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研究成果報告(精簡版)

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目錄

Efficiency Measurements in Multi-activity Data Envelopment Analysis with Shared Inputs: An Application to Farmers' Cooperatives in Taiwan

I. INTRODUCTION

Taiwan's farmers' cooperatives (TFCs) are the largest farmers' associations in Taiwan. As in many developing countries around the world, TFCs have played an important role in assisting the government to promote certain policy goals for agricultural development. Subsidize credit programs were offered by the government to promote certain policy goals such as assisting farmers to enlarge their operation or to adopt a new technology. The TFCs serve as a venue to assist farmers or rural poor to acquire the low-interest credits to whom regular lenders would not serve. As the favorable conditions for agricultural production have declined over time, the TFCs have also begun to take on a broader role in promoting village construction and enhancing farmers' welfare, thereby helping to bring about wider development. After Taiwan became a member of the WTO in 2002, the TFCs were given a new role to minimize the impact of WTO entry through the promotion of local products in global markets.

Initially, the TFCs were designed to provide credit, extension, insurance, and marketing services to their members, who are mostly farmers or residents located in rural areas. Each association consists of four departments to carry out these services. Profits from the credit departments are used for improving cooperative marketing, insurance and extension services whereas the activities of the extension, insurance, and marketing services attract savings to the TFCs which can later serve as loanable funds that can be made available to the eligible members.

The close linkages among the services and the close ties between the cooperatives and the government have made TFCs the most important institutions in financing rural Taiwan. However, the performance varied greatly among the TFAs. By the mid-1990s, some of credit departments of the successful TFAs have rivaled the commercial banks while the others reply heavily on government subsidized credits. On September 2001, the insolvency problem led the government take over 35 poorly-performing credit departments of TFAs by 10 commercial banks. It is widely believed that these grassroots institutions' financial crises are owing to the cost inefficient operations, which falls short of maximizing profits and maintaining healthy levels of capital asset ratios. Some of the causes are inherent in the TFAs' non-profit maximizing orientations, while others are found to be a direct consequence of inefficient operations. Some argue that the subsidized credits create detrimental effects on the TFA's competitiveness because it impairs their incentive to minimize costs (e.g., Wang et al., 2008). Others focus on the political involvement of the managers of TFAs with the local politicians and related corruption issues. However, the multi-purpose nature of the TFCs and the complementary effect of inter-firm networking to serve rural development purposes are often overlooked.

In this study, we propose the adoption of a multi-activity data envelopment analysis (MDEA) method by Beasley (1995) and Tsai and Mar Molinero (1998, 2002) to examine the role of teamwork in the efficiency performance of the TFCs. The efficiency measure derived from the traditional data envelopment analysis (DEA) model implicitly assumes that each TFC is equally efficient in all activities, and that the TFC is free to apply any of its inputs to any of its outputs in the most desirable way (Mar Molinero, 1996). In comparison, the MDEA identifies the particular strengths and weaknesses of the TFCs by distinguishing which department operates in the most efficient manner as well as under the most productive scale. It allows us to determine how much of the internally shared inputs are associated with each department. The primal and dual relationships of the MDEA model are also used to estimate the status of returns to scale for the whole team and the four departments individually.

The remainder of this paper is organized as follows. The next section describes the methodology of MDEA followed by a description of the empirical model. Section Three discusses the data and Section Four presents the empirical results. Section Five concludes.

2. METHODOLOGY

Following Tsai and Mar Molinero (1998, 2002)'s approach, the traditional DEA model is extended to a multi-activity fashion by allowing each activity to grade its performance and RTS property with its own technology frontier. This multi-activity efficiency measure provides a performance measure with activity-based information as part of the aggregated score.

Consider again that there are $k = 1, \cdots, K$ DMUs and that each engages in I activities. Let $X_k^1, X_k^2, \cdots, X_k^I$ and $X_k^s = (x_{k,1}^s, x_{k,2}^s, \cdots, x_{k,L}^s)$ denote the dedicated input vector and shared inputs of DMU k, respectively, where X_k^i is the input vector associated solely with the ith activity while $x_{k,l}^s$ is the lth input shared by the I activities. Because $x_{k,l}^s$ is a shared input, it is assumed that some portion $\mu_{k,l}^i \, (0 < \mu_{k,l}^i < 1, \ \sum_{i=1}^{I} \mu_{k,l}^i = 1)$ of this shared input is allocated to the ith activity. In the MDEA model, $\mu_{k,l}^i$ is a decision variable to be determined by the DMU. Thus, the ith activity employs X_k^i and $\mu_k^i X_k^s$ to jointly produce desirable output Y_k^i and undesirable output B_k^i in which $\mu_k^i X_k^s = (\mu_{k,1}^i x_{k,1}^s, \mu_{k,2}^i x_{k,2}^s, \cdots, \mu_{k,L}^i x_{k,L}^s)$, $Y_k^i = (y_{k,1}^i, y_{k,2}^i, \cdots, y_{k,M_i}^i)$ and $B_k^i = (b_{k,1}^i, b_{k,2}^i, \cdots, b_{k,R_i}^i)$.

The production technology with variable returns to scale and shared inputs for the ith activity can be defined as follows:

$$T^i = \{ (x^i, y^i, b^i) \ : \ \sum_{k=1}^{K} z_k^i y_{k,m_i}^i \geq y_{m_i}^i, \qquad m_i = 1, \ldots\ldots, M_i.$$

$$\sum_{k=1}^{K} z_k^i b_{k,r_i}^i = b_{r_i}^i, \qquad r_i = 1,\ldots\ldots, R_i.$$

$$\sum_{k=1}^{K} z_k^i x_{k,n_i}^i \le x_{n_i}^i, \qquad n_i = 1,\ldots\ldots, N_i.$$

$$\sum_{k=1}^{K} z_k^i \mu_{k,l}^i x_{k,l}^s \le \mu_{k,l}^i x_l^s, \qquad l = 1,\ldots\ldots, L. \tag{1}$$

$$0 < \mu_{k',l}^i < 1 \qquad l = 1,\ldots\ldots, L.$$

$$z_k^i \ge 0, \qquad k = 1,\ldots\ldots, K.$$

$$\sum_{k=1}^{K} z_k^i = 1 \}$$

Then the directional distance function can be used as the basis for estimating the weighted-average inefficiency of each DMU ($\beta^{k'}$) by solving the following MDEA model:

$$Max \quad \beta^{k'} = \sum_{i=1}^{I} w^i \beta_{k'}^i \tag{2}$$

$$\text{s. t.} \quad \sum_{k=1}^{K} z_k^i y_{k,m_i}^i \ge (1+\beta_{k'}^i) y_{k',m_i}^i, \qquad m_i = 1,\ldots\ldots, M_i. \quad i = 1,\ldots\ldots, I \tag{3}$$

$$\sum_{k=1}^{K} z_k^i b_{k,r_i}^i = (1-\beta_{k'}^i) b_{k',r_i}^i, \qquad r_i = 1,\ldots\ldots, R_i. \quad i = 1,\ldots\ldots, I \tag{4}$$

$$\sum_{k=1}^{K} z_k^i x_{k,n_i}^i \le (1-\beta_{k'}^i) x_{k',n_i}^i, \qquad n_i = 1,\ldots\ldots, N_i. \quad i = 1,\ldots\ldots, I \tag{5}$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} z_k^i \mu_{k',l}^i x_{k,l}^s \le \sum_{i}^{I} (1-\beta_{k'}^i) \mu_{k',l}^i x_{k',l}^s, \qquad l = 1,\ldots\ldots, L. \tag{6}$$

$$\sum_{i=1}^{I} \mu_{k',l}^i = 1 \qquad l = 1,\ldots\ldots, L. \tag{7}$$

$$\sum_{k=1}^{K} z_k^i = 1 \qquad i = 1,......, I \tag{8}$$

$$z_k^i \geq 0, \qquad k = 1,......, K. \quad i = 1,......, I \tag{9}$$

$$0 < \mu_{k',l}^i < 1, \quad \beta_{k'}^i \geq 0, \tag{10}$$

where $\beta_{k'}^i$ are the inefficiency score for the ith activity and w^i is a positive number which represents the relative importance or managerial preferences given exogenously to the various activities and their sum is standardized to be equal to 1. This MDEA model is essentially designed to minimize the inputs and undesirable outputs and at the same time maximize the desirable outputs for each activity concurrently. This means that a DMU will be unable to attain efficient status unless all of its activities perform efficiently. In addition, according to the performance of each activity, we can easily distinguish which activity should be improved first.

Here, we would also like to examine the returns to scale properties of each DMU. Therefore, the dual form of the above model is described as follows:

$$Min \quad -\sum_{i=1}^{I}\sum_{m_i=1}^{M_i} u_{m_i}^i y_{k',m_i}^i + \sum_{i=1}^{I}\sum_{n_i=1}^{N_i} v_{n_i}^i x_{k',n_i}^i + \sum_{i=1}^{I}\sum_{r_i=1}^{R_i} \rho_{r_i}^i b_{k',r_i}^i + \sum_{l=1}^{L} v_l^s x_{k',l}^s + \sum_{i=1}^{I} \delta_{k'}^i \tag{11}$$

$$\text{s.t} \quad -\sum_{m_i=1}^{M_i} u_{m_i}^i y_{k,m_i}^i + \sum_{n_i=1}^{N_i} v_{n_i}^i x_{k,n_i}^i + \sum_{r_i=1}^{R_i} \rho_{r_i}^i b_{k,r_i}^i + \sum_{l=1}^{L} v_l^s \mu_{k',l}^i x_{k,l}^s + \delta_{k'}^i \geq 0, \tag{12}$$

$$\sum_{m_i=1}^{M_i} u_{m_i}^i y_{k',m_i}^i + \sum_{n_i=1}^{N_i} v_{n_i}^i x_{k',n_i}^i + \sum_{r_i=1}^{R_i} \rho_{r_i}^i b_{k',r_i}^i + \sum_{l=1}^{L} v_l^s \mu_{k',l}^i x_{k',l}^s \geq w^i, \tag{13}$$

$$u_{m_i}^i, v_{n_i}^i, v_l^s \geq 0, \; \rho_{r_i}^i, \delta^i \; free, \tag{14}$$

where $u_{m_i}^i, v_{n_i}^i, \rho_{r_i}^i, v_l^s$ are multipliers for desirable outputs, inputs, undesirable outputs, and shared inputs, respectively. When the equality holds in equation (18), an aggregate measure of technical inefficiency may be defined as follows:

$$TIE_{k'} = \frac{-\sum_{i=1}^{I}\sum_{m_i=1}^{M_i} u_{m_i}^i y_{k',m_i}^i + \sum_{i=1}^{I}\sum_{n_i=1}^{N_i} v_{n_i}^i x_{k',n_i}^i + \sum_{i=1}^{I}\sum_{r_i=1}^{R_i} \rho_{r_i}^i b_{k',r_i}^i + \sum_{l=1}^{L} v_l^s x_{k',l}^s + \sum_{i=1}^{I} \delta_{k'}^i}{\sum_{i=1}^{I}\sum_{m_i=1}^{M_i} u_{m_i}^i y_{k',m_i}^i + \sum_{i=1}^{I}\sum_{n_i=1}^{N_i} v_{n_i}^i x_{k',n_i}^i + \sum_{i=1}^{I}\sum_{r_i=1}^{R_i} \rho_{r_i}^i b_{k',r_i}^i + \sum_{l=1}^{L} v_l^s x_{k',l}^s}.$$

This measure is the weighted result of I activities' individual inefficiency (see Appendix A for the proof). Moreover, the constraint (12) ensures that the efficiencies do not exceed unity (see Appendix B).

Following the similar criteria stated above, the shadow price δ^i can be used to determine the RTS status for each activity. As Tsai and Mar Molinero (1998, 2002) indicated, there are two interesting consequences regarding the RTS properties in the MDEA model. First, different activities are allowed to operate under different RTS since each activity may have its own production technology. Second, the overall status of the RTS of each DMU depends on the individual RTS of all activities' δ^i (i.e., $\sum_{i=1}^{I}\delta^i$). Thus a DMU may appear to be operating under CRS and to be scale efficient when it is actually operating under IRS in some activities and under DRS in the others and is scale inefficient. Thus, the scale efficiency in the context of a multi-activity DEA is much more complex than the traditional DEA model would suggest.

3. DATA AND VARIABLE SPECIFICATION

The empirical application is implemented using the data from the *Farmers' Association Yearbook* of 2003 published by the Taiwan Provincial Farmers' Association. Regarding the specification of the variables, for the marketing activity the specific input of operating expenditures (x_1^1) is used to produce two outputs, namely, the income from marketing (operating income, y_1^1) and other income (y_2^1). Similarly, the insurance department employs the specific input of operating expenditures (x_1^2) to produce total insurance income (y_1^2). The extension department uses operating expenditures (x_1^3) to carry out extension services (y_1^3), farmers' education (y_2^3), and rural welfare programs (y_3^3). The credit departments employ two inputs, namely, loanable funds (x_1^4) and capital expense (x_2^4) to produce two desirable outputs, i.e., total loans (y_1^4) and non-loan receipts (y_2^4), and one undesirable output, namely, non-performing loans (b_1^4).

Among the four departments, there are two shared inputs: labor (x_1^s), which is defined as the number of employees and managers, and fixed assets (x_2^s), which include the net present values of land, buildings, machines, equipment and other fixed capital.

Table 1 provides the sample means and standard deviations for all variables and the relationship for them is given in Figure 1.

4. EMPIRICAL RESULTS

Table 2 reports the summary statistics of inefficiencies where unequal weights are specified. Note that the inefficiency score β should be larger than or equal to zero and that a higher score indicates a more inefficient status. The results diverge from 0.000 to 0.398 with a sample mean of 0.222. This suggests that on average there is room for TFCs to expand their outputs by 22.2% and decrease their inputs and undesirable outputs by the same proportion to become a fully efficient unit. The second column also shows that, out of the 201 TFCs, only 13 (6.47%) can be considered to be globally efficient. This is because we define the overall inefficiency measure ($\beta^{k'}$) of each TFC as the weighted- average inefficiency of four of its activities ($\sum_{i=1}^{I} w^i \beta_{k'}^i$). Therefore, unless the TFC performs efficiently in terms of the production of all its four departments, it cannot be evaluated as being technically overall efficient.

As for individual activities, the performances of marketing and credit departments are in general much better than those of insurance and extension departments. The mean values of the insurance and extension departments' β are 0.412 and 0.559, respectively, with high standard deviations, while the means of the other two departments are 0.042 and 0.041 with much smaller standard deviations. The priority given by the managers of TFCs to the marketing and credit departments, as a consequence of earning more profit, could be the major reason which explains this phenomenon. Nevertheless, the lower average and the more divergent performance of the extension and insurance departments suggest that the challenge to improve the overall efficiency lies in these two departments.

As stated in the first section, the TFCs are multi-purpose arrangement in which each department provide complementary service to each other. Therefore, the performance of one department would cause certain impact on the other departments. Table 3 shows that although the coefficients are not large, both of the Pearson correlation and Spearman's rank correlation tests indicate that there are significant positive correlation between the performances of all the pairs of departments. This suggests the existence of complementary relations among the four departments. If the TFCs are able to improve their performance on extension activities, it will have dual effects, a direct effect on overall efficiency gains and an indirect spillover effect on improving the performance of the other three departments.

We also compute the efficiency scores using equal weights following Diez-Ticio and Mancebon (2002). The results in Table 4 show that the mean value of overall inefficiency is 0.263 with 0.043, 0.041, 0.420, and 0.550 for the marketing, credit, insurance, and extension departments, respectively. When compared with the results presented in Table 2, it can be found that the overall efficiency deteriorates significantly because the weights assigned to the activities with high efficiency scores are lower than the weights assigned to the activities with low efficiency scores. However, the mean values for the four activities do not change significantly. In addition, Table 4 presents the Kendall rank correlation coefficients between the two measurements and the results strongly reject the null hypothesis of independence in ranking. This implies that changing the priority regarding individual activities will neither influence the mean values nor their relative rankings.

Next, the nature of the RTS of TFCs is explored in Table 5 where the numbers and percentages of TFCs operating under decreasing, constant and increasing RTS by activity are summarized. It can be found that the status of RTS differs considerably among the four activities. Table 5 also indicates that more than 50 percent of TFCs operate under insufficient scales in their credit, insurance, and extension departments, suggesting that their efficient performance in three out of four departments can be improved through expansion. However, for the marketing department, DRS prevail suggesting that this department is either over-capitalized or over-staffed, and should be contracted in most TFCs. Besides the implications on the need for intra-TFC realignment, this result suggests that the marketing service of agricultural products at the local level has reached a limit. It is thus necessary for the marketing services to operate over broader geographical areas through strategic alliances or consolidations into a regional or even national operation.

Finally, the overall status of RTS can be obtained by aggregating the RTS results for all four activities. Table 5 also demonstrates that only 1.5 percent of the TFCs operate under the optimal scale. The number of TFCs considered to be too large (i.e., DRS) is almost identical with the number of those considered to be too small (i.e., IRS). Therefore, although recent legislation has increased the pressures on TFCs to consolidate, it is very important to take into account the discrepancies in RTS to ensure that the TFCs are operating under the most productive scale.

In terms of the policy aspect, the results above suggest that the TFCs should pay more attention to improving the efficiency of their insurance and extension departments despite the fact that these two departments are non-profit-oriented operations. More importantly, due to the complementary relations of the four departments of the TFCs, the enforcement of the function of the insurance and extension departments will also be beneficial for the other two departments. Thus, Policies that promote the consolidation of TFCs may not be sufficient to meet the public expectation on institutional reform. How to enhance the inter-firm networking is as important as the intra-firm consolidation.

5. CONCLUSIONS

This study proposes a modified MDEA model that decomposes the efficiency measures into components that reflect the multi-purpose characteristics or multi-activity nature of a production entity. The directional distance functions are used to construct a non-radial measure of performance in which the optimal input/output adjustment and the optimal allocation of shared inputs are simultaneously taken into consideration. The MDEA overcomes the inflexibility of alternative approaches by allowing the allocation of shared inputs to be optimally determined. It ensures that multi-activity efficiencies are fully realized by first generating efficiency scores based on a comparison of individual activities among peers and then embedding them into a maximization of the overall achievement with constraints on shared inputs. In so doing, an individual department benefits from an additional efficiency gain which can be difficult to achieve without reallocating the shared inputs among its partners.

An empirical study on Taiwan's farmers' cooperatives is used to offer policy suggestions as to how TFCs can effectively allocate their fixed resources among different departments in a multi-activity environment. Such a measure can also be used for rewarding the individual groups of a team based on their relative contributions to the team's overall performance. The empirical results suggest that there exist significant divergences in terms of the performance among the four departments of the TFCs. The TFCs should pay more attention to improving the efficiency of their insurance and extension departments despite the fact that these two departments are non-profit-oriented operations. The complementary effects across the four departments of the TFCs indicate that the enforcement of the function of the insurance and extension departments will be very helpful for the other two departments and for the overall performance. Furthermore, the wide divergences in the RTS statuses among the TFCs and their four departments warrant continuing deregulation of the TFCs by easing restrictions on their ability to acquire or consolidate with other TFCs and to operate over broader geographical areas.

Finally, to our knowledge, the MDEA technique has been applied to the performance evaluation of the education and healthcare sectors, but this is the first time it has been applied to agricultural cooperatives. Due to the particular characteristics of agricultural production, not only do the farmers' cooperatives engage in several parallel missions, but the farmers themselves are often involved in several business activities at the same time for various reasons. Thus the proposed method can also be applied to a wide range of agribusiness entities in the future.

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Table1. Summary Statistics of All Variables

Category	Variable name	unit	Mean	Std. Dev.
1. Marketing department				
Specific inputs	Operating expenditure (x_1^1)	NT$ millions	83.27	113.06
Outputs	Operating income (y_1^1)	NT$ millions	85.11	114.94
	Other income (y_2^1)	NT$ millions	4.76	8.99
2. Insurance department				
Specific inputs	Operating expenditure (x_1^2)	NT$ millions	1.36	3.88
Outputs	Operating income (y_1^2)	NT$ millions	2.26	3.75
3. Extension department				
Specific inputs	Operating expenditure (x_1^3)	NT$ millions	17.33	30.67
Outputs	No.of extension duties (y_1^3)	Thousands	0.33	0.37
	Farmers' education (y_2^3)	NT$ millions	2.11	3.22
	Welfare activity(y_3^3)	Thousands of persons	5.13	10.69
4. Credit department				
Specific inputs	Loanable funds (x_1^4)	NT$ millions	4,931.87	4,551.49
	Capital expense (x_2^4)	NT$ millions	23.72	18.13
Desirable outputs	Total loans (y_1^4)	NT$ millions	1,857.38	1,973.20
	Non-loan receipts (y_2^4)	NT$ millions	2,885.12	2,798.16
Undesirable outputs	Non-performing loans(b_1^4)	NT$ millions	365.82	442.08
5. Shared input				
	Labor (x_1^s)	No. of persons	67.91	37.20
	Fixed assets (x_2^s)	NT$ millions	236.59	258.79
6. Environmental variable				
	Membership ratio(e_1)	%	36.50	23.96

Table 2. Summary Statistics of Inefficiency Measures of TFCs

	Multi-activity DEA					Traditional DEA
	Overall	Marketing	Insurance	Extension	Credit	
Mean	0.222	0.041	0.412	0.559	0.042	0.003
SD	0.112	0.036	0.272	0.331	0.051	0.008
Max	0.398	0.207	0.981	0.987	0.254	0.043
Min	0.000	0.000	0.000	0.000	0.000	0.000
No. of fully efficient units	13	52	29	31	84	176
% of fully efficient units	6.47	25.87	14.43	15.42	41.79	87.56

Table 3. Correlation Coefficients of Performance Measures between Different Departments

	Pearson Correlation				Spearman's Rank Correlation			
	Marketing	Insurance	Extension	Credit	Marketing	Insurance	Extension	Credit
Marketing	1	0.150*	0.471**	0.290**	1	0.195**	0.485**	0.412**
Insurance		1	0.214**	0.284**		1	0.182**	0.355**
Extension			1	0.223**			1	0.293**
Credit				1				1

* Significant at the 5%，** Significant at the 1%

Table 4. Comparison for Different Specifications on Efficiency Weights

	Overall	Marketing	Insurance	Extension	Credit
Using COA weights	0.222	0.041	0.412	0.559	0.042
Using equal weights	0.263	0.043	0.420	0.550	0.041
t statistics[a]	3.459**	0.455	0.291	-0.274	-0.224
Kendall's rank test	0.796**	0.930**	0.971**	0.978**	0.967**

a. the difference in means of these two groups of efficiencies scores are compared.
* Significant at the 5%，** Significant at the 1%

Table 5. Numbers and Percentages in Total of TFCs Experiencing DRS, CRS or IRS

	Overall	Marketing	Insurance	Extension	Credit
IRS	92(45.8%)	65(32.3%)	105(52.2%)	106(52.7%)	122(60.7%)
CRS	3 (1.5%)	5 (2.5%)	33(16.4%)	5 (2.5%)	6 (3.0%)
DRS	106(52.7%)	131(65.2%)	63(31.3%)	90(44.8%)	73(36.3%)

a Percentages may not add to 1 because of rounding.

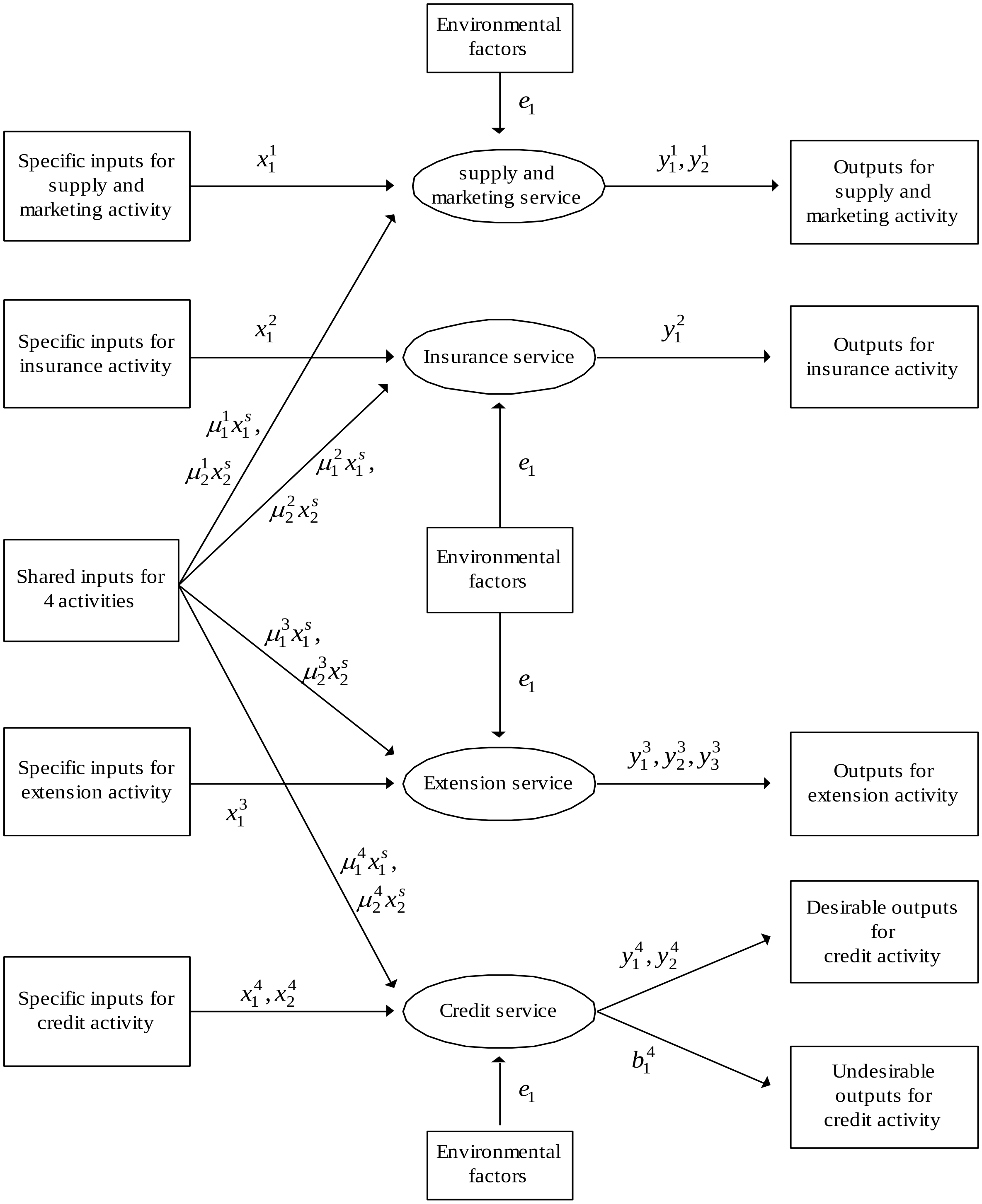

Figure 1. The Team Production Process of a TFC

Appendix A.

For notational ease, the proof is shown in the matrix form. In addition to the notation defined above, we also denote $u^i = (u_1^i, u_2^i, \cdots, u_{M_i}^i)$, $v^i = (v_1^i, v_2^i, \cdots, v_{N_i}^i)$, $\rho^i = (\rho_1^i, \rho_2^i, \cdots, \rho_{R_i}^i)$, and $v^s = (v_1^s, v_2^s, \cdots, v_L^s)$. The technical inefficiency measure is defines as follows:

$$TIE_{k'} = \frac{-\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s + \sum_{i=1}^{I} \delta_{k'}^i}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s}$$

$$= \frac{(-u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s + \delta_{k'}^1) + \cdots + (-u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s + \delta_{k'}^I)}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s}$$

$$= \frac{(-u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s + \delta_{k'}^1)}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s} \times \frac{u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s}{u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s}$$

$$+ \cdots + \frac{(-u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s + \delta_{k'}^I)}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s} \times \frac{u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s}{u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s}$$

$$= \frac{(-u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s + \delta_{k'}^1)}{u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s} \times \frac{u^1 y_{k'}^1 + v^1 x_{k'}^1 + \rho^1 b_{k'}^1 + v^s \mu_{k'}^1 x_{k'}^s}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s}$$

$$+ \cdots + \frac{(-u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s + \delta_{k'}^I)}{u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s} \times \frac{u^I y_{k'}^I + v^I x_{k'}^I + \rho^I b_{k'}^I + v^s \mu_{k'}^I x_{k'}^s}{\sum_{i=1}^{I} u^i y_{k'}^i + \sum_{i=1}^{I} v^i x_{k'}^i + \sum_{i=1}^{I} \rho^i b_{k'}^i + v^s x_{k'}^s}$$

$$= TIE_{k'}^1 \times w^1 + \cdots + TIE_{k'}^I \times w^I$$

$$= \sum_{i}^{I} w^i TIE_{k'}^i$$

Appendix B.

Here, we use the activity 1 of DMU k as an example to present this proof. The technical inefficiency of activity 1 is defined as follows:

$$TIE_k^1 = \frac{-u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s + \delta_k^1}{u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s}.$$

So the technical efficiency can be calculated by the following formulation and should not exceed 1.

$$TE_k^1 = 1 - \frac{-u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s + \delta_k^1}{u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s} \le 1.$$

Then, we have

$$\frac{(u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s) - (-u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s + \delta_k^1)}{u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s} \le 1$$

$$\Rightarrow 2u^1 y_k^1 - \delta_k^1 \le u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s$$

$$\Rightarrow -u^1 y_k^1 + v^1 x_k^1 + \rho^1 b_k^1 + v^s \mu_k^1 x_k^s + \delta_k^1 \ge 0$$

Thus, we obtain the constraint (17) as i =1. Note that we can use the similar method to show that the combination of the constraints in equation (17) ensures that the aggregate efficiency for DMU k should not exceed 1.

計畫成果自評

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Po-Chi Chen, Shih-Hsun Hsu, Ching-Cheng Chang, Ming-Miin Yu, Efficiency Measurements in Multi-activity Data Envelopment Analysis with Shared Inputs: An Application to Farmers' Organizations in Taiwan." Paper presented at the XXVII Conference of the International Association of Agricultural Economists, August 16- 22, 2009, Beijing, China.