Resources, Conservation and Recycling xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Full length article

Sustainable water use and water shadow price in China's urban industry

Wei Wang[a], Hualin Xie[a,b,**], Ning Zhang[c,d,e,*], Dong Xiang[e]

[a] Co-innovation center of institutional construction for Jiangxi eco-civilization, Jiangxi University of Finance and Economics, Nanchang 330013, China
[b] Research of Land Management, Jiangxi University of Finance and Economics, Nanchang 330032, China
[c] Department of Economics, & Institute of Resource, Environment and Sustainable Development, Jinan University, Guangzhou, Guangdong 510632, China
[d] China Center for Economic Development and Innovation Strategy Research, Jinan University, Guangzhou 510632, China
[e] China Institute for Micro, Small and Medium-sized Enterprises, Qilu University of Technology, Jinan, Shandong 250353, China

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form 28 June 2016
Accepted 5 September 2016
Available online xxx

Keywords:
Industrial water
Green use efficiency
Global non-radial directional distance function (DDF)
Shadow price
Urbanization

ABSTRACT

China is faced with a serious water shortage problem, and industrial sector is a major water consumer. How to improve the efficiency of industrial water use is extremely important for sustainable use of water in China. This paper applies a global non-radial directional distance function (GNDDF) to measure the green use efficiency of industrial water (GUEIW) incorporating undesirable outputs during 2004–2012. We calculate the two components of GUEIW named economic efficiency of industrial water (ECEIW) and economic efficiency of industrial water (ENEIW), and the shadow price of industrial water to explore the bias between the actual prices and the shadow ones. The results show that the GUEIW shows a W type curve over the study period, and its growth is mainly driven by the ECEIW. The regional heterogeneity of the GUEIW is significant. The eastern region of China enjoys the highest GUEIW, while the central region suffers the poorest performance in the GUEIW. The western region has the largest internal gap of the GUEIW. The actual prices of industrial water in all the provinces are much lower than the shadow ones, and appropriate increase in the industrial water price is helpful to raise the GUEIW. Some policy implications are also suggested.

1. Introduction

China's urban industrial economy has achieved remarkable progress since the reform and opening up policy in late 1970s. As an important input in the industrial production, the amount of industrial water consumption has shown an obvious rising trend. As shown in Fig. 1, the total amount of industrial water in China shows an upward trend in 2004–2012, and it is as high as 142.2 billion tons in 2012. The water use efficiency in China's industry sector is relatively low, and millions of tons of water is wasted in the process of industrial production in recent years (Deng et al., 2016). On the other hand, water pollution caused by industrial production has posed great threat to people's health. We can find in Fig. 1 that the amount of industrial wastewater discharge is up to 24.66 billion tons, and it shows a slight decrease trend since 2007. Specifically, in 2012, the amounts of chemical oxygen demand (COD) and ammonia nitrogen (AN) in industrial wastewater are 3.38 and 2.64 million tons, respectively. Unfortunately, most of them are directly discharged into the water supply sources, which made almost each province in China experience accidents of river and lake pollution. It is well known that China is a nation with a serious water shortage problem, and the amount of water available per capita is only about a quarter of the world average level in 2012 (Wang et al., 2015). The awful waste of water and frequent water pollution incidents has made the problem of water shortage more severe, causing great negative impacts on social and economic development (Cheng et al., 2009; Xie and Wang., 2015a; Cai et al., 2016). Therefore, improving the water use efficiency and abating water pollution are critical for sustainable water use in China (Gao et al., 2014; Liu et al., 2014; Hu et al., 2016; Tu et al., 2015).

Fortunately, the central government of China is now aware of the problems and prepared to solve them. To save the precious water as much as possible, the State Economic and Trade Commission announced that the annual growth rate and the total amount of industrial water in China should fall below 130 billion tons,

---

[*] Corresponding author at: Department of Economics, & Institute of Resource, Environment and Sustainable Development, Jinan University, Guangzhou, Guangdong 510632, China.
[**] Corresponding author.

E-mail addresses: landuse2008@126.com (H. Xie), zn928@naver.com (N. Zhang).

http://dx.doi.org/10.1016/j.resconrec.2016.09.005

Please cite this article in press as: Wang, W., et al., Sustainable water use and water shadow price in China's urban industry. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.09.005

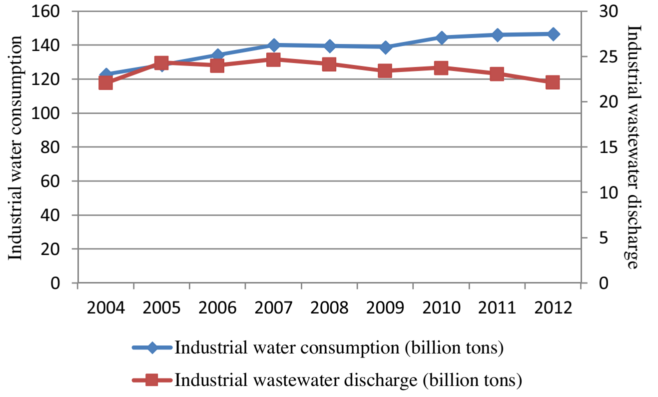

Fig. 1. Industrial water consumption and industrial wastewater discharge, 2004–2012 (http://nianjian.cnki.net/).

which accounts for less than 1.2% of the national water consumption during the 2001–2010.[1] In 2011, Chinese central government announced its most stringent water management plan known as the "3 Red Lines" water policy, which clearly stipulates the total amount of water consumption, the improvement of water use efficiency and water pollution treatment.[2] On the other hand, to deal with the problem of water pollution, the National People's Congress Standing Committee issued the *Law of Prevention and Control of Water Pollution* in 2008, which aimed at implementing strict regulation on industrial water pollution.[3] In addition, the Chinese State Council issued the "*Water pollution prevention action plan*" in April 2015, which consisted of a series of targets for water pollution regulation. In particular, the water quality in more than 70% of the seven major river basins in China should reach or exceed the class III standard by 2020, and this ratio should increase to 75% by 2030.[4] The industrial water use efficiency is expected to be greatly improved under those regulations (Cai, 2008). However, most of the policies from the central government are mainly based on the water use status of the whole country, which tend to ignore the regional heterogeneity. Actually, the characteristics of water use vary in different provinces, and appropriate and targeted countermeasures are necessary. For instance, since 2016, the Hebei Province has introduced a pilot policy namely "water resource tax" for Small and Medium-sized Enterprises. Therefore, it is extremely important to analyze the status of industrial water use at a regional level.

Additionally, as suggested by Kumbhakar and Bhattacharyya (1992), price plays an important role in determining the use efficiency of resource. Specifically, a relatively lower price can easily promote waste of water, and a relatively higher price of water may lead to higher production costs, which encourage producers to save water (Li and Ma, 2014). Thus, the price should be set within a reasonable range to achieve sustainable use of water. Unfortunately, the government has long determined the price of resource in China, and the water market can hardly play the role of setting reasonable prices and optimizing the allocations of resources. In particular, the local governments always tend to distort the price of water for their own interests, e.g., lowering the water price to attract more industrial investment, which could easily result in huge waste of water resource, and posing great threat to sustainable use of water resource (Fan and Mo, 2014). Therefore, how to calculate the reasonable price of water is a necessary and urgent issue.

Regarding the research methods for estimating the relative use efficiency of resources, many related recent studies would prefer distance function approach, which incorporates multiple input and output factors simultaneously (Zhang and Xie, 2015; Shao, 2016; Wu et al., 2014; Bian et al., 2014; Geissler et al., 2015; Jaeger and Rogge, 2014). There are two main methods to estimate the distance function, i.e., the nonparametric data envelopment analysis (DEA) approach and the parametric approach. The DEA approach, which is first proposed by Charnes et al. (1978), has gained much popularity in recent studies (Ren et al., 2013). A major advantage of the DEA approach over the parametric method is that a specific functional form on the underlying technology is not required (Zhang et al., 2014a,b; Zhang and Choi., 2014; Ren et al., 2014). As for the studies on evaluating the water use efficiency in China, Hu et al. (2006) conducted a pioneer empirical analysis in a total-factor DEA framework to evaluate the water use efficiency at the country level, and they presented the concept of water adjustment amount to determine the optimal scale of water use. Liao and Dong (2011) applied a similar approach to evaluate the water use efficiency at a provincial level. However, these studies only consider the economic efficiency, which might be regard as partial analysis because they ignore the pollutants caused by industrial production (e.g., wastewater and greenhouse gases). Therefore, we should incorporate both of the desirable and undesirable outputs in the model, and we can call the efficiency computed from this model "green use efficiency" (Wang et al., 2016; Xie et al., 2016; Zhao et al., 2009; Manzardo et al., 2014). In addition, most previous studies tended to apply a radial DEA approach, which aimed at expanding the good outputs and the contracting the bad outputs at the same rate. This is inconsistent with the actual production activities, and it often leads to the case where many of the observations under evaluation have the same efficiency value of 1, making raking the observations quite difficult (Zhou et al., 2007). Moreover, as Zhang et al. (2014a) pointed out, many related studies applied cross-sectional data other than time-series data, and the studies based on cross-sectional data could be regarded as contemporaneous efficiency evaluations. It is obvious that production technologies of each year are always not the same, and results based on contemporaneous production technology may not be reasonable. To overcome the problems, Zhang et al. (2014a,b) proposed a global non-radial DDF (GNDDF) approach, which expanded the good outputs and the contracted the bad outputs at different rates, and enveloped all of the contemporaneous technologies over the study period.

Some studies have estimated the prices of resources mainly based on cost or revenue function. However, as Atkinson and Halvorsen (1984) suggested, the cost or revenue function is not suitable when incorporating undesirable output and imperfect markets of resources. There are two approaches to estimate the shadow prices of input or output factors, i.e., the parametric and nonparametric methods. With respect to the parametric approach, which often takes a translog from, is widely applied in the studies on estimating the shadow prices of inputs and undesirable outputs. Coggins and Swinton (1996) employed the output distance function to compute the shadow price of sulfur dioxide of coal-burning electric utility plants in Wisconsin, US. Lee (2005) proposed an input distance functions to measure the shadow price of US electric power. Lee and Jin (2012) estimate the shadow price of nuclear capital and thermal capital in Korea based on a similar approach. Lee and Zhang (2012) computed the shadow price of carbon dioxide (CO_2) for the Chinese manufacturing industries. As for the nonparametric methods, Choi et al. (2012) calculated the shadow price of carbon dioxide in China based on the dual model of DEA approach. At the regional level, Zhang et al. (2014b) estimated the shadow prices of wastewater, sulfur dioxide and soot in Poyang Lake Ecological Economic Zone in China using a similar model.

---

[1] http://www.gov.cn/gongbao/content/2001/content_60999.htm.
[2] http://www.gov.cn/zwgk/2012-02/16/content_2067664.ht.
[3] http://www.gov.cn/flfg/2008-02/28/content_905050.htm.
[4] http://env.people.com.cn/n/2015/0416/c1010-26854928.html.

Please cite this article in press as: Wang, W., et al., Sustainable water use and water shadow price in China's urban industry. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.09.005