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Interfaces with Other Disciplines

Eco-efficiency and eco-productivity change over time in a multisectoral economic system ☆

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ABSTRACT

We measure eco-efficiency of an economy by means of an augmented Leontief input–output model extended by constraints for primary inputs. Using a multi-objective optimisation model the eco-efficiency frontier of the economy is generated. The results of these multi-objective optimisation problems define eco-efficient virtual decision making units (DMUs). The eco-efficiency is obtained as a solution of a data envelopment analysis (DEA) model with virtual DMUs defining the potential and a DMU describing the actual performance of the economy. This procedure is then extended to an intertemporal approach in the spirit of the Luenberger productivity indicator. This indicator permits decomposing eco-productivity change into eco-efficiency change and eco-technical change. The indicator is then further decompounded in a way that enables us to examine the contributions of individual production factors, undesirable as well as desirable outputs to eco-productivity change over time. For illustration purposes the proposed model is applied to investigate eco-productivity growth of the Austrian economy.

1. Introduction

One of the goals of the European Union's strategy for a smart, sustainable and inclusive growth (the so called Europe 2020) is the reduction of CO_2 emissions by 20% compared to 1990 levels (European Commission, 2010). Since a general aim of the economic policy in Europe remains to keep economic growth, a reduction of air pollution requires an increase of eco-efficiency. In this context, increasing eco-efficiency means decoupling pollution (e.g. CO_2 emission) from economic development. Without such a de-linking the environmental target cannot be fulfilled. Another goal of Europe 2020 is the increase of energy efficiency which is defined as a reduction of energy consumption. This reduction clearly implicates also a raise in eco-efficiency. Strengthening eco-efficiency has also been identified by the United Nations Industry and Development Organization (UNIDO) as one of the major strategic elements in its work on sustainability. It constituted a Cleaner and Sustainable Production Unit (UNIDO, 2012a) and started an Eco-efficiency (Cleaner-Production) Program (UNIDO, 2012b).

The concept of eco-efficiency was first described by Schaltegger and Sturm (1989). They defined eco-efficiency as ratio between environmental impact added and value added. Eco-efficiency aims at achieving more goods and service outputs with less resource inputs as well as less waste and emissions. Eco-efficiency is related to sustainability in the sense that the later is a broader notion whereas the former is a new indicator of economic performance. It differs from sustainability in that it takes into account environmental and economic dimensions but does not include social aspects. Eco-efficiency is a necessary but not a sufficient condition for achieving sustainability. Measurement of eco-efficiency is important to determine success (economic and environmental), identify and track trends, prioritize actions and ascertain areas for improvement. Monitoring eco-efficiency on the macro-level is useful in order to make sustainability accountable.

Like in Korhonen and Luptacik (2004), in this paper it is assumed that decision making units (say, countries) want to produce desirable outputs as much as possible and produce minimal undesirable outputs (e.g. pollutions) with less inputs. In contrast, usual analysis of (technical) efficiency defines efficiency as a ratio of a weighted sum of desirable outputs to a weighted sum of inputs,

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and does not take undesirable outputs into consideration. The concept of eco-efficiency has the advantage over traditional (technical) efficiency that it considers inputs, desirable outputs and undesirable outputs in one model and takes economical as well as ecological aspects simultaneously into account.

The efficiency analysis of any decision making unit (DMU) without taking economic as well as ecological issues into account often yields erroneous inferences concerning the real health of the DMU. This is precisely because there always exists a trade-off between economy and environment, and an economy's performance is not sustainable without a healthy ecological system. Because win–win solutions for economy and ecology seem quite elusive in practice, there arises the concept of trade-offs and efficiency frontiers for economy. Therefore, there is a need to have a measure of performance characterised by an eco-efficiency frontier that aims at providing efficient solutions in relation to the objective of optimising the goals of economy as well as ecology. That is, DMUs lying on the eco-efficiency frontier cannot increase the output of economic goods and services without increasing at least one input or increasing waste and emissions. These DMUs are efficient in the sense of Koopmanns (1951). As is known from the literature (see e.g. Färe, Grosskopf, Lovell, & Pasurka, 1989; Färe & Grosskopf, 1996; Sahoo, Luptacik, & Mahlberg, 2011; Tyteca, 1996, 1997), the nonparametric methodology of data envelopment analysis (DEA) helps estimating the eco-efficiency frontier. Particularly in the context of eco-efficiency analysis, the main challenge is the lack of measures like market prices for undesirable outputs to be used as weights to aggregate various inputs, desirable outputs and undesirable outputs. Although various techniques for eco-efficiency measurement have been presented in the literature, most eco-efficiency measures are either very limited or depend on subjective arbitrary weighting scheme. The technique of DEA endogenously generates the most favourable weights that maximise the relative efficiency of the evaluated DMU in comparison with the maximum attainable efficiency. This means that DEA presents every evaluated DMU in its most favourable environment.

In the paper by Luptacik and Böhm (2010) eco-efficiency of a whole economy is measured by means of an augmented Leontief input–output model extended by constraints for primary inputs. Using multi-objective optimisation models an eco-efficiency frontier of the economy is generated. The solutions of the multi-objective optimisation problems define eco-efficient virtual decision making units (DMUs). The eco-efficiency of the economy can be obtained as a solution of a DEA model with the virtual DMUs defining the potential and a DMU describing the actual performance of the economy. This model allows us taking into account the interdependences of the sectors in an economy in eco-efficiency analyses. Furthermore, it permits estimating eco-efficiency of an economy with respect to its own potential and without the need to compare it with other economies – economies that may possess different technologies and varying mutual interdependencies due to international trade.

This model, however, is purely static and cannot account for eco-efficiency change (catch-up) or explain changes in eco-technology (frontier shift) over time. One main aim of this study is to extend the static eco-efficiency analysis to an intertemporal setting. For this purpose the Luenberger productivity indicator is utilised, which was introduced by Chambers, Färe, and Grosskopf (1996). This indicator measures productivity change (*PRODCH*) and permits decomposing it into change in efficiency (*EFFCH*) on the one hand and change in the frontier technology, i.e., technical change (*TECHCH*) on the other.

This measure differs from the more frequently applied Malmquist productivity index in two primary ways. Firstly, it is constructed based on directional distance functions, which simultaneously adjust outputs and inputs in a direction chosen by the investigator, and, secondly, it has an additive structure, i.e. it is expressed as differences rather than ratios of distance functions. Contrary to several other indexes and indicators applied in productivity studies (e.g. Fisher index, Törnqvist index, Bennet–Bowley indicator) the proposed measure does not demand price information at any stage.

The Luenberger indicator itself is not capable of attributing eco-productivity change to changes in use of production factors or in production of undesirable or desirable outputs. To overcome this limitation our indicator is decomposed in a way that enables one to examine the contributions of individual production factors and individual (desirable and undesirable) outputs to eco-productivity change. The results allow the inference of which inputs and/or desirable/undesirable outputs of an economy are the drivers of eco-productivity change.

Our paper is structured as follows. Section 2 presents in detail the (static) model of Luptacik and Böhm (2010) and extends this model in line with the directional distance function approach. Section 3 introduces our method to measure eco-efficiency and eco-productivity change over time; whilst Section 4 deals with an illustrative empirical application of the proposed model, with Section 5 left for our concluding remarks.

2. Methodology

2.1. The augmented Leontief input–output model

The conventional Leontief's input–output model conveniently describes the production relations of an economy in period t for a given nonnegative vector of final demand for n goods produced in n interrelated sectors; gross output of the sectors in period t is denoted by a n-dimensional vector. Production technology in period t is given by a $(n \times n)$ input coefficient matrix. This in turn informs the use of a particular good i required for the production of a unit of good j. Luptacik and Böhm (2010) introduced a restriction of the use of primary input factors by the available primary input quantities in period t in this model.

The conventional Leontief's input–output model has been extended to a model version including pollution generation and abatement activities. The well known augmented Leontief model (Leontief, 1970; see also Lowe (1979), Luptacik & Böhm (1999), & Miller & Blair (2009)) is written as

$$\begin{bmatrix} I - A_{11,t} & -A_{12,t} \\ -A_{21,t} & I - A_{22,t} \end{bmatrix} \begin{bmatrix} x_{1,t} \\ x_{2,t} \end{bmatrix} \geqslant \begin{bmatrix} y_{1,t} \\ -y_{2,t} \end{bmatrix} \tag{1}$$

where the following notation is used: $x_{1,t}$ is the n-dimensional vector of gross industrial outputs in period t; $x_{2,t}$ is the o-dimensional vector of anti-pollution activity levels in period t; $A_{11,t}$ is the $(n \times n)$ matrix of conventional input coefficients (including competitive imports), showing the input of good i per unit of the output of good j (produced by sector j) in period t; $A_{12,t}$ is the $(n \times o)$ matrix with $a_{ik,t}$ representing the input of good i per unit of the eliminated pollutant k (eliminated by anti-pollution activity k) in period t; $A_{21,t}$ is the $(o \times n)$ matrix showing the output of pollutant k per unit of good i (produced by sector i) in period t; $A_{22,t}$ is the $(o \times o)$ matrix showing the output of pollutant k per unit of eliminated pollutant l (eliminated by anti-pollution activity l) in period t; I is the identity matrix; $y_{1,t}$ is the n-dimensional vector of final demands (reduced by the vector of competitive inputs) for economic commodities in period t (also referred to as net output or desirable output); $y_{2,t}$ is the o-dimensional vector of the net generation of pollutants in period t which remain untreated after abatement activity (also referred to as tolerated level of net pollution or undesirable output). The k-th element of this vector represents the pollution standard of pollutant k and indicates the tolerated level of net pollution.