Incorporating bad outputs in non-parametric frontier models

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Growing societal concerns about climate change and other pollution issues, and more generally about sustainability, have forced firms to undertake actions aimed at decreasing their impact on the environment. Such actions may be costly for the firms in terms of investment costs or pollution abatement costs. In this context, the methods to evaluate firm performance (i.e. to conduct benchmarking analyses) have been adapted and are still being adapted to take into account the generation of 'bad' (or undesirable) outputs (i.e. waste, pollution, noise…) along with 'good' (or desirable) outputs. Empirical applications in the literature show that conclusions differ whether bad outputs are incorporated or excluded: this is for example the case of the impact of public subsidies on the efficiency of farms in the European Union (Latruffe et al., 2017).

Two methodological frameworks are available to evaluate firm performance and more precisely firm efficiency (i.e. the optimal use of inputs to generate outputs given a technology): (*i*) a parametric framework (the stochastic frontier analysis), and; (*ii*) a non-parametric framework (the Data Envelopment Analysis (DEA)) where a piece-wise frontier enveloping all firms is constructed with linear programming, and distance to the frontier captures efficiency.

Within DEA, several models to take into account bad outputs have been developed (see for instance Dakpo et al., 2016, for a review). Earlier approaches have treated pollution either as an additional input in the production technology, or as an output under the weak disposability

assumption. This latter assumption implies that a reduction in the level of good outputs is needed to reduce the level of pollution. These two approaches have been later criticised, and the materials balance approach, which is mostly based on the first two laws of thermodynamics, has been developed to assess the environmental efficiency of firms. More recently, other approaches have been formulated such as the by-production approach, based on the multi-ware production theory, grounded on the idea that a complex system cannot be represented by a single functional form. Therefore, the by-production approach considers two production technologies, one associated to the production of good outputs and the second to the generation of bad outputs. The weak G-disposability assumption has also been proposed to incorporate bad outputs while simultaneously considering the mass balance equation. A non-standard approach known as the eco-efficiency frontier considers the value-added and environmental impacts.

Various R packages implement DEA procedures (e.g. Wilson, 2008; Oh and Suh, 2013; Bogetoft and Otto, 2015) but packages incorporating bad outputs into DEA models are not yet available on R. Therefore, we propose to bridge this gap by developing a 'badDEA' package. Such a package would unfold all the aforementioned approaches in their different variants: the objective of the firm (increase in the good outputs, decrease in the bad outputs or decrease in the inputs), the scale possibilities (increasing, decreasing or constant returns to scale), and the efficiency nature (radial, non-radial or directional distance function). The package would also aim at providing implicit prices (also called shadow prices) of bad outputs, which could for instance be useful in evaluating marginal abatement costs of pollution at the firm level. As such, 'badDEA' would provide an up-to-date code of the literature in pollution-adjusted efficiency measurement and would be the first of its kind in R.

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