Energy Economics 48 (2015) 117–126

Contents lists available at ScienceDirect

Energy Economics

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

Energy savings potential in China's industrial sector: From the perspectives of factor price distortion and allocative inefficiency

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ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form 19 November 2014
Accepted 27 November 2014
Available online 26 December 2014

JEL Classification:
C32
O33
Q48

Keywords:
Energy savings potential
Shadow price model
Allocative efficiency
Energy price distortion

ABSTRACT

China's industrial energy consumption accounted for 70.82% of national and 14.12% of world energy usage in 2011. In the context of energy scarcity and environmental pollution, the industrial sector in China faces unsustainable growth problems. By adopting the stochastic frontier analysis (SFA) framework, this paper analyzes the factor allocative efficiency of China's industrial sector, and estimates the energy savings potential from the perspective of allocative inefficiency. This paper focuses on three issues. The first is examining the factor allocative inefficiency of China's industrial sector. The second is measuring factor price distortion by the shadow price model. The third is estimating the energy savings potential in China's industrial sector during 2001–2009. Major conclusions are thus drawn. First, factor prices of capital, labor and energy are distorted in China due to government regulations. Moreover, energy price is relatively low compared to capital price, while is relatively high compared to labor price. Second, the industry-wide energy savings potential resulted from energy allocative inefficiency was about 9.71% during 2001–2009. The downward trend of energy savings potential implies the increasing energy allocative efficiency in China's industrial sector. Third, a transparent and reasonable pricing mechanism is conducive to improving energy allocative efficiency.

1. Introduction

China's industrial sector has achieved remarkable growth since the policy of reform and opening up. However, the development model of high investment and high consumption has resulted in the serious problem of unsustainability (Yuan et al., 2008). China's industrial energy consumption accounted for 70.82% of national and 14.12% of world energy usage in 2011, respectively. In order to conserve energy and reduce emissions, the Chinese government put forward a binding target of energy intensity reduction in 2006, and further set a more stringent objective of "total energy controls" in 2011. In this context, energy conservation should be a major strategy for China's industrial sector to meet the future increasing energy demand.

From the perspective of efficiency, energy savings potential can be measured by the correcting space of "inefficiency". According to Farrell (1957), inefficiency is divided into two parts: one is technical inefficiency; the other is allocative inefficiency (or price inefficiency). Based on the production function theory, technical inefficiency indicates the failure of realizing the maximum output with a given set of inputs. In other words, the gap between the actual output and the output that realizes technical efficiency at the production frontier is technical inefficiency (Zhou and Ang, 2008). The amount of unnecessary energy inputs, which can be estimated by the extent of technical inefficiency, is defined as the technical energy savings potential in China.

In fact, the characteristic of allocative inefficiency in China's industrial sector is also obvious. The indicator of factor price is not included in the measurement of technical inefficiency, while it is considered in measuring allocative inefficiency. Based on the cost function theory, allocative inefficiency equals the gap between the actual cost and the optimal cost, which implies that the cost minimization is unrealized because of factor price distortion. Therefore, energy savings potential can be estimated by measuring the unnecessary energy cost resulted from energy price distortion.

The actual factor price in the imperfect factor market in China has deviated from the theoretical factor price that is under the perfectly competitive market for a long time. Factor market in China is still distorted compared to the consumption goods market, which has a higher degree of marketization because of China's entry into the World Trade Organization (WTO) in 2001. In other words, factor price and allocation are still determined by the administrative forces rather than the supply and demand. Particularly, in the factor market of energy, government decisions still play a decisive role in energy pricing, and thus energy subsidy is pervasive in China (Lin and Jiang, 2011; Ouyang and Lin, 2014). Energy has been overused in industrial subsectors in

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http://dx.doi.org/10.1016/j.eneco.2014.11.020
0140-9883/

China because of the undervalued energy price, and the issue of energy allocative efficiency has attracted increasing attention from scholars (Tao et al., 2009; Wang and Wu, 2014).

In this paper, from the perspective of allocative inefficiency, the energy savings potential of China's industrial sector is measured by the gap between the actual energy consumption and the targeted (optimal) energy consumption. However, opinions of scholars are divided on the definition as well as the econometric methods of the targeted (optimal) energy consumption in China. For example, the technical efficiency of production was considered by Yu (2011). Using the data envelopment analysis (DEA) method, the study estimated the production frontiers of all provinces in China and calculated the energy efficiency of each province. The similar method has been adopted by Hu and Wang (2006), Sun et al. (2010), and Zhou et al. (2007, 2008a, 2008b). Using the slacks-based measure model of DEA, Rao et al. (2012) investigated the energy consumption slacks and energy savings potential of 30 regions in China. Although the nonparametric DEA approach has the limitation of excluding statistical noise, Zhou et al. (2010) have overcome such limitations by developing the DEA bootstrapping algorithm. Based on the translog production function, from the perspective of energy substitution, Tao et al. (2009) explored the factor distortion of China's industrial sector under the framework of SFA. Using the same method, Sun and Lin (2014) analyzed the factor allocative efficiency and then calculated the energy savings potential attributed to the reallocation of energy factors. Based on the definition of the Shephard Distance Function proposed by Zhou et al. (2012), Lin and Du (2013) conducted an empirical research concerning the impact of factor market distortion on energy efficiency.

Different methods and indexes have been adopted by scholars in measuring factor market distortion. For instance, using the ratio of marginal revenue product (MRP) over factor price, Wang and Wu (2014) measured the extent of factor market distortion. Ma et al. (2008) calculated the missing technological change, factor demand and inter-factor and inter-fuel substitution potential for China. Khademvatani and Gordon (2013) employed a restricted profit function to model the shadow value of energy as a proper and meaningful marginal energy efficiency index. Haller and Hyland (2014) used a translog cost function to analyze the capital–energy substitution potential. In energy economics, the shadow-pricing model is often used to approximate marginal abatement costs of undesirable outputs such as carbon dioxide (CO_2) emissions. As found in the review study of Zhou et al. (2014a), a few number of different shadow pricing models were proposed. Apparently, those models have their specific strengths. The shadow price is used to measure the undesirable output, which may be interpreted as the opportunity cost of abating one additional unit of undesirable output in terms of the loss of desirable output. For example, Wang et al. (2013) employed a non-radial directional distance function approach to empirically investigate energy efficiency and energy productivity by including CO_2 emissions as an undesirable output. From a perspective of efficiency analysis, Zhou et al. (2014b) examined the optimal control of CO_2 emissions.

The existing studies show that allocative inefficiencies are costly, because the potential of profitability maximization or cost minimization has not been achieved. In most cases, analyses are conducted on the basis of the assumptions that under the neoclassical analysis framework, in which, we assume that firms would make cost minimization decisions according to the observed market price. However, the above assumptions usually fail to establish in reality, because the marginal technical substitution is usually unequal to the actual (observed) price. In other words, decisions on unobservable shadow prices reflect the divergence from the efficient behaviors. Schmidt and Knox Lovell (1979) first demonstrated how to incorporate allocative distortions by introducing errors in the first-order conditions for cost minimization. Christopoulos and Tsionas (2002), Burki and Khan (2004), and Khiabani and Hasani (2010) extended this approach to measure the impacts of allocative inefficiency on resource allocation and factor substitutability in the manufacturing sectors of Greek, Pakistan and Iran, respectively.

The purpose of this paper is to discuss the factor allocative inefficiency of China's industrial sector and measure the corresponding energy savings potential. This paper makes three contributions in literature. The first contribution is to explain allocative inefficiency by combining the analysis framework of Farrell (1957) and shadow price model, and to measure the factor allocative inefficiency of China's industrial sector by correcting technical inefficiency first and then by applying the analysis framework of the shadow price model. The second contribution is to measure the factor price distortion by the shadow price model. The third contribution is to estimate the energy savings potential in China's industrial sector during 2001–2009 from the perspective of factor allocative efficiency. Section 2 introduces the methodology and data processing. Section 3 provides the empirical results. Section 4 discusses technical efficiency, allocative efficiency, price distortion and energy savings potential of China's industrial sector. Section 5 provides conclusions and implications.

2. Methodologies and data source

2.1. Theoretical framework

In Subsection 2.1, we provide the theoretical framework for measuring energy savings potential resulted from allocative inefficiency.

From a microeconomic perspective, Farrell (1957) defined allocative efficiency as the ability to produce a given output with the minimized cost. Similarly, Christopoulos and Tsionas (2002) defined allocative efficiency as the ability of a firm to minimize cost by equating firm-specific marginal value product (MVP) with firm-specific marginal cost under certain technical conditions.

The theoretical description of allocative efficiency (*AE*) refers to the relationship between allocative efficiency (*AE*) and cost efficiency (*CE*) and technical efficiency (*TE*). The input–output relationship of an industry can be illustrated by Fig. 1. The horizontal axis represents the energy factor, and the vertical axis represents other (non-energy) factors. Point A is the observed per unit of output of an industry, which uses x_1^A unit of energy and x_2^A unit of non-energy factors of production. $L(y)$, which is the isoquant curve and the technological frontier of an industry, represents different combinations of energy and non-energy inputs for producing one unit of output under the conditions of completely efficient technologies. In Fig. 1, point C is technically efficient relative to point A. The index of technical efficiency (*TE*) is defined as OC/OA, so that the technical inefficiency can be defined as $1 - \text{OC/OA} = \text{AC/OA}$. For an industry that is under the constant return to scale, a given quantity of output can be produced using the input share of OC/OA. In

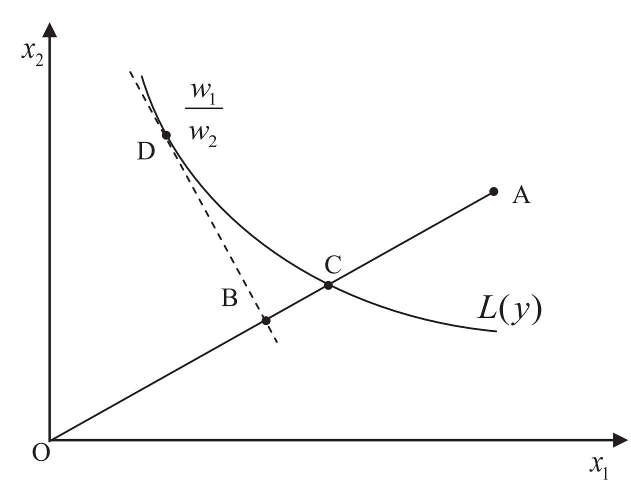

Fig. 1. Allocative inefficiency under the framework of Farrell (1957).