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A common-weights DEA model for centralized resource reduction and target setting ☆

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ABSTRACT

Data Envelopment Analysis (DEA) is a powerful tool for measuring the relative efficiency for a set of Decision Making Units (DMUs) that transform multiple inputs into multiple outputs. In centralized decision-making systems, management normally imposes common resource constraints to maximize operating revenues and minimize operating expenses. In this study, we propose an alternative DEA model for centrally imposed resource or output reduction across the reference set. We determine the amount of input and output reduction needed for each DMU to increase the efficiency score of all the DMUs. The contribution of the proposed model is fourfold: (1) we take into consideration the performance evaluation of the centralized budgeting in hierarchical organizations; (2) we use a Common Set of Weights (CSW) method based on the Goal Programming (GP) concept to control the total weight flexibility in the conventional DEA models; (3) we propose a comprehensive approach for optimizing the inputs and/or outputs contractions and improving the final efficiencies of the DMUs while reducing the computational complexities; (4) we compare the proposed method with an approach in the literature; and (5) we demonstrate the applicability of the proposed method and exhibit the efficacy of the procedure with a numerical example.

1. Introduction

Changing economic conditions have challenged many financial institutions and banks to search for more efficient ways to assess their operations. Non-parametric frontier analysis was first introduced by Farrell (1957) and later developed into Data Envelopment Analysis (DEA) by Charnes, Cooper, and Rhodes (1978) as a linear programming based technique for efficiency assessment. DEA is a powerful mathematical method for determining the relative efficiency of a set of functionally similar Decision Making Units (DMUs) (e.g., banks, brokerage firms, and insurance companies) that use multiple inputs to produce multiple outputs. Although in theory the conventional DEA assumes that all DMUs enjoy complete autonomy in accessing available resources, the DMUs are in practice often subject to common resources and market constraints imposed by a central decision maker. Hence, in many real-world situations, one may have to consider retrenchment programs requiring curtailment of some of the inputs and outputs for a variety of exogenous reasons. However, a good retrenchment program should not diminish any DMU efficiencies. For example, consider a public agency in charge of staffing and supplying a school district with special resources and assigning students to different schools. A budget reduction in the district will result in budget cuts in the schools while demographic changes may lead to reductions in the number of students across the board in the district. In both cases, it is desirable to maintain or improve technical efficiency of the schools after resource reallocation. Several researchers have applied the input and/or output deterioration to DEA models in the literature. Activity planning in DEA was proposed by Banker, Charnes, Cooper, and Clarke (1989), Bogetoft (1993, 1994, 2000) and Golany and Tamir (1995).

Cook and Kress (1999) were the first to introduce the idea of resource or cost allocation in DEA by characterizing an equitable way for allocating the shared costs. However, their approach cannot provide the cost allocation for the DMUs in a straightforward

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way and requires a huge computational burden. Jahanshahloo, Hosseinzadeh Lotfi, Shoja, and Sanei (2004) identified the shortcoming of Cook and Kress's (1999) approach and devised a simple method for costs allocation without solving any linear program. Cook and Zhu (2005) extended Cook and Kress's (1999) approach to an equitable direct cost allocation method. Lin (2011) extended Cook and Zhu's (2005) method for allocating fixed resources with some additional constraints by eliminating the occasional infeasibility problem in their method. Athanassopoulos (1995) proposed a method for target setting and resource allocation in multi-level planning problems using Goal Programming (GP) and DEA. Athanassopoulos (1998) later proposed a resource allocation model which consisted of two steps: (1) determining the optimal weights using a multiplier DEA model; and (2) defining the feasible trade-offs in allocation. Athanassopoulos, Lambroukos, and Seiford (1999) imposed upper and lower bounds on inputs for each individual DMU that had to be satisfied after reallocation.

Ito, Namatame, and Yamaguchi (1999) reallocated the management resources to provide the maximum outputs using the concept of the production possibility set of the DEA-BCC (Banker, Charnes, & Cooper, 1984) model. Wei, Zhang, and Zhang (2000) introduced the inverse DEA model using the concept of an inverse optimization problem in which the efficiency remains unchanged in the presence of data changes (interested readers for more details on the inverse optimization are referred to Ahuja & Orlin (2001)). The authors tried to answer the question: If some of the inputs of the DMU are changed by a certain amount, by how much should the outputs be changed in order to preserve the original level of efficiency. Their inverse DEA model was solved as a Multi-Objective Linear Programming (MOLP) problem. Yan, Wei, and Hao (2002) developed an inverse generalized DEA model and then discussed the application of the extended model to resource reallocation problems. Hadi-Vencheh, Foroughi, and Soleimani-damaneh (2008) presented a counterexample to show that Wei et al. (2000)'s method does not always produce useful results when using a weakly efficient solution of the MOLP problems. Cook and Zhu (2003) developed a DEA model for the maximally achievable efficiency measurement of highway maintenance crews by reduction in the inputs without impacting the outputs. Beasley (2003) used a non-linear program to maximize the average efficiency scores of the DMUs to simultaneously allocate fixed costs, input resources, and output targets. Amirteimoori and Kordrostami (2005) modified the constraints of Beasley's (2003) model to minimize cases of infeasibility. Korhonen and Syrjänen (2004) developed a resource-allocation model for finding an equitable allocation plan using DEA and MOLP. Jahanshahloo, Hosseinzadeh Lotfi, and Moradi (2005a) presented a method for fairly allocating a fixed output among DMUs without solving any linear program while keeping the efficiency scores unchanged. Amirteimoori and Shafiei (2006) proposed a DEA-based method for equitably removing a fix resource from all the DMUs and ensuring that the efficiency of units before and after reduction remains unchanged. Li and Cui (2008) presented a resource allocation framework consisting of a various returns to scale model, an inverse DEA model, a common weight analysis model, and an extra resource allocation algorithm. Li, Yang, Liang, and Hua (2009) first considered the linkage between the efficiency scores and the cost allocation and then developed a DEA approach to allocate the fixed cost between DMUs.

Pachkova (2009) proposed a DEA model to reallocate inputs based on the trade-off between the maximum allowed reallocation cost and the highest possible aggregate efficiencies of all the DMUs. Vaz, Camanho, and Guimarães (2010) first assessed the efficiency of retail stores with several selling sections in a network DEA model under Variable Returns to Scale (VRS) and showed how resource reallocation and target setting in Färe, Grabowski, Grosskopf, and Kraft's (1997) method improves the efficiency scores. Bi, Ding, Luo, and Liang (2011) suggested a resource allocation and target setting model for a parallel production system based on Kao's (2009) parallel DEA model. In their proposed model, the sub-DMUs were evaluated using the common weights without deteriorating the efficiency. Amirteimoori and Mohaghegh Tabar (2010) proposed a DEA approach for resource allocation and target setting problems. In their setting, the decision maker(s) could decide to allocate additional resources equitably among all DMUs and, in exchange, demand additional aggregate output from them. Amirteimoori and Emrouznejad (2011) presented a DEA-based approach to determine the highest possible input reduction and lowest possible output deterioration without reducing the efficiency score for each DMU. We demonstrate the advantages of the method proposed in this study by comparing it with the approach in Amirteimoori and Emrouznejad (2011). Similar to Amirteimoori and Emrouznejad (2011, 2012) presented an alternative DEA-based approach involving an additional assumption that the sum of the efficiencies of the DMUs is improved with respect to their prior performance. Recently, Lozano, Villa, and Canca (2011) introduced a number of non-radial, output-oriented and centralized DEA models for resource allocation and target setting for inputs with integer constraints.

Lertworasirikul, Charnsethikul, and Fang (2011) extended the inverse DEA model to VRS by using preserved efficiency for all DMUs in a resource allocation problem. This inverse DEA study considered the efficiency scores of all DMUs while the previous studies on the inverse DEA, c.f., Wei et al. (2000) and Yan et al. (2002), take the efficiency of the considered DMU into consideration. They proposed a MOLP model for the inverse DEA model and transformed into a linear programming model to obtain an optimal solution. Their method was applied to a case study at a motorcycle-part company. Wei and Chang (2011) introduced the optimal system design DEA model to optimally implement a DMU's resource allocation. Their model helps DMUs discover an optimal design or configuration given some cost or effort constraints. Hosseinzadeh Lotfi, Hatami-Marbini, Agrell, Aghayi, and Gholami (2013) recently proposed an allocation mechanism using a common dual weights approach for allocating the fixed resources to the units and equitably setting the expected common increase of the targets to the DMUs.

In the original DEA model, Charnes et al. (1978) proposed that the efficiency of a DMU can be obtained as the maximum of a ratio of weighted outputs to weighted inputs, subject to the condition that the same ratio for all the DMUs must be less than or equal to one. In fact, there are no restrictions on how much weight (multiplier) can be placed on each input or output relative to the others. Thus, the endogenous weights for each individual DMU are chosen uniquely to maximize its own efficiency. This characteristic of DEA is called "total weights flexibility". Obviously, it is possible that a particular DMU only takes into account weights on a few variables. Moreover, it is highly implausible and overly conservative to assume that each DMU faces unique marginal costs and benefits when evaluating a set of structurally comparable units. Consequently, many applications involve decision makers providing a priori preferred weights in efficiency evaluation.

Many researchers have focused on the problem of unacceptable weighting schemes. Dyson and Thanassoulis (1988) proposed a method for absolute weight restrictions. Charnes, Cooper, Huang, and Sun (1990) demonstrated that undesirable weighting plans are unavoidable in many DEA applications and proposed cone ratio restrictions models to provide more realistic weights. Thompson, Dharmapala, and Thrall (1995) used Charnes et al.'s (1990) models and introduced the "assurance region" as a special case of the cone ratio concept (Thompson, Langemeier, Lee, Lee, & Thrall, 1990). There are some extensions of the assurance region concept in the DEA literature (see Allen, Athanasopoulos, Dyson, & Thanassoulis (1997) and Cook & Seiford (2009) for a comprehensive overview).