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Measuring sustainability performance for China: A sequential generalized directional distance function approach

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ABSTRACT

This paper aims to present certain composite sustainability efficiency indicators for China based on a sequential generalized directional distance function. This approach can measure the sustainability performance of a country with diverse outputs, nature of technologies, and non-radial slacks. First, we propose the concept of a generalized directional distance function under a sequential environmental production technology. Second, we develop several standardized composite indicators related to sustainability performance. We then estimate the sequential generalized directional distance function based on a series of sequential data envelopment analysis models. Finally, we empirically examine regions in China using the proposed model and present some implications based on the empirical results.

1. Introduction

In 1987, the United Nations defined sustainable development as those activities that aim "to meet the needs of the present without compromising the ability of future generations to meet their own needs"; since then, environmental and sustainability issues have been receiving increasing attention. International standardization efforts have resulted in sustainability reporting indexes such as GRI and ISO 26000 that are now internationally recognized and widely adopted. As sustainability gains greater importance in business, companies are now reshaping their definition of value to include it, in addition to their traditional goal of profit maximization. Quantitative sustainability measurement makes it possible to set specific goals and provides an efficient tool for company innovation. More importantly, sustainability performance indicators can provide information on any aspect of the relationship between the environment and socio-economic activities, and constructing sustainability performance indicators can guide public policy-making as part of the process of sustainability governance. However, despite increased awareness of the conceptual and practical applications of sustainability measures, questions about the methods by which to measure corporate sustainability performance effectively remain unanswered. As Briassoulis (2001) indicates, little progress has been made toward improving such measurements. Therefore, it is necessary to construct a sustainability performance measurement framework on more integrated terms to facilitate companies and policy makers in confirming whether their development is sustainable.

Sustainability requires the harmonious reconciliation of environmental, social, and economic demands, referred to as the "three pillars" of sustainability. Therefore, the term sustainability measurement indicates the quantitative basis for the informed management of sustainability (Scott Cato, 2009). The metrics used for the measurement of sustainability involve the environmental, social, and economic domains, both individually and in various combinations, and include indicators, benchmarks, audits, indexes, and accounting, as well as assessments, appraisals, and other reporting systems (Dalal-Clayton and Sadler, 2009). Some of the most widely used sustainability measures include corporate sustainability reporting, triple bottom line accounting, and estimating the quality of sustainability governance for individual countries using the environmental sustainability and environmental performance indexes.

These methods may be referred to as partial indicators, because they can only partially reflect the aspects of sustainability performance from a single dimension. Ramanathan (2002) points out that a more holistic approach would be to use the production frontier technique and combine all the relevant indicators, such as environmental performance, economic efficiency, and social equitability, into an overall index for performance comparison. As Zhou and Ang (2009) indicate, composite indicators are increasingly gaining recognition as a useful tool for performance monitoring. Therefore, such composite indicators could provide more insightful information than partial indicators.

In the literature, multidimensional production efficiency, especially data envelopment analysis (DEA), has been widely used to benchmark energy efficiency and environmental performance (see Lozano and Gutiérrez, 2008; Picazo-Tadeo and Prior, 2009; Wang et al., 2013; Zhou et al., 2008).

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Among the various production efficiency methods, the recently developed directional distance function (DDF) approach has gained much popularity and has the capacity to expand good outputs and reduce inputs and bad outputs. The DDF is widely used in many environmental applications, such as environmental performance (Lozano and Gutiérrez, 2008; Picazo-Tadeo and Prior, 2009), eco-efficiency (Picazo-Tadeo et al., 2012; Zhang et al., 2008), energy efficiency (Zhang et al., 2013; Zhou et al., 2012), and environmental productivity growth (Kumar, 2006; Weber and Domazlicky, 2001; Zhang and Choi, 2013c). Zhang and Choi (2014) present a comprehensive literature review on DDF use in energy and environmental studies. However, the use of DDF has been restricted to environmental studies, and thus far, no studies have used this method for sustainability measurement, which includes wider aspects of the environmental, economic, and social domains. In particular, as these aspects change over time, the dynamic trends of the aspects become much more important.[1] The present study aims to bridge this gap by developing a new DDF method, namely, sequential generalized DDF (SGDDF), to measure sustainability performance from a multidimensional viewpoint.

As the traditional DDF developed by Chambers et al. (1996) aims to reduce inputs and expand outputs at the same rate, we can regard it as a radial efficiency measure. However, this radial measure has several limitations such as undesirable outputs and slack (Fukuyama and Weber, 2009). Therefore, it has a relatively weak discriminating power in ranking the entities to be evaluated (Zhou et al., 2012). Against this backdrop, recent studies sought to develop alternative non-radial efficiency measures. For instance, Fukuyama and Weber (2009) present a slack-based inefficiency measure by extending the DDF and Färe and Grosskopf (2010) propose a generalized DDF (GDDF).

In this study, we extend the GDDF proposed by Färe and Grosskopf (2010) by incorporating undesirable outputs and sequential environmental technology. We first develop an SGDDF by considering both the nature of technology and non-radial slack. Several standardized indicators have been developed for modeling sustainability performance using the proposed approach. This paper contributes to the literature in the following aspects. First, we propose a new approach, an SGDDF with undesirable outputs. Second, we apply this new approach to sustainability performance measurement. Lee and Saen (2012) used the DEA approach for measuring sustainability performance; however, no studies have employed the DDF for sustainability measurement. Finally, we also empirically study the Chinese regions in terms of sustainability performance based on a multidimensional approach. With regard to China, empirical studies have focused on the energy or environmental performance of China at the national (Song et al., 2013), provincial (e.g., Choi et al., 2012; Wang et al., 2011; Wei et al., 2012; Zhang and Choi, 2013a), industrial (Chen and Santos-Paulino, 2013; Lee and Zhang, 2012), and firm (Zhang and Choi, 2013b) levels. However, no studies have focused on the sustainability performance for China based on the DDF approach. China's economic development of has not been achieved in a sustainable manner. Although China now ranks second in terms of GDP globally, it ranks first in terms of energy use and carbon emissions. Hence, balancing economic development with environmental protection has become an increasingly important issue for China. Thus, investigating the sustainability performance of the Chinese economy has meaningful implications.

The remainder of this paper is organized as follows. Section 2 describes the methodology of the SGDDF approach. In Section 3, we employ the methodology described in Section 2 and empirically test the sustainability performance of Chinese regions. Section 4 concludes the paper and presents some implications.

[1] Yu et al. (in press) use the metafrontier DDF to measure the corporate sustainability performance of China's state-owned listed companies in 2010 from a micro-level perspective. In this study, we employ sequential DDF to measure the dynamic sustainability performance of the Chinese provinces from a macro-level perspective.

2. Methodology

2.1. SGDDF

Assume that each region is involved in a sustainable production process. Assume further that there are $n = 1, \ldots, N$ regions in China and that each region uses input vector $x \in \Re_+^M$ to jointly produce output vector $y \in \Re_+^S$ and undesirable output $b \in \Re_+^J$. The input vectors are capital (K), labor (L), and energy (E); the output vectors too are divided into three, economic output (GDP), environmental output (pollutants including SO_2, Chemical Oxygen Demand [COD], and CO_2), and social inequality output (Gini coefficient). Obviously, GDP is a desirable output and the pollutants and Gini-coefficient are undesirable outputs. A sustainable production process is illustrated in Fig. 1.

A multi-output production technology with undesirable outputs can be described as

$$T = \{(x, y, b) : x \,\text{can produce}\, (y, b)\}, \quad (1)$$

where T is often assumed to satisfy the standard axioms of production theory (Färe and Grosskopf, 2005). For instance, inactivity is always possible and finite amounts of input can produce only finite amounts of output. In addition, inputs and desirable outputs are often assumed to be strongly or freely disposable. For a reasonable joint production technology model, as described in Färe et al. (1989), the assumptions of weak disposability and null-jointness need to be imposed on T. Technically, the two assumptions can be expressed as follows:

(i) If $(x, y, b) \in T$ and $0 \le \theta \le 1$, then $(x, \theta y, \theta b) \in T$;
(ii) If $(x, y, b) \in T$ and $b = 0$, then $y = 0$.

The assumption of weak disposability implies that reducing the pollutants in economic development is a costly affair in terms of proportional reduction in GDP. In addition, reducing a country's social inequality gap is also usually a costly affair because the government should balance the country's growth and social equality, which could result in a slowdown of economic growth. The assumption of null-jointness indicates that undesirable outputs and inequality are unavoidable for economic development.

The conventional DDF is a radial efficiency (inefficiency) measure that may overestimate efficiency in the presence of a slack (Fukuyama and Weber, 2009). Further, non-radial efficiency measures are often advocated in performance measurement owing to their distinct advantages (Barros et al., 2012; Chang and Hu, 2010; Lu et al., 2013; Zhou et al., 2012). As such, Färe and Grosskopf (2010) provide a GDDF that seeks maximal increases in outputs while simultaneously reducing

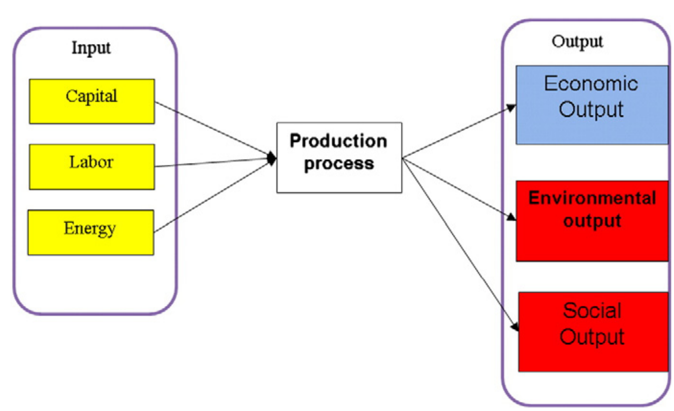

Fig. 1. Sustainable production process.