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Applying the Water Footprint and dynamic Structural Decomposition Analysis on the growing water use in China during 1997–2007

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ABSTRACT

China has experienced rapid economic development during the recent years. In the meantime, the total water use in China has greatly increased, causing considerably severe water shortage. To quantify how the social-economic development drives the change of water use is of great importance for Chinese government. This study aims to quantitatively investigate the determinants of the growing water use in China during 1997–2007. China's water usages in 1997–2007 are indicated by the Internal Water Footprint (IWF), External Water Footprint (EWF), and Exported Virtual Water (ExVW) using an input–output based WF analysis. A dynamic Structural Decomposition Analysis (SDA) model is employed to decompose the changes in the total WFs (TWF) into five social-economic determinants. The dynamic SDA model, which uses a nonlinear path function to simulate the real paths followed by determinants, is a further development of a path-based SDA algorithm. To validate the dynamic SDA, a comparison study is carried out against the commonly used mean decomposition model. The results from the WF analysis show that, during 1997–2007, the increase of China's water use is dominated by the ExVW, which increases significantly due to the expansion of exports. While the changes in the IWF and EWF tend to help mitigating the water pressure. The dynamic decomposition results indicate that the consumption level is the dominant factor of China's water use growth, and the changes in water-saving technology and final demand pattern contribute largely to offsetting the water use growth. The model comparison shows that the dynamic SDA model is more advanced in obtaining reliable results and addressing the static issue of traditional SDA models. This study provides a robust framework for understanding the water use situation from the social-economic perspectives, which benefits sustainable water management.

1. Introduction

China is experiencing rapid economic development in recent years. Associated with the economic development, the total water use in China has been increasing dramatically from 556.6 billion m^3 in 1997 to 618.3 billion m^3 in 2013 (Ministry of Water Resources of China, 1997–2013). The water use growth consequently increases the severity of water shortage in China, a water scarce country (Jiang, 2009).

Many studies focus on analyzing the relationship between social economic development and water use in China. The water utility associating the regional differences in water resource and economy of China was investigated enormously (Guan and Hubacek, 2008; Miao et al., 2011a; Zhang and Anadon, 2014; Zhao et al., 2015). Furthermore, Hubacek et al. (2009) and Hubacek and Sun (2005) studied the impacts of China's social-economic changes on water usage. These studies indicate that the growing water use in China is driven by the social-economic development. Nevertheless, these studies are more likely to evaluate the water use status rather than to investigate the underlying reasons for the water use changes. It is necessary to quantify how the social-economic drivers change the water usage in China. This valuable information will assist policy-makers to better understand the water use situation, as well as to develop more efficient water management plan in future.

The technique of Structural Decomposition Analysis (SDA) is a useful technique for quantifying the social-economic determinants of changes in an aggregate indicator over time. It uses the information from the input–output (IO) tables extended with the aggregate indicator, which enables SDA to deal with the effects of indirect demand, production structure and final demand (Hoekstra

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and van den Bergh, 2003; Su and Ang, 2012; Yang et al., 2015a). Since the 1990s, SDA has been extensively employed in investigating the drivers of the changes in energy use (Cellura et al., 2012) and related emissions (Huang and Wu, 2013). Recently, several researchers started using SDA for explaining the reasons of the water use changes in the region and nations including Beijing, China (Zhang et al., 2012), Spain (Cazcarro et al., 2013), and USA (Wang et al., 2014). Notably, a mean decomposition method is commonly used in the previous SDA studies addressing the well-known non-uniqueness issue of SDA (Dietzenbacher and Los, 1998).

However, the mean decomposition method has a major disadvantage, which is termed “static issue”. Static issue means that the applied method can only deal with a short study period limited by the base and end year IO tables (Zhang et al., 2012). For long study periods, the changes of an indicator in the sub-periods are separately treated, instead of integrally analyzed, by the mean decomposition method. This can result in uncertainty in the structural decomposition using series IO tables. In response to the drawback of traditional mean decomposition method, Yang et al. (2015b) proposed a path-based SDA model, which is able to produce unique decomposition results and extends the capability of SDA model in coping with dynamic problems. In this paper, we further improve the path-based SDA model proposed by Yang et al. (2015b) to obtain dynamic decomposition of China’s water use changes.

The main goal of this study is to quantitatively explain how the social-economic determinants drive China’s water use to grow up. Specifically, we concentrate our efforts on: (1) evaluating the water use situation during 1997–2007 using an IO based Water Footprint (WF) analysis; (2) quantifying the effects of the governing factors on China’s water use growth employing the new dynamic SDA model mentioned above; and (3) validating the methodology by comparing the performances of the dynamic SDA model with the mean decomposition method. The rest of this paper is organized as follows: Section 2 provides the details on the data collection and methodology; the study results are shown in Section 3; Section 4 exhibits the discussion, and the conclusions and limitations of this work are given in Section 5.

2. Data sources and methodology

2.1. Data sources

The data collected for investigating China’s water use growth include the IO tables, population, and the sectoral water usage during 1997–2007. The study period is limited to 1997–2007 for two reasons. First reason is that during 1997–2007 China has shown rapid social-economic development and enormous total water use growth. Another reason is the data’s availability. China’s IO table in 2007 is the latest published IO dataset and the sectoral water use data are retrievable since 1997 from China Environmental Statistics Year Book. The three data sources are specifically described as following.

The IO table depicts the input and output flows of product between economic sectors. It is a useful data structure for analyzing the WF in economic activities and for quantifying the economic determinants of China’s growing water use. In this study, five time-series IO tables from 1997 to 2007 are collected. The 1997, 2002 and 2007 data are obtained from National Bureau of Statistics of China (1999, 2006, and 2009). The 2005 data are retrieved from Chinese Input–Output Association (2014). And the 2000 data are collected from the personal communication with the Department of National Economic Accounting. There are 124, 40, 122, 42 and 135 different sectoral divisions in the IO tables of 1997, 2000, 2002, 2005 and 2007, respectively. Due to the different sectoral categorizations among these IO tables, we further aggregate the various divisions into 27 sectors as shown in Table 1. All the monetary values in these IO tables are adjusted to 2007 prices.

Table 1
China’s sectoral division after aggregation.

Sector code	Name
1	Agriculture
2	Mining
3	Food, tobacco and beverage processing
4	Textile goods
5	Wearing
6	Paper and products
7	Petroleum processing
8	Chemicals
9	Non-metal mineral products
10	Metal smelting and processing
11	Metal products
12	Electric and electronic equipment
13	Electricity, gas and water production and supply
14	Other manufacturing
15	Transport and storage
16	Post, telecommunication and computer services
17	Commerce
18	Restaurant and hotel
19	Tourism
20	Finance and insurance
21	Real estate
22	Household service
23	Health, sports and welfare
24	Cultural, educational and recreational services
25	Scientific research
26	Other professional and technical services
27	Public administration and other services

In consideration of China’s population expansion in the past, the population is regarded as one of the governing factors of the water use growth. Thus, the population data for 1997, 2000, 2002, 2005 and 2007 are obtained from China National Bureau of Statistics (2013). The total population in China for 1997, 2000, 2002, 2005 and 2007 are 1236.26, 1267.43, 1284.53, 1307.56 and 1321.29 million, respectively (China National Bureau of Statistics, 2013).

Water use is the core variable data for the WF analysis and the dynamic SDA. In this study, water use refers only to the blue water from surface and ground water, which is defined identically in Yang et al. (2015b). The sectoral water use data are collected for 1997, 2000, 2002, 2005 and 2007, respectively. In detail, the agricultural water use data are obtained from Chinese Water Resources Bulletin (Ministry of Water Resources of China, 1997–2007). The data of freshwater used in the secondary sectors are collected from China Environmental Statistics Year Book (National Bureau of Statistics of China, 1998, 2001, 2003, 2006 and 2007). For the tertiary sectors, the water use data are primarily estimated based on the direct water use coefficients (DWUCs) reported in China’s water resources IO table in 2002 (Researching Group of Chinese Input-Output Association, 2007). The DWUCs of different service sectors are assumed to be as the same as the coefficients of the IO tables in 1997, 2000, 2002, 2005 and 2007. Then, the sectoral water use data for the five years are calculated by multiplying the DWUCs with the service outputs, separately. The calculated water use data are further calibrated within the 27 sectors, allowing the total amount of water uses for the primary, secondary and tertiary sectors are consistent with the reported data from the Chinese Water Resources Bulletin.

2.2. WF analysis

In this study, the WF analysis is a procedure applying the WF theory to indicate the water use situation in China. WF is defined as the volume of water needed for the production of goods and services