Journal of Cleaner Production 112 (2016) 2943–2952

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Congestion measurement under different policy objectives: an analysis of Chinese industry

Lei Chen, Ying-Ming Wang*, Liang Wang

School of Economics & Management, Fuzhou University, Fuzhou 350116, PR China

ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form
16 September 2015
Accepted 16 September 2015
Available online 28 September 2015

Keywords:
Data envelopment analysis (DEA)
Undesirable outputs
Congestion
Chinese industry

ABSTRACT

In recent years, the economic performance of Chinese industry has improved significantly; however, the congestion caused by excessive investment has plagued its sustainable development. In order to make full use of resources, it is necessary for the Chinese government to measure industrial congestion from different perspectives. However, most studies for measuring congestion only consider desirable outputs, even if, in practice, these are always accompanied by undesirable outputs. In this paper, three policy objectives are proposed for industrial development in China: the economic priority, the environmental priority, and the economic and environmental win-win. Three new data envelopment analysis (DEA) models with undesirable outputs were built for measuring undesirable congestion, desirable congestion, and double-congestion, respectively, for these policy objectives. These approaches can, not only identify congestion situation, but also calculate the total amount of congestion, and were applied to an analysis of the congestion of regional industries in China. Results show that most regions have some form of longstanding input congestion under different policy objectives, with this resulting in serious waste of resources. Based on the results obtained, some suggestions for sustainable industrial development in China are proposed.

1. Introduction

Resource scarcity and environmental degradation constitute major policy issues worldwide. The use of minimal resources to produce as many benefits as possible with minimal pollution is thus key to the promotion of sustainable development. To realize this goal, many scholars have researched feasible development options, with one of the main foci of research being the avoidance of excessive resource use in production, to avoid congestion. Congestion refers to a particular economic phenomenon where a reduction in one or more inputs is associated with an increase in one or more outputs, without affecting other inputs or outputs. Congestion is, for evident reasons, considered to be an unnecessary waste of resources and should be avoided in practice. However, Sueyoshi and Goto (2012) argued that the traditional concept of congestion only considers the relationship between inputs and desirable outputs, without taking pollutant emissions into account. They therefore termed traditional congestion *undesirable congestion*, contrasting this to congestion of undesirable outputs (defined as *desirable congestion*). The elimination of undesirable congestion and the promotion of desirable congestion are significant for economic development and environmental protection.

Data envelopment analysis (DEA) is a nonparametric approach to evaluate the relative efficiency of decision making units (DMUs) with multiple inputs and outputs, and was first proposed by Charnes et al. (1978). Many scholars are now working in this area, with many important results produced, such as the BCC model (Banker et al., 1984), the cross efficiency model (Du et al., 2014), and the environmental efficiency model (Chang et al., 2013). Since the treatment of congestion within the DEA framework was first proposed by Färe et al. (1985), DEA has become an important method for addressing congestion. The slack-based approach, proposed by Cooper et al. (1996), is a two-model approach for measuring congestion effects by comparing differences between observed and expected amounts. To improve on this approach, a one-model method for congestion evaluation was developed (Cooper et al., 2002). Unlike previous congestion research, which expressed congestion effects in terms of excessive inputs, some scholars have started to evaluate congestion effects from the perspective of outputs (Tone and Sahoo, 2004; Wei and Yan, 2004). Khodabakhshi (2009) developed a modified one-model approach based on

* Corresponding author. Tel.: +86 0591 22866681.
E-mail addresses: chenlei0593@hotmail.com (L. Chen), msymwang@hotmail.com (Y.-M. Wang), wangliangg322@hotmail.com (L. Wang).

http://dx.doi.org/10.1016/j.jclepro.2015.09.064
0959-6526/

relaxed combinations of inputs to measure input congestion. Noura et al. (2010) proposed a new one-model method to deal with the congestion problem, with this requiring considerably less computation than Cooper et al.'s model (2002). Marques and Simões (2010) and Simões and Marques (2011) reviewed three main approaches in the DEA literature for measuring the congestion effect, using these effectively to identify congestion in worldwide airports and in Portuguese hospital services, while Kao (2010) discussed the advantages and disadvantages of these methods through geometric interpretation. Sueyoshi and Goto (2012) classified congestion into undesirable and desirable congestion, and a series of studies were carried out based on these categories (Sueyoshi and Goto, 2014; Sueyoshi and Wang, 2014). Khoveyni et al. (2013) developed a slack-based DEA model to distinguish between strong and weak congestion, while Wu et al. (2013) proposed a new approach for measuring congestion with undesirable outputs, applying this to analysis of congestion in regional industries in China. Fang (2015) also proposed a DEA approach, based on the directional distance function, to simultaneously measure congestion in the presence of desirable and undesirable outputs.

However, most studies for evaluating congestion effect only consider inputs and desirable outputs, but do not take undesirable outputs into account. Wu et al. (2013) and Fang (2015) recognized the role of undesirable outputs, but neither was able to specify the amount of congestion. Undesirable outputs, such as carbon dioxide emitted during production, often play a significant role in sustainable development strategies. Generally, DEA studies addressing undesirable outputs can be classified into three categories. The first category mainly focuses on the treatment approach of undesirable outputs. Hailu and Veeman (2001) treated undesirable outputs as inputs for processes, with this approach easy to use but unable to reflect the real production process. Seiford and Zhu (2002) used a linear function to translate undesirable outputs into desirable outputs. Lozano and Gutiérrez (2011) used a slack-based measure (SBM) approach and Huang et al. (2015) used a metafrontier directional distance function (MDDF) approach to handle undesirable outputs. The second category includes studies of the disposability of undesirable outputs. Färe et al. (1985) distinguished between weak and strong disposability of undesirable outputs, attracting considerable attention among production economists (Guo and Wu, 2013; Podinovski and Kuosmanen, 2011; Yang and Pollitt, 2010). Sueyoshi and Goto (2012) proposed the natural and managerial disposability of undesirable outputs to further extend the concept of disposability. The third category includes empirical studies, extending across many fields. One of these is the evaluation of sustainable development (Rashidi et al., 2015; Song et al., 2015; Vlontzos et al., 2014; Wang et al., 2013).

China's economy has developed significantly in recent years, with the country becoming the second leading economic entity in the world following the United States (Zhang and Yang, 2013). Industry dominates the national economy and it is also the main source of energy consumption and pollution (Li and Shi, 2014). It is therefore important for China to strike a balance between industrial economic development and environmental protection, with many scholars working towards such a balance from different perspectives (He et al., 2013; Meng et al., 2013; Wu et al., 2014). However, in the case of the problem of industrial congestion, relevant research remains limited.

In general, traditional models are unable to recognize a congestion situation and the specific amount of congestion in cases where both desirable and undesirable outputs exist. In order to address these deficiencies, the aim of this study is to construct three new alternative DEA models for measuring congestion, with these applied in order to measure industrial congestion in 30 Chinese regions under different policy objectives. The study provides suggestions for the promotion of sustainable development in Chinese industry from a new perspective of congestion. We adopted the approach proposed by Seiford and Zhu (2002) to deal with undesirable outputs, not only because this is simple to use, but also because it reflects real production processes. Indeed, this is one of the most frequently used methods in the literature for dealing with undesirable outputs using a traditional DEA formulation. For example, Chen et al. (2015) treated undesirable economic activity outputs using this method, employing a DEA technique to evaluate environmental efficiency in 30 provinces of China during the period 2001–2010. Sueyoshi et al. (2013) argued that the assumption of weak disposability of undesirable outputs is limited, assuming that desirable and undesirable outputs increase or decrease in the same proportion. They also argued that there can be many factors influencing the quantity of undesirable outputs, including technological innovation. This paper therefore analyzes the congestion problem considering the free disposability of undesirable outputs. Taking into account the study of Cooper et al. (2002), which applied a one-model approach to measure the congestion effect, three new models are developed. These are used for measuring undesirable congestion, desirable congestion, and double-congestion, respectively. When these models were applied to measure industrial congestion in 30 Chinese regions, we found different amounts of congestion under different policy objectives.

The remainder of this paper is organized as follows. Section 2 introduces the one-model congestion approach proposed by Cooper et al. Section 3 outlines the three proposed new models for measuring congestion with undesirable outputs under different policy objectives. Section 4 applies these models for in-depth analysis of the congestion problem of regional industries in China. Finally, Section 5 presents the main conclusions of the study.

2. Preliminaries: one-model congestion approach

In this section, we briefly describe the one-model congestion approach developed by Cooper et al. (2002), which is based on an earlier two-model congestion approach (Cooper et al., 1996). We do not provide detailed descriptions of the two-model steps and of the process of converting this to a one-model approach; interested readers are advised to refer to Cooper et al. (1996, 2002).

Assuming there are n DMUs, i.e. $\{DMU_j|j=1,2,\ldots,n\}$, and each produces s outputs y_{rj} $(r = 1,2,\ldots,s)$ using m inputs x_{ij} $(i = 1,2,\ldots,m)$, input congestion can be determined using model (1), as follows:

$$
\begin{aligned}
&\max \theta + \varepsilon\left(\sum_{r=1}^{s} s_r^{+} - \sum_{i=1}^{m} s_i^{-c}\right)\\
&s.t.\ \sum_{j=1}^{n} x_{ij}\lambda_j = x_{i0} - s_i^{-c}, \quad i = 1,\cdots,m,\\
&\quad \sum_{j=1}^{n} y_{rj}\lambda_j = \theta y_{rj} + s_r^{+}, \quad r = 1,\cdots,s,\\
&\quad \sum_{j=1}^{n} \lambda_j = 1,\\
&\quad s_i^{-c}, s_r^{+}, \lambda_j \geq 0; \quad j = 1,\cdots,n; \ \ r = 1,\cdots,s; i = 1,\cdots,m,
\end{aligned} \tag{1}
$$

where $\varepsilon > 0$ is a Non-Archimedean element smaller than any positive real number. The intensity variables $\lambda_j (j = 1,\ldots,n)$, slack variables s_i^{-c} and s_r^{+}, and radial measure θ are decision variables. Of these, the slack variable s_i^{-c} represents the amount of congestion for the ith input, and the radial measure θ represents the efficiency of a specific DMU_0 being evaluated.