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Data Envelopment Analysis and non-discretionary inputs: How to select the most suitable model using multi-criteria decision analysis

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ABSTRACT

Within Data Envelopment Analysis, several alternative models allow for an environmental adjustment. The majority of them deliver divergent results. Decision makers face the difficult task of selecting the most suitable model. This study is performed to overcome this difficulty. By doing so, it fills a research gap. First, a two-step web-based survey is conducted. It aims (1) to identify the selection criteria, (2) to prioritize and weight the selection criteria with respect to the goal of selecting the most suitable model and (3) to collect the preferences about which model is preferable to fulfil each selection criterion. Second, Analytic Hierarchy Process is used to quantify the preferences expressed in the survey. Results show that the understandability, the applicability and the acceptability of the alternative models are valid selection criteria. The selection of the most suitable model depends on the preferences of the decision makers with regards to these criteria.

1. Introduction and objectives

The external environment could influence the ability of management to convert inputs into outputs and, as a result, impact entities' technical efficiency. Following Coelli, Prasada Rao, O'Donnel, and Battese (2005, p. 190), an environmental variable is defined as a factor that could influence the efficiency of an entity, where such a factor is not a traditional input and is assumed to be outside of the manager's control. Because it is not under the control of managers, such a factor is also called a non-discretionary variable. It cannot be varied at the discretion of an individual manager but nevertheless needs to be taken into account to measure efficiency (Cooper, Seiford, & Tone, 2007, p. 215).

Examples of environmental variables include ownership differences (such as public versus private), location characteristics, labor relations (such as conflicting versus peaceful relationships between trade unions and employers' organizations) and government regulations (Fried, Schmidt, & Yaisawarng, 1999).

Data Envelopment Analysis (DEA) is a commonly used approach to the measurement of efficiency. Within DEA, several models allow for an environmental adjustment. Following Muñiz (2002), they can be grouped in three categories: (1) one-stage models (Banker & Morey, 1986a, 1986b; Ruggiero, 1996; Yang and Paradi in Muñiz et al. (2006), (2) multi-stage models including two-stage (Ray, 1988, 1991), three-stage (Fried, Lovell, Schmidt, & Yaisawarng, 2002; Muñiz, 2002; Ruggiero, 1998) and four-stage models (Fried et al., 1999) and (3) program analysis models (Charnes, Cooper, & Rhodes, 1981).

There are few published studies which compare these models with one another. Some studies use simulated data to compare alternative DEA models' results to the 'true' efficiency estimates performed by the simulation (Cordero, Pedraja, & Santín, 2009; Estelle, Johnson, & Ruggiero, 2010; Harrison, Rouse, & Armstrong, 2012; Muñiz et al., 2006; Ruggiero, 1996, 1998, 2004).[1] These studies provide mixed results about the convergence of alternative models with the 'true' efficiency.

Other studies (Cordero-Ferrara, Pedraja-Chaparro, & Salinas-Jiménez, 2008; Huguenin, 2014; Muñiz, 2002; Yang & Pollitt, 2009) use empirical data in order to specifically benchmark alternative DEA models. In these studies, comparisons are made between the efficiency estimates of the alternative models. The best available evidence suggests that there is no consensus on the best model to use (Cordero-Ferrara et al., 2008). It also suggests that the majority of models deliver diverging results (Huguenin, 2014). In other words, the efficiency scores generated by the models are significantly different. Consequently, recommendations and policy implications may differ according to the model used.

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[1] 'True' efficiency is determined by an artificial set of data as the production function, used to simulate data, is known.

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From a political standpoint, these diverging results could potentially lead to opposite decisions. From an applied research standpoint, they should represent a serious matter of concern. And from a decision making standpoint, they may lead to opposing managerial choices.

As no consensus emerges on the best model to use, practitioners and decision makers face the difficulty of selecting the model which is right for them, in other words, the model which best reflects their own preferences.[2] Some authors, such as Wong and Li (2006), qualify this difficulty as the selection 'dilemma'. When some alternative models can be applied to a similar empirical case, the choice of model thus becomes a strategic issue.

The aim of this study is to illustrate how Analytic Hierarchy Process (AHP), a multi-criteria decision analysis method, could be applied in order to help select the most suitable model among a choice of alternative models. As far as the author is aware, this has never been done before. The current study thus focuses on the process of selecting the most suitable model, rather than on the result itself generated by this process. As a result, it does not aim to identify the most suitable model which is representative of a particular population, for instance the DEA community. The preferences expressed by the sample of respondents are, as a result, used for illustrative purpose. AHP is a recognized expert system used in several studies published by Expert Systems with Applications (Ishizaka & Labib, 2011). Ultimately, this study aims to provide practical guidelines about the process of implementing AHP in the current context.

2. DEA and AHP: a literature review

2.1. Data Envelopment Analysis

DEA is a performance measurement technique. It finds its origin in Charnes, Cooper, and Rhodes (1978). See Huguenin (2013) for a synthesized presentation of DEA or Cooper et al. (2007) for a comprehensive treatment of the methodology.

DEA has been applied to various areas, both in the private and in the public sectors. See, for instance, Nguyen, Roca, and Sharma (2014) for an application in banking, Fuentes (2011) and Fuentes and Álvarez-Suárez (2012) for applications in travel agencies or Harrison and Rouse (2014) for an application in education. Most studies in various fields have opted for DEA as their methodological approach, as in the education sector (Agasisti, Bonomi, & Sibiano, 2014).

Within DEA, several models have been developed to allow for an environmental adjustment (Muñiz, 2002). Among them, four models are retained as alternatives in this study. These models are retained because they are all, to some extent, user-friendly and easily accessible to practitioners and decision makers (Huguenin, 2014).

The Banker and Morey (1986a) model (BM1986a) and the Banker and Morey (1986b) model (BM1986b) are the first two models retained. In BM1986a, the entities are grouped into homogenous categories defined by the level of the environmental variables. In order to measure efficiency, entities are compared only with other entities with similar or worse environmental variables. In BM1986b, the environmental variables are included directly into the model as non-discretionary variables. This model takes into account the fact that environmental variables are not under the control of management and cannot be treated as discretionary factors. As a result, the constraints on the environmental variable are modified. Interested readers will find the specification of these models in Banker and Morey (1986a, 1986b).

Although they have been criticized, BM1986a and BM1986b are supported by Harrison et al. (2012) who note that these models are widely used by researchers. They have generated at least 239 different publications (Löber & Staat, 2010, p. 810). Harrison et al. (2012, p. 263) stress that it suggests that many researchers have found these models appropriate for their particular context. They also mention that "given there is no DEA model that is clearly superior in controlling for non-discretionary inputs, researchers continue to refer to the work of Banker and Morey (1986a, 1986b), p. 263)". See for instance Garrett and Kwak (2011) for an application of BM1986a and Muñiz (2002) for an application of BM1986b.

The third model retained is the Ray (1991) model (R1991). This model contains two stages. In the first stage, a basic DEA model is performed using only discretionary variables. After obtaining the technical efficiency scores (TE) from the first stage, R1991 uses an OLS model to regress these scores upon non-discretionary variables in the second stage. Since Ray (1991), other types of regression have been used in the second stage. For instance, McCarty and Yaisawarng (1993) are the first to use a Tobit regression. R1991 is recommended by Coelli, Prasada Rao, and O'Donnel (2005) in most cases. It has demonstrated its superiority to other models which allow for an environmental adjustment (Ruggiero, 1998, 2004). See for instance Burney, Johnes, Al-Enezy, and Al-Musallam (2013) for an application of R1991. Interested readers will find the specification of this model in Ray (1991).

Finally, the fourth model retained is the Yang and Paradi model in Muñiz et al. (2006, p. 1176) (YP2006). This model applies a handicapping measure based on the levels of the non-discretionary variables. Entities with a favorable environment are penalized by the handicapping measure. Non-discretionary inputs are adjusted with a higher handicap and non-discretionary outputs are adjusted with a lower handicap. As a result, adjusted inputs have a higher value than original inputs and adjusted outputs have a lower value than original outputs. Interested readers will find the specification of YP2006 in Muñiz et al. (2006).

YP2006 is relatively little known and used. Compared to BM1986a, it does not lessen the discriminating power of DEA, as it does not categorize the entities. YP2006 is particularly suited when discretionary inputs and/or outputs are augmented or diminished according to the condition of the environment. See for instance Yang and Paradi (2006) for an application.

Note that other models than BM1986a, BM1986b, R1991 and YP2006 could have been considered. The inclusion or the removal of one or several models is likely to modify the results produced by AHP. However, as the current study focuses on the process of selecting the most suitable model rather on the results itself generated by this process, the choice of models included in the survey is, in itself, not determinant.

2.2. Analytic Hierarchy Process

AHP is a multi-criteria decision analysis (MCDA) method. MCDA methods have been developed to help the decision maker in the personal decision process. These methods take into account the preferences of the decision maker, which is subjective information. As an ideal solution suiting all the criteria usually does not exist, MCDA methods identify a compromise solution.

Roy (1981) defines four main types of problems which require decision making: choice, sorting, ranking and description. The current study aims to select the most suitable DEA model (i.e.

[2] One could argue that the awareness of the advantages and the drawbacks of each alternative model is sufficient information in order to select the most suitable model, even in situations where all models could technically be performed. This is probably true for DEA experts, but not for practitioners who are often informed users of DEA models, but no specialists. As a result, multi-criteria decision analysis methods could help practitioners in order to select the most suitable model.