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A fixed cost allocation based on the two-stage network data envelopment approach☆

Ming-Miin Yu [a], Li-Hsueh Chen [a,]*, Bo Hsiao [b]

[a] Department of Transportation Science,National Taiwan Ocean University,No. 2 Pei-Ning Road,Keelung 20224,Taiwan
[b] Department of Information Management,Chang Jung Christian University,No. 1 Changda Road, Gueiren District,Tainan City 71101,Taiwan

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ABSTRACT

The conventional paradigm of resource allocation model in single-stage data envelopment analysis (DEA) assumes that no internal structure is in production process. However, this paradigm does not consider that subunits may jointly use some fixed inputs from their organization, hence the importance of allocating fixed costs among subunits. Furthermore, in the fixed cost allocation problem, many studies use conventional DEA principles and produce self-evaluation efficiency scores. However, fixed cost allocation may contribute to each of subprocesses simultaneously. This study proposes an alternative approach to fixed cost allocation based on the two-stage network DEA (NDEA) and the concept of cross-efficiency. The study presents a numerical example to illustrate the applicability of the method. The results show that if two decision-making units (DMUs) have similar output profiles, the DMU with higher input values receives less fixed cost, whereas if two DMUs have similar input profiles, the DMU with higher output values receives more fixed cost. This study contributes in creating a novel approach to show how to allocate adequately the fixed cost to all DMUs when considering efficiency.

1. Introduction

When subunits jointly use a common system from their organization, the individual units have to share the total expense of building the common system. Examples include sharing the fixed cost of owning/leasing a common telecommunications cable (Beasley, 2003) and allocating a manufacturer's advertising expenditures among local retailers (Cook & Zhu, 2005). Hence, how to allocate appropriately fixed costs among homogeneous but competitive subunits in an organization is important. Recent researches use data envelopment analysis (DEA) to solve the fixed cost allocation problem from the efficiency perspective.

DEA plays an important role in performance evaluation and benchmarking ever since DEA's development (Charnes, Cooper, & Rhodes, 1978). In fact, the literature introduces many DEA models and applications after the first CCR model (e.g., Berbegal-Mirabent, Lafuente, & Solé, 2013; Chebat, Filiatrault, Katz, & Tal, 1994; Gonzalez-Padron, Akdeniz, & Calantone, 2014; Luo & Donthu, 2005). DEA's primary use is for performance estimation but has many applications; for example, problem solving in decision making and management. An important application is on allocating fixed cost among peer DMUs. DEA is superior to other methods because DEA examines the effect of feasible allocation plans by considering the empirical description of the production possibility set (Li, Yang, Liang, & Hua, 2009).

Cook and Kress (1999) first try to solve the cost allocation problem from DEA viewpoint by treating the allocated fixed cost as an additional input and obtaining the equitable allocation according to the invariance principle and the Pareto minimality principle. Similarly, Beasley (2003) proposes a nonlinear model and adds some additional constraints to obtain a unique cost allocation by maximizing the average efficiency across all DMUs. Amirteimoori and Kordrostami (2005) propose an alternative approach that combines the efficiency invariance (Cook & Kress, 1999) and Beasley (2003) additional constraints to get a unique allocation. Building on efficiency invariance, Cook and Zhu (2005) extend Cook and Kress's (1999) from input orientation to output orientation, and provide a feasible but not optimal cost allocation. Li et al. (2009) treat the fixed cost as a complement of other inputs and form an alternative approach to allocate fixed costs. Lin (2011a) indicates that Cook and Zhu's (2005) probably has no feasible solution when adding some special constraints. Lin further extends Cook and Zhu's (2005) with some additional constraints to obtain a feasible cost allocation. Lin (2011b) proposes as well the proportion of fixed cost to each DMU and adopts the minimal deviation principle to guarantee the satisfaction of the efficiency invariance. Li, Yang, Chen, Dai, and Liang (2013) introduce the concept of satisfaction degree and propose a max-min model consisting in maximizing all DMU's satisfaction degrees to generate a unique fixed cost allocation. In Mostafaee's (2013) new DEA-based approach, Mostafaee minimizes the gaps among the allocated costs and the efficiency measures and the returns to scale classifications of all

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* Corresponding author.
E-mail addresses: yumm@mail.ntou.edu.tw (M.-M. Yu), yannachen@gmail.com (L.-H. Chen), bhsiao@mail.cjcu.edu.tw (B. Hsiao).

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DMUs remain the same. Du, Cook, Liang, and Zhu (2014) develop a DEA-based iterative approach building on the cross-efficiency concept to solve fixed cost allocation problem.

Table 1 provides a comparison with different DEA-based fixed cost allocation approaches according to the following criteria: allocation principles, performance-measuring models, and approaches for allocating fixed costs. Table 1 shows that some studies assume that the efficiency does not change after the cost allocation, whereas some studies assume that the average efficiency increases after the cost allocation. All studies use the one-stage DEA models, which treat the internal structure as "black box" to build the fixed cost allocation approaches.

However, the operational process usually includes multiple stages. For example, the operational process of a bank comprises the deposit process and lending process. Sub-processes of individual subunits also use the common system that organizations build. Hence, fixed cost allocation may contribute to each of those sub-processes simultaneously. The above studies ignore that possibility, do not consider the internal structure of operational process (ignoring the internal structure may

Table 1
Comparison table of the DEA-based fixed cost allocation approaches.

Authors	Allocation principles	Models	Approaches
Cook and Kress (1999)	Efficiency invariance	One-stage DEA	Step 1: Assess the pre-allocation efficiency score of each DMU and obtain the optimal values of weight variables. Step 2: Use the optimal values of weight variables of inputs obtained from step 1 to allocate costs.
Beasley (2003)	Efficiency maximization	One-stage DEA	Step 1: Maximize the average of post-allocation efficiency of all DMUs. Step 2: Determine the flexibility associated with fixed cost allocation for each DMU based on the optimal value of the average post-allocation efficiency obtained from step 1. Step 3: Allocate the costs by minimizing the gaps between the maximum and minimum proportions of the flexibility obtained from step 2.
Amirteimoori and Kordrostami (2005)	Efficiency invariance	One-stage DEA	Step 1: Maximize the average of pre-allocation efficiency of all DMUs to obtain the optimal values of weight variables. Step 2: Allocate the fixed costs by minimizing the maximum gaps between the maximum and minimum deviation of the fixed costs for all DMUs based on the optimal values of weight variables obtained from step 1.
Cook and Zhu (2005)	Efficiency invariance	One-stage DEA	Step 1: Assess the pre-allocation efficiency score of each DMU and obtain the optimal values of intensity variables. Step 2: Allocate cost based on the optimal values of intensity variables obtained from step 1.
Li et al. (2009)	Efficiency maximization	One-stage super-efficiency DEA	Step 1: Treat the fixed cost as a complement of other inputs and assess the post-allocation efficiency score of each DMU. Step 2: Allocate the fixed cost by minimizing gaps on the allocated costs among all DMUs and maximizing the proportional increment over and above the minimum efficiency for each sensitive DMU.
Lin (2011a)	Efficiency invariance	One-stage DEA	Step 1: Assess the pre-allocation efficiency score of each DMU and obtain the optimal values of intensity variables. Step 2: Determine the values of the slack variables, which represent the gaps between the optimal allocated costs and the actual allocated costs, by minimizing the sum of all slack values based on the optimal values of intensity variables obtained from step 1. Step 3: Calculate the maximum fixed costs based the optimal values of intensity variables obtained from step 1 and the optimal slack values obtained from step 2. Step 4: Obtain an equitable fixed cost allocation by minimizing the difference between the maximum and the minimum proportion of fixed costs paid by all DMUs.
Lin (2011b)	Efficiency invariance	One-stage DEA	Step 1: Assess the pre-allocation efficiency score of each DMU and obtain the optimal values of intensity variables. Step 2: Calculate the proportion of the fixed costs allocated to each DMU by the relative efficiencies and the input–output scales of DMU, and obtain the proportion costs. Step 3: Determine the cost allocation by minimizing the square of the distance between the allocated costs and the corresponding proportion costs based on the optimal values of intensity variables obtained from step 1.
Li et al. (2013)	Efficiency maximization	One-stage DEA	Step 1: Calculate the maximal and minimal allocated costs for all DMUs. Step 2: Maximize the satisfaction degree of each DMU to get the allocated cost.
Mostafaee (2013)	Efficiency invariance	The combined primal-dual form of the one-stage DEA	Step 1: Assess the pre-allocation efficiency score of each DMU and obtain the optimal values of intensity variables. Step 2: Allocate the fixed costs by minimizing the gaps among allocated costs based on the optimal values of intensity variables and the pre-allocation efficiency scores obtained from step 1.
Du et al. (2014)	Efficiency maximization	One-stage cross-efficiency DEA	Step 1: Assess the post-allocation efficiency score for each DMU based on the cross-efficiency concept. Step 2: Continue the iterative process until the efficiency score for any DMU cannot improve. Afterwards, derive the optimal fixed cost allocation.

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