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Measuring water use performance in the cities along China's South-North Water Transfer Project

Zhuang Miao[a], Jichuan Sheng[b,*], Michael Webber[c], Tomas Baležentis[d], Yong Geng[e], Weihai Zhou[b]

[a] Western China Economic Research Center, Southwestern University of Finance and Economics, Chengdu, Sichuan, 611130, China
[b] Business School, Nanjing University of Information Science & Technology, 219 Ningliu Road, Nanjing, Jiangsu, 210044, China
[c] School of Geography, University of Melbourne, 221 Bouverie Street, Parkville, VIC, 3010, Australia
[d] Lithuanian Institute of Agrarian Economics, V. Kudirkos str. 18, LT-03105 Vilnius, Lithuania
[e] School of Environmental Science and Engineering, Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, 200240, China

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ABSTRACT

Due to the construction and operation of China's South-North Water Transfer Project (SNWTP), it is necessary to conduct broader research on the underlying trends and factors of the water-use performance in the SNWTP's cities from the perspective of "resource-economy-environment" system. This paper attempts to identify the optimal paths and measures for improving the water-use performance as measured by the Luenberger productivity indicator and its decomposition. The results show that sewage discharge, free-of-charge water use and leakage are the crucial variables that constitute major contributions to the overall inefficiency value associated with urban water use in the SNWTP. The static efficiencies of water consumption indicate better performance of the cities of the middle route if opposed to those of the eastern route. The results suggest that the cities that receive water from both of eastern and middle routes, have better performance in water use than other cities, while the static efficiency in the other water-consuming areas on the eastern and middle routes do not differ in this regard. The results also indicate that the water-use productivity for the SNWTP follows a downward trend during 2006–2014.

1. Introduction

Sustainable development has become an important issue in the political agendas across different countries (J. Chen, Cheng, Nikic, & Song, 2018; Wu, Zhou, Guo, & Liu, 2017; Yu, Yu, & Lu, 2018). The use of water resources comprises an important facet of sustainability especially in areas where water endowments are rather scarce. Sustainable use of water resources requires proper frameworks for performance analysis (Azad & Ancev, 2014; Cai, Gong, & Yu, 2017; M.; Zhang, Chen, & Wu, 2018). China's South-North Water Transfer Project (SNWTP) aims to change the current situation of unevenly distributed water resources in China by transferring water from the Yangtze River to North and Northwest China through the construction of eastern, middle and western routes. The project has become one of the largest and most ambitious inter-basin water transfer projects in the world (Pohlner, 2016). The SNWTP eastern route (ER) mainly extends northwards by Yangtze River Water Transfer Project in Jiangsu Province. The eastern route makes full use of the Beijing-Hangzhou Grand Canal and the existing rivers in the Huai and Hai River Basins to transfer water (Sheng & Webber, 2017). The middle route (MR) draws water from the Danjiangkou Reservoir in the middle and upper reaches of the Han River, the largest tributary of the Yangtze River, and delivers water to Beijing through new trunk channels. The west route seeks to transfer water from tributaries of the upper reaches of the Yangtze River, but it is still in the planning stage due to complex terrain and ecological issues (Ma et al., 2016). The entire SNWTP is to connect the four catchments of the Yangtze River, Huai River, Yellow River and Hai River from south to north and eventually form a water grid featuring "four horizontals and three verticals" (Ministry of Water Resources, 2002) in China. Finally, the SNWTP will affect almost one-third of China's land area (Q. Zhang, Xu, Shen, Li, & Wang, 2009). The SNWTP is expected to cost more than 240 billion yuan (Y. Zhao, 2014), and cause resettlement of more than 300,000 people (Rogers, Barnett, Webber, Finlayson, & Wang, 2016). As of 2018, the first phases of the eastern and middle routes have been completed in 2013 and 2014 respectively, and the first phase operation has officially commenced. The

* Corresponding author.
E-mail address: jsheng@nuist.edu.cn (J. Sheng).

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two routes, with a total length of nearly 2900 km, can provide 27.8 billion m^3 freshwater annually to the arid north area from the Yangtze River basin in southern China (Ministry of Water Resources, 2002).

Existing literature on SNWTP's performance is still scarce. Most studies focus more on specific project management, such as water resource allocation and water pricing (Z. S. Chen, Wang, & Qi, 2013; Cheng, Li, & Liu, 2018; Wei, Yang, Abbaspour, Mousavi, & Gnauck, 2010; Yang & Zehnder, 2005), and the environmental risks of construction (Xin, Li, Finlayson, & Yin, 2015; Quanfa; Zhang, 2009; Q.; Zhang et al., 2009; Zhu, Zhang, Chen, & Zhao, 2008). None of these studies analyses the possible impacts of the SNWTP on water-use performance in the cities along the routes based on the framework of resource-economy-environment. This gap in the literature makes it difficult to assess the social and economic impacts objectively caused by the SNWTP. Several studies focus on the possible impacts of the SNWTP on urban water use in the SNWTP cities (Barnett, Rogers, Webber, Finlayson, & Wang, 2015; Berkoff, 2003; Sheng & Webber, 2017, 2018; Sheng, Webber, & Han, 2018; Xia, Zhang, Liu, & Yu, 2007; X.; Zhao et al., 2015). These studies realized that the SNWTP would change water-use performance along the routes, but did not to systematically evaluate water-use performance since the beginning of the SNWTP construction up to the present. Indeed, the SNWTP is one of the most important factors for changing the water-use performance in these cities (X. Zhao et al., 2015), although one cannot argue that the SNWTP is the sole factor behind the changes in water-use performance.

The rapid economic growth of SNWTP cities led to a substantial increase in water consumption and sewage discharge (Bian, Yan, & Xu, 2014). Large quantities of untreated industrial sewage are directly discharged into lakes and rivers along the routes. In addition, non-point source pollution caused by agricultural production poses a tremendous threat to rivers and lakes along the routes (Quanfa Zhang, 2009). To ensure water quality in the SNWTP area, China's government has proposed three goals for SNWTP water resources management policy: “saving water then diverting water, controlling pollution then transferring water, protecting environmental then using water” (State Council, 2014). At the beginning of the construction, the State Council approved the pollution control plan for SNWTP eastern route and the plan for water pollution control and water and soil conservation in Danjiangkou Reservoir area and the upstream region (State Council, 2003, 2006). China has also introduced eco-compensation system (Dong & Wang, 2011; Pohlner, 2016) to address the issue of water pollution in the SNWTP, which combines the payment for watershed services with the “polluter pays” principle.

Some water-saving policies have been set up along with the implementation of the SNWTP. At the beginning of construction, the creation of the water-saving society was stressed in the Water Law (People's Republic of China, 2002). Furthermore, three five-year plans for water-saving society construction have been set up (Ministry of Water Resources, 2012; National Development and Reform Commission, Ministry of Water Resources, & Ministry of Construction, 2007; National Development and Reform Commission, Ministry of Water Resources, & Ministry of Housing and Urban-Rural Development, 2017). To improve the water-use efficiency, China has put forward water resources management system and “three red lines” for water resources development and utilization, water-use efficiency and water pollution thus institutionally promoting the social-economic development according to water availability (State Council, 2012a).

There has been uncertainty about what the effects of the SNWTP. The official discourse focuses on pollution control and efficiency. This implies the need for improving water efficiency (Hu et al., 2006). On the other hand, the SNWTP reduces water scarcity and promotes economic growth, which might increase pollution and diminish efforts to improve efficiency. The net effect of all the factors needs to be revealed. Therefore, it is necessary to examine the role of the SNWTP in terms of water-use efficiency. However, the earlier studies on water-use performance generally emphasized water as an input in producing a single desirable output (such as GDP) (Lee, Tansel, & Balbin, 2011; Long & Pijanowski, 2017), without considering some unavoidable and undesirable outputs (such as sewage discharges) (Bian et al., 2014). From the perspective of source-specific decomposition of the water-use productivity change, the approach of the productivity change decomposition based on data envelopment analysis (DEA) provides the relevant insights. What is more, the sources of change in the water productivity (technical efficiency change and technical progress) can be further decomposed in terms of the input and output variables (Deng, Li, & Song, 2016; Speelman, D'Haese, Buysse, & D'Haese, 2008; Wang, Bian, & Xu, 2015). Therefore, the productivity change decomposition framework constitutes an appropriate approach to assess the water-use efficiency.

This paper makes the following contributions: (i) we analyze the critical factors behind improvement of the static performance of the SNWTP cities by measuring the static inefficiency values; (ii) we identify the key factors influencing the dynamics of the water-use performance in the SNWTP cities by exploiting the variable- and source-specific decompositions of the water-use productivity change; and (iii) we evaluate the water-use performance in the SNWTP from the viewpoint of the sustainable development path by taking into consideration water-use intensity and water-use productivity change associated with sewage discharge.

The paper is structured as follows. Section 2 introduces the measurement and decomposition framework of water-use productivity change. Section 3 presents the results of the empirical analysis. Section 4 discusses the changes in water-use productivity and the sustainable development path of water use in the SNWTP cities. Section 5 presents the conclusions.

2. Methods and data

To accurately evaluate the water-use performance in the SNWTP cities, this paper decomposes the water-use performance by using a Luenberger indicator that includes sewage discharge. We firstly establish a meta-frontier spanning multiple periods and treat each city as a decision-making unit (DMU) (Ramanathan, 2003). By measuring the distance between the DMU and the meta-frontier we obtain the technical efficiency scores. The inefficiency scores can be further decomposed in terms of input and output variables (Zhou, Ang, & Poh, 2008).

2.1. Environment production technology for water-use performance

Establishing a framework involving undesirable outputs is a prerequisite for analysis of the water-use productivity. With the increasing emphasis on environmental issues, pollutants, as environmental constraints are recently characterized in various analytic frameworks (Molinos-Senante, Sala-Garrido, & Hernández-Sancho, 2016; Xie, Yuan, & Huang, 2017). Following Färe and Grosskopf (2010) and Zhou, Ang, and Wang (2012), we assume that each SNWTP city is a DMU. There are P input variables $x = (x_1, \ldots, x_p) \in R_P{}^+$, Q desirable output variables $y = (y_1, \ldots, y_q) \in R_Q{}^+$, and R undesirable output variables $b = (b_1, \ldots, b_r) \in R_R{}^+$ for each DMU (Chung, Färe, & Grosskopf, 1997). Thus, the input, desirable output and the undesirable output variables of the i-th DMU in period t are arranged into vectors (x_i^t, y_i^t, b_i^t). Assuming strong disposability of inputs and desirable outputs and undesirable outputs; we can characterize the environmental production technology as

$$P^t(x^t) = \{(y^t, b^t): \lambda X \le x_{iP}^t, \lambda Y \ge y_{iQ}^t, \lambda B \le b_{iR}^t \ \forall\ P, Q, R, \lambda \ge 0\}, \quad (1)$$

where λ is a vector of non-negative intensity variables, and X, Y, and B are the vectors of input, desirable output and undesirable output