.1435)	0.5378
	Elasticity at Average Samples				
1	0.175	0.032	0.361	0.042	
2	0.095	0.021	0.058	0.053	
3 or more	0.054	0.048	0.143	0.141	

Note: Q = percent of high quality melons marketed; E = percent of early melons marketed; M = Melon yield per are; and P = Yield of other crops per are. *Significant at 5-percent level. **Significant at 1-percent level.

A comparison of the elasticity coefficients by size group, with particular attention to the significance of the regression coefficients, shows that, in the size group of one full-time worker, the effect of melon yield per are is at the maximum, followed by the effect of the high quality of total melons marketed, and the effect of the total quantity of early melons marketed is at the minimum. The yield per are of other crops displays no significant effect. In the size group of three-or-more full-time workers, the effect of the yield per are of other crops is at the maximum, followed by the effect of the total quantity of early melons marketed; melon yield per are and the high quality of total melons marketed do not display a significant figure. In groups of two full-time workers, the difference in technical efficiency among farms is small, so that the coefficient of determination is small and only the effect of the high quality of total melons marketed is significant, which is at the maximum. The effect of this group by factors shows a middle character between the group of one full-time worker and the group of three-or-more full-time workers.

The means of raising technical efficiency based on this analysis differ among groups with different numbers of full-time workers. In the group with one full-time worker, labour is relatively scarce so that technical efficiency is raised by means of increasing the yield per are of melons grown in tunnels and marketed in July and by improving the quality of the melons. However, this has little effect on increasing the yield per are of other crops. In comparison, in groups with three-or-more full-time workers, labour is relatively abundant, so that technical efficiency is raised by means of increasing the quantity marketed of early melons cultivated in plastic houses and the yield of other crops, but the effects of increasing the yield per are and high quality of melons are insignificant. Agricultural cooperatives must change the method of inducing improvements in farm management in relation to the number of full-time workers.

Diagnosis of Farm Management Performance

The technical efficiency of melon farms shows a wide difference even among farms with the same number of full-time workers. The method of improving technical efficiency differs among groups. The procedure and method for diagnosing management performance are illustrated using the example of farm G from among the class with the lowest efficiency.

The inputs and outputs of inefficient farms are changed into those of a theoretical optimum farm by computing the weighted sum of inputs and outputs of some efficient farms based on the optimum solution of DEA (Tone, 1988). Table 3 shows the inputs and outputs of farm G and three efficient farms, A, B, and C, composing its solution and a theoretical optimum farm G′. The inputs and outputs in G′ are the figures arrived at by the sum of the products in A, B, and C multiplied by 0.00816, 0.53243, and 0.43456, respectively. The diagnosed farm, according to those measurements, applies approximately the same inputs as in an actual situation and can be made more efficient by raising all the outputs of melon and other crops, the percentages of high quality, and total quantity of early melons marketed.

Table 3—Inputs and Outputs of the Diagnosed Farm G and the Efficient Farms Composing an Optimum Solution on that Farm

	Diagnosed Farm	Efficient Farms Composing Optimum Solution on the Diagnosed Farm			Theoretical Optimum Farm
	G(0.668)	A(1.000)	B(1.000)	C(1.000)	G′(1.000)
Weight		0.00816	0.53243	0.43456	
X_1 (a)	60	70	30	100	60
X_2 (a)	110	65	155	62	110
X_3(worker)	3.0	3.0	3.0	3.0	2.9
Y_1(million ¥)	4.05	7.11	3.65	9.34	6.06
Y_2(million ¥)	8.67	7.57	16.41	9.63	12.98
Y_3(percent)	12.1	59.1	68.8	43.6	56.1
Y_4(percent)	–	38.0	1.0	32.8	15.1

Note: Figures in parentheses represent the measure of technical efficiency.

It is difficult to perceive precise methods of improving the diagnosed farm from the theoretical optimum farm in Table 3. The method of improvement can be clarified by investigating the technology of efficient farms B and C with a higher weight and surveying the record of the types of crops they grow and their melon production management. Table 4 shows a comparison of the actual results of types of crops and melon production in the diagnosed farm G with those of efficient farms B and C. Diagnosed farm G, for winter cropping, whether it uses B or C efficient farms as the model, is forced to avoid competition over labour when harvesting cabbage and planting melons by eliminating mixed cabbage cropping. For summer cropping, several differences occur in cropping types depending on whether B or C is used as the model. When B is used as the model, the diagnosed farm reduces the areas of melon under extensive tunnel cultivation and converts part of this to intensive cultivation in plastic houses to bring the shipment time forward while increasing area planted to the more labour-extensive watermelon to make more effective use of uplands. However, when C is used as the model, the farm stops growing watermelon and expands the planted area of melons, combining tunnel cultivation with plastic house cultivation to avoid competition over use of labour. The diagnosed farm can raise technical efficiency by selecting either of cropping systems B or C or a combination of both. The choice of which cropping system is to be adopted depends on decision making by the farmers themselves.

Table 4—Use of Cultivated Land and Management Performance of Melon Crops in the Diagnosed Farm and Efficient Farms

	Diagnosed Farm		Efficient Farms			
	G (0.668)		B (1.000)		C (1.000)	
Size of cultivated land (a)	170		185		162	
Planted area of:						
Melon (a)	60		30		100	
Watermelon (a)	20		100		–	
Cabbage (a)	120		100		25	
Radish (a)	120		70		70	
Other crops (a)	50		15		95	
Total (a)	370		315		290	
Melon crops:						
Average yields per are (kg)	235		331		309	
Average prices sold (¥/kg)	287		368		302	
Field practice:						
Planted area (a)	22	18	20	10	28	25
Month and day of seeding	2/10	3/10	2/10	2/20	2/25	3/24
Period from pollination to harvesting (days)	58	49	58	56	56	51
Number of seedlings per are	91	67	69	72	69	56

Note: Under Field practice, only those fields seeded within the 10 February–31 March period are presented because of space limitations.

Problems exist in the management of melon production on diagnosed farm G in the case of both plastic house cultivation (seeded in February) and tunnel cultivation (seeded in March). In the former case, the seedlings are planted too densely. Consequently, it is necessary to bring forward the shipment time by planting seedlings sparsely and promoting their growth. In the latter case, the melon harvest date is forced forward by impeding the growth process, as can be estimated from the fact that the time from pollination is short.

The DEA can thus be seen to be useful in measuring technical efficiency and diagnosing management performance of farming systems that have multiple objectives. Farm diagnosis can obtain the desired effect by analysing technical efficiency based on DEA in combination with other information that represents technology indices and the management performance of crop production. The analytical method used in this study can be of practical use in supporting the decision making of individual farms and various other agricultural production organizations.

Note

[1]Chiba University.

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Discussion Opening—*Mária Sebestyén Kostyál* (Budapest University of Economic Sciences)

The paper provides a useful method for commercial cooperatives to help less efficient farms improve their competitiveness. Comments are related to three main questions: the method selected, some of the conclusions, and the role of agricultural cooperatives.

Data envelopment analysis (DEA) has been developed as a tool for analysing production data. It is an interesting initiative to use this method in the case of mixed farms, but great care has to be taken when using DEA in the case of agricultural production units. This is because of the high degree of uncertainty (as with the weather) influencing the results of agricultural production, and is also why the method is applied mainly to industrial production units.

The next concern is the time horizon used, since the analysis was done on the basis of one year. It would have been useful if the final analysis had used at least a three-year data base.

Since the method handles the inputs in a highly simplified way (land, without any differentiation, and labour are represented in the model), the results obtained must be used very carefully when resource allocation is the main question. It can be assumed that the interest of the producers is to gain the highest margin, under the given conditions and constraints, between the cost of the inputs used and the market values of products. To set up the best production strategy, more factors have to be taken into consideration than the method presented can handle. It would be most interesting to learn what kind of additional methods the author may suggest in order to provide a more comprehensive set of tools for farm-level decisions.

The conclusions include the interesting finding that the higher the number of full-time workers, the lower the level of technical efficiency. This statement needs careful analysis. The two reasons given in the paper are not totally convincing. First, if the number of full-time workers increases and the number of part-time farmers decreases, technical efficiency can decrease only in one case; when the performance of the full-time workers is much lower than that of the part-time ones. Second, it seems natural that, after employing more full-time workers, the ratio of fixed assets is not bound to rise. On the contrary, it might even fall if output is not expected to grow.

Since the category of melon farms is not defined, it is hard to see whether the paper deals only with those mixed farms where the land is used for melon production above a certain ratio (e.g., 40 percent) or on every farm where melons are grown at all. Fairly big differences can be envisaged in technical efficiency measures between farms where melon can be considered as a main product and those where melon production has a very low share.

A fuller description of the role of cooperatives is needed, especially their marketing strategy and how they make cooperatives follow it. Is the interest of the cooperative always the same as that of every single farm? The topic also offers an opportunity to discuss the types of activities that cooperatives should carry out to assist member farms in order to make them more competitive; for instance, the tools used by cooperatives to maintain production at the level that the market needs.

[The author's reply appears on page 282.]