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Interfaces with Other Disciplines

Multi-output efficiency with good and bad outputs [☆]

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ABSTRACT

Cherchye, De Rock, Dierynck, Roodhooft, and Sabbe (2013) introduced a DEA methodology that is specially tailored for multi-output efficiency measurement. The methodology accounts for jointly used inputs and incorporates information on how inputs are allocated to outputs. In this paper, we present extensions that render the methodology useful to deal with undesirable (or "bad") outputs in addition to desirable (or "good") outputs. Interestingly, these extensions deal in a natural way with several limitations of existing DEA approaches to treat undesirable outputs. We also demonstrate the practical usefulness of our methodological extensions through an application to US electric utilities.

1. Introduction

Data Envelopment Analysis (DEA; after Charnes, Cooper, & Rhodes (1978)) evaluates the efficiency of a Decision Making Unit (DMU) by comparing its input–output performance to that of other DMUs operating in a similar technological environment.[4] The method is intrinsically nonparametric as it is avoids using (unverifiable) parametric/functional structure for the production technology. It "let the data speak for themselves" and directly starts from the observed input–output combinations (associated with the evaluated DMUs). It reconstructs the production possibilities by (only) assuming standard production axioms (such as monotonicity and convexity). DMU efficiency is then measured as the distance of the corresponding input–output combination to the efficient frontier of this empirical production possibility set. By now, DEA has become very popular both as an analytical research instrument and a decision-support tool.

Recently, Cherchye, De Rock, Dierynck, Roodhooft, and Sabbe (2013) developed a novel DEA methodology that is specially tailored for multi-output efficiency measurement.[5] The methodology accounts for joint inputs in the production process and incorporates specific information on how inputs are allocated to individual outputs. In what follows, we will present several extensions of this multi-output efficiency measurement methodology, to show its usefulness to deal with undesirable (or "bad") outputs. To this end, we will introduce the new concept of "sub-joint" inputs, and indicate how output objectives can be included in the multi-output efficiency analysis. Interestingly, as we will indicate, these extensions deal in a natural way with several limitations of existing DEA approaches to treat undesirable outputs.

We will demonstrate the practical usefulness of our newly developed methodology through an application to US electric utilities. Obviously, electricity production processes are characterized by not only good but also bad outputs, i.e. greenhouse gas emissions. We remark that electric utilities effectively do have an economic motivation to reduce greenhouse gases. As we will explain more in detail in Section 4, the Acid Rain Program of the Clean Air Act puts limitations on the greenhouse gas emissions, and utilities are penalized if they pollute too much.

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4 See, for example, Färe, Grosskopf, and Lovell (1994), Cooper, Seiford, and Zhu (2004), Cooper, Seiford, and Tone (2007), Fried, Lovell, and Schmidt (2008), Cook and Seiford (2009) for reviews.

5 See also Cherchye, De Rock, and Vermeulen (2008) and Cherchye, Demuynck, De Rock, and De Witte (2014) for closely related studies.

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The rest of this paper unfolds as follows. Section 2 motivates our analysis. Section 3 introduces our methodology for multi-output efficiency evaluation with undesirable outputs, sub-joint inputs and output objectives. Section 4 uses this method to evaluate the efficiency of US electric utilities. Section 5 summarizes our main conclusions.

2. Multi-output efficiency and bad outputs

In this section, we motivate the theoretical and practical relevance of our following analysis. In doing so, we will also position our main contributions in the relevant literature.

2.1. Multi-output efficiency with output objectives

Standard DEA models treat the conversion of inputs into the outputs as a "black box": they do not assume any particular structure on how inputs are linked to outputs. However, in many empirical applications it is possible to allocate particular inputs to specific outputs. The methodology of Cherchye et al. (2013) can account for such information. In particular, the new methodology characterizes each output by its own production technology, while accounting for interdependencies between the different output-specific technologies (through jointly used inputs). An interesting feature of the methodology is that it has more discriminatory power than standard DEA methods, precisely because it uses the available information on the allocation of inputs to outputs and because it explicitly models the economies of scope stemming from joint input use.

More specifically, the starting point of the methodology is that the presence of economies of scope form a prime economic motivation for simultaneously producing multiple outputs. Basically, economies of scope originate from so-called *joint* inputs, which have a "public good" nature in that they simultaneously benefit the production of all the outputs that are produced. Cherchye et al.'s methodology explicitly distinguishes between these joint inputs and *output-specific* inputs, which are allocated to individual outputs. A first extension of the current paper is that we introduce the concept of *sub-joint* inputs, which at the same time contribute to multiple outputs but not to all outputs. In other words, like joint inputs, these sub-joint inputs act as public goods in the production process, but only for a subset of outputs. In a sense, this new category of inputs is situated between the categories of joint inputs (contributing to all outputs) and output-specific inputs (contributing to individual outputs).

In the present paper, we will show that the use of output-specific production technologies characterized by (sub)joint inputs is particularly useful in settings characterized by undesirable outputs. Indeed, inputs that simultaneously generate not only good outputs but also bad outputs are essentially (sub)joint inputs. As such, Cherchye et al.'s methodology for multi-output efficiency measurement provides a natural framework for efficiency analysis with good and bad outputs. This will constitute the basic starting point of our formal argument developed in the following sections.

At this point, we remark that our approach bears a close relationship to several existing approaches in the DEA literature. Firstly, there is a clear connection with network DEA (see Fare & Grosskopf (2000) and Färe, Grosskopf, & Whittaker (2007)). Network DEA also makes use of what we call output-specific inputs.[6] However, the crucial difference between our approach and network DEA pertains to our modeling of (sub)joint inputs. As explained above, this type of inputs plays an important role in our approach because it defines the interdependencies between the production processes associated with different outputs. By contrast, to the best of our knowledge, the existing literature on network DEA abstracted from this possibility of jointly used inputs. Secondly, Salerian and Chan (2005) and Despic, Despic, and Paradi (2007) present two alternative methods to model inputs that contribute to some outputs but not to others. As such, these models can actually be interpreted as special cases of our model with (sub)joint inputs.

All the above approaches have in common that they try to enhance the realism of the efficiency analysis by integrating information on the internal production structure. We believe that our methodology provides a unifying framework that is consistent with these approaches. This framework should be particularly attractive to empirical researchers who are familiar with standard DEA techniques and interested in the analysis of multi-output production characterized by (sub)joint inputs.

The second methodological extension that we will present pertains to the fact that the original method of Cherchye et al. (2013) focused exclusively on the minimization of input quantities. In what follows, we will show how to include output objective considerations in the efficiency evaluation, so offering the possibility to simultaneously consider input and output improvements in the efficiency assessment. Again, we will argue that such output objectives can be especially relevant in the context of undesirable outputs. In particular, it allows for explicitly incorporating specific targets regarding the reduction of these bad outputs in the evaluation exercise. At this point, however, we emphasize that the usefulness of this output objective methodology is not restricted to settings with undesirable outputs. Actually, we believe the concept of output objectives can be particularly useful in many alternative contexts where specific (good) output (expansion) objectives are important together with input reduction.

As a concluding remark, by incorporating output objectives in the analysis, we actually do consider simultaneous input and output adjustments in the efficiency evaluation exercise. Interestingly, this falls in line with the existing literature on undesirable outputs, which typically uses non-oriented models that seek simultaneously the reduction of inputs, the increase of good outputs and the decrease of bad outputs. In this sense, our use of output objectives effectively defines a "non-oriented" (or "semi-oriented") version of the method originally proposed by Cherchye et al. (2013).

2.2. Efficiency measurement with undesirable outputs

In the literature, we can distinguish two main approaches to integrate undesirable outputs into DEA efficiency analysis. The first approach, which is the dominant one in the literature, uses specific DEA models to deal with undesirable outputs (defined by specific production axioms and/or specific efficiency measures). The second approach uses standard DEA models but with a special treatment of the undesirable outputs (i.e. as transformed into desirable outputs or as inputs). Before presenting our own approach, we briefly review each of these existing approaches. This will also help us to highlight the specificities of our novel approach.

The first existing approach makes use of DEA models that are specially tailored to handle undesirable outputs. Here, one possibility is to introduce specific production axioms to reconstruct the production possibilities. The most popular axioms are weak disposability (see Färe, Grosskopf, Lovell, & Pasurka (1989)), which implies that bad outputs can only be reduced with a proportional reduction of desirable (or "good") outputs, and null-jointness (see Färe & Grosskopf (2004)), which states that the only way to produce no bad output is to produce no good output. See also Sahoo,

[6] Both network DEA and our approach assume that the output-specific inputs are observed for each different output. There exist a number of alternative approaches that are not based on observing this information (i.e. the exact decomposition (over outputs) of the output-specific inputs is unknown to the empirical analyst). See, for example, Cook, Habadou, and Teunter (2000), Beasley (2003), Lozano and Villa (2004), Li, Yang, Liang, and Hua (2009), Yu, Chern, and Hsiao (2013) and Du, Cook, Liang, and Zhu (2014). In principle, these other approaches can be combined with ours but, for compactness, we will not discuss this in the current paper.

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