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Invited Review

Modelling pollution-generating technologies in performance benchmarking: Recent developments, limits and future prospects in the nonparametric framework

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ABSTRACT

This article is a critical review of methods integrating environmental aspects into productive efficiency. We describe the classic modelling approach relying on the weak disposability assumption, and explain the major recent developments around the inclusion of undesirable outputs in production technology modelling, namely the materials balance principles and the weak G-disposability, the by-production modelling and the cost disposability assumption, and the unified model under natural and managerial disposability concepts. We discuss the limits inherent in each methodology and suggest future research perspectives.

1. Introduction

Externalities or spillovers arise in the presence of market failures where some actions of a group of agents generate social costs (or social benefits) that accrue to external parties not involved in the market transaction (McConnell & Brue, 2007). The case of pollution-generating activities is particularly relevant in this context. The question of the internalisation of the social costs arising from pollution has become an important area of interest for economists. In the presence of environmental regulations aimed at the internalisation of pollution costs by firms, some resources within firms might be diverted to mitigate pollution and, hence, best-practice comparisons (i.e. performance benchmarking) that do not account for this would inevitably lead to spurious results (Kopp, 1981). Besides, integrating environmental aspects into productive efficiency can provide policy-makers with helpful information on production systems that can lead to improving the design of new policies. Within this framework, Pittman (1983) used the index number theory of Caves, Christensen, and Diewert (1982) to develop a new productivity comparison methodology that incorporated undesirable outputs'[1] control behaviour. However, this methodology was based on a translog transformation function which required information on prices for undesirable outputs. Pollution being a non-marketed good, computing Pittman's productivity indices may be challenging. By contrast, the development of activity analysis enables efficiency evaluation based on quantity information only.

Two paradigms have been developed, one involving parametric models (econometric models which require the specification of a functional form) and one using mathematical programming methods (such as Data Envelopment Analysis—DEA). In this paper we focus on the latter, since such methods offer a large range of possibilities due to their flexibility and the less restrictive assumptions inherent in them. In the literature using such mathematical programming methods, the implicit positive correlation between pollution and desirable outputs has been formalised in different ways.

(i) A first approach treats pollution as a free disposable input (Hailu & Veeman, 2001; Yang & Pollitt, 2009).[2] The main argument behind this approach is that emissions of

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[1] Hereafter, the expressions "bad", "undesirable", "detrimental", "incidental", "residual", and "unwanted" goods, as well as "bads", are used to qualify pollution or pollutants. By contrast, "good" outputs are also named "desirable" or "intended" outputs.

[2] The free disposability (strong disposability) of inputs states that if any input is increased (whether proportionally or not), output does not decrease.

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environmentally detrimental products can be viewed as the use of the environment's capacity that is necessary for their disposal (Considine & Larson, 2006; Paul, Ball, Felthoven, Grube, & Nehring, 2002). Thus, according to the advocates of this approach, considering these emissions as inputs is likely to be a good way of accounting for the consumption of natural resources. Some other scholars (Barbera & McConnell, 1990; Baumol, Panzar, & Willig, 1988; Cropper & Oates, 1992; Tahvonen & Kuuluvainen, 1993) believe in a positive relationship between good and bad outputs for a reason clearly expressed in Mahlberg and Sahoo (2011) as: "undesirable outputs incur costs for a firm because it requires the diversion of productive inputs from the production of desirable (good) outputs for abatement purposes in compliance with the environmental regulations". However, as argued by Førsund (2009), this idea is more convincing at a macro level where "a single relation with residuals as inputs may be regarded as a reduced form of a larger system", although at a micro level the author explicitly shows that treating a bad output as an input inevitably leads to zero production of bad output for a producer being an economic actor. From another perspective, Haynes, Ratick, Bowen, and Cummings-Saxton (1993) stated that undesirable outputs can be viewed as "unavoidable" residuals, which are subsets of pollution-generating inputs, and thus can be treated as inputs. The idea of considering undesirable outputs as additional inputs has, however, been seriously challenged as it deflects from the physical laws (Färe & Grosskopf, 2003) and the materials balance principles (Ayres, 1995; Ayres & Kneese, 1969). Rigorously speaking, undesirable outputs are not inputs, and treating them as additional inputs will not reflect the true production process (Seiford & Zhu, 2002). As summarised by Scheel (2001), when pollution is treated as an input "one abstracts from the underlying input-output structure which is usually defined by the nature of the production process. Instead, the only information needed is whether the data have to be minimized or maximized . . ." Moreover, by assuming free disposability of undesirable outputs, such modelling includes situations where "finite amount of input can produce an infinite amount of bad output, thus violating the law of mass conservation" (Podinovski & Kuosmanen, 2011). Considering bad as inputs is then physically unacceptable because of the violation of the boundedness of output sets. All these criticisms make the model that treats bad outputs as extra inputs unrealistic and thus to be avoided. Based on this situation, we do not discuss this case further in the paper.

(ii) A second group of approaches extends models such as the frontier eco-efficiency models based on Korhonen and Luptacik (2004) and Lauwers (2009), which construct a production system where only undesirable outputs are used as inputs to produce the good output (Mahlberg, Luptacik, & Sahoo, 2011). This approach is not discussed here since it is based on an incomplete production process. Another approach known as the LCA+DEA approach associates Life Cycle Assessment (LCA) and DEA (Iribarren, Vazquez-Rowe, Moreira, & Feijoo, 2010).[3] We also ignore this model here because its objective is not the minimisation of undesirable outputs, but rather the potential reduction of these outputs in the case where all production units are technically efficient. The model fails to capture all the input's substitution possibilities that could help optimise the environmental performance. Another range of approaches relies on data transformation so that undesirable outputs can be equivalently treated as good outputs (Lovell, Pastor, & Turner, 1995; Sahoo, Luptacik, & Mahlberg, 2011). However, Färe and Grosskopf (2004a) showed that the results obtained from such data transformation are inconsistent. This is intuitive since the transformation distorts the real production process. Moreover, the model implies that undesirable outputs can be reduced without any cost, which is not realistic (Du, Lu, & Yu, 2014). Hence, we also do not consider this approach in our paper.

(iii) A third approach considers pollution as outputs by assuming the weak disposability of these bad outputs and the null-jointness of both production types (good outputs and bad outputs) (Färe & Grosskopf, 2009; Färe, Grosskopf, & Pasurka, 1986; Färe, Grosskopf, Lundgren, Marklund, & Zhou, 2012). The weak disposability concept describes a situation where outputs are intimately linked and their amounts cannot be changed independently. In the case where bad outputs are present, it implies that reducing the levels of these outputs necessarily requires reducing the quantities of intended outputs in a proportional way. The null-jointness property accounts for situations where, if zero levels of bad outputs are generated, then zero levels of good outputs are produced. This approach relying on weak disposability and null-jointness is commonly used in the literature. However, as argued by Coelli, Lauwers, and Van Huylenbroeck (2007) and Hoang and Coelli (2011), the weak disposability assumption (WDA) violates the first law of thermodynamics.[4] It can be demonstrated that under certain conditions, such as the presence of end-of-pipe technologies to abate pollution, the WDA and the null-jointness assumption can become compatible with the materials balance principles (Hampf & Rødseth, 2014). Yet, in many situations end-of-pipe equipment is technologically unavailable or economically unaffordable (Rødseth & Romstad, 2013). In addition, making the WDA conform to the materials balance principles, does not mean that the approach is correct. We provide a thorough discussion of the limits of the WDA in the third section.

(iv) With respect to the limits associated with the WDA, an approach based on the materials balance principles was introduced into production theory by Lauwers, Van Huylenbroeck, and Rogiers (1999) and later furthered by Coelli, Lauwers, and Van Huylenbroeck (2005) and Lauwers and Van Huylenbroeck (2003). Relying on the mass/energy balance equation—which is simply an accounting identity that links in an equivalent way the quantity of materials that goes into a production process to the amount of outputs including residual ones—enables the estimation of an iso-environmental line in the same vein as iso-cost lines. However, as explained by Ebert and Welsch (2007), it essentially focuses on materials inputs and ignores any interaction that might exist between these materials inputs and non-materials ones. The method will thus identify decision making units (DMUs)[5] that use few materials inputs as environmentally efficient, despite their reliance on non-materials inputs. In addition, recently Hoang and Rao (2010) underlined the problem of "the lack of universally accepted weights for various material inputs". Taking the example of eutrophication and gas pollution in agriculture, the authors discussed the difficulties in aggregating these two impacts in the case of the materials balance.[6] They then proposed an extension based on

[3] 'Environmental LCA is the compilation and evaluation of the material and energy flows as well as the potential environmental impacts of these throughout the life cycle of a product' (Ekvall & Finnveden, 2001).

[4] This law can be related to one of the theses of the Greek philosopher Anaxagore and lately renewed as the famous saying of Antoine Lavoisier "Nothing is lost, nothing is created, everything is transformed".

[5] DMUs are production entities which use inputs to produce outputs.

[6] As suggested by one reviewer, the issue here is the difficulty of assessing the environmental impacts of pollutants, and it is worth stressing that this is different