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# Drivers of industrial water use during 2003–2012 in Tianjin, China: A structural decomposition analysis

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ABSTRACT

To ease the growing water crisis, Tianjin has pioneered the implementation of *the most stringent water management system* in China. Presently, Tianjin achieves the highest industrial water efficiency in China. In 2010, Tianjin was named the first "Water-Saving Society Construction Demonstration City" by the Chinese central government. To provide a theoretical basis and supporting data for the construction of "national water-saving cities", a decomposition method is adopted to quantitatively analyze changing industrial water use in Tianjin. Data are decomposed using a refined Laspeyres model, highlighting changes associated with industrial restructuring, followed by detailed sectoral analysis. There are two distinct stages of industrial water use: before 2008, industrial water use decreased, driven predominantly by technological advances; after 2008, higher industrial output led to greater industrial water use that overshadowed the water savings achieved by technological development. Nevertheless, water efficiency showed limited improvement, despite the increasing industrial scale and output of certain industrial sectors. The findings show that in Tianjin, reduced industrial water use is not the primary objective, but an associated combination of industrial development and structural adjustment.



## 1. Introduction

China suffers a shortage of water resources, and Tianjin has the lowest per capita water resources at the provincial level (Zhang et al., 2008). To ease the intensifying water crisis, Tianjin took the lead in implementing *the most stringent water management system* that specifies water efficiency targets (Yi et al., 2011) and achieved a dramatic improvement in water efficiency. In 2013, water use per unit of gross domestic product (GDP) was reduced to 17.52 $m^3$, less than one-sixth of the national average, and water use per unit of industrial added value was reduced to 8.3 $m^3$, representing the highest industrial water efficiency in China (People.cn, 2011). These two indicators signal that the level of water efficiency in Tianjin attains or even exceeds that of some developed countries (Ministry of Industry and Information Technology of the People's Republic of China et al., 2013). For this reason, the Chinese Government recognized Tianjin as a "Water-Saving Society Construction Demonstration City" in the hope that arid north China would learn from Tianjin to "speed up the transformation of economic development patterns and promote the strategic adjustment of economic structure" (People.cn, 2012). This was in order to achieve "… the central government's water management objectives of water sustainability, which should be factored in the planning of cities and industrial development" (Shi et al., 2015). The task force (Shang et al., 2015), commissioned by the Chinese Ministry of Water Resources (MWR) and the Tianjin Municipal Water Authority, conducts consultancy studies of "change in Tianjin's industrial water use and attribution analysis", and the research findings are expected to provide a theoretical and data basis for creating more "national water-saving cities".

Industrial water use trends are closely related to levels of

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economic and social development (Duarte et al., 2014). In general, industrial water use firstly shows drastic growth, then zero-growth, and finally declines (Merrett, 1997). As early as 1964, Sweden took the lead to curb the rise in its industrial water use, followed by the Netherlands, Japan, and the United States, and in the subsequent 20 years, many developed countries reduced their industrial water use. In 2000, 17 of the 24 OECD (Organization for Economic Cooperation and Development) member states saw a decline in industrial water use (Jia, 2001), and many countries adopted strict mandatory regulations in response to extreme water shortage (Holt et al., 2000). This is easily explicable. During the early stages of industrialization, the underpinning energy-intensive heavy industries and expanding industrial scale entailed a sharp rise in industrial water use (Kirkpatrick et al., 2011). When extensive industrial development resulted in serious environmental damage and resource pressure, there was a shift toward the development of high-yield, low-energy-use industries, combined with an emphasis on industrial restructuring and the promotion of water-saving technologies and processes (Munasinghe, 1999; Bao and Fang, 2012). Jia et al. (2006) found that the Kuznets Curve could describe changes in industrial water use in OECD countries. In other words, after increasing in line with industrial output, industrial water use subsequently stabilized when GDP reached a certain (high) level and then tended to decline.

In addition to improving water management systems and economic control measures, reasonable industrial structure, high water efficiency and water saving technologies are also important for reducing industrial water use (Tate, 1986; Reynaud, 2003). Fujii et al. (2012) suggested using water prices to promote water saving in China, based on analysis of regional differences in industrial water efficiency. Gumbo et al. (2003) studied the impact of production processes on water use in wire galvanizing, soft drink manufacturing and sugar refining, and found that more advanced equipment and technologies were conducive not only to water saving, but also pollution mitigation. Levidow et al. (2016) held that production process innovation can bring significant improvement in water efficiency and further associated benefits in water saving and ecological protection. Yu et al. (2014) established an optimal water network in a dyeing and finishing industrial park. Through this study, Yu et al. (2014) concluded that adjustments to industrial water supply structure could markedly improve water reuse and reduce the use of fresh water. Li et al. (2008) predicted that China's industrial water use will continue to increase until 2020, and that this is a negative trend that can be reversed only through the large-scale transformation of industrial facilities and industrial restructuring oriented towards water saving.

Drivers of industrial water use may involve industrial scale expansion, water-saving technologies, and industrial structural adjustment. A quantitative analysis method is needed to examine the impact of driving factors. In this regard, Jia et al. (2004) conducted a quantitative analysis of the role of industrial restructuring on average water use quotas. Taking Beijing (China) as a case study, Jia et al. (2004) suggested that adjustment of industrial structure has a larger influence on average water use quotas than that of other sectors. Sun and Wang, (2009) quantitatively measured the economy growth effect, structural adjustment effect and water efficiency effect for water use changes. This study appears to the first to use a decomposition model with a thorough consideration of spatial-temporal differences in regional water use. Cazcarro et al. (2013) developed a structural decomposition analysis to study the relationship between economic growth and water use in Spain. Through this study, Cazcarro et al. (2013) found that the growth in Spanish demand would have implied an increase in water use almost three times the growth actually observed. Further, an important conclusion drawn from the study was that water intensity, and especially improvements in technology, slowed growth in water use. Shang et al. (2016) introduced a “partiality to high water use” method to describe the influence of industrial structural adjustment on industrial water use. In their study, Shang et al. (2016) roughly estimated the degree of influence of all of above three factors by the use of multi-factor analysis.

The existing literature on model-based quantitative analysis of changes in industrial water use is still limited (Shang et al., 2016), though factor decomposition models have been widely used in the energy, environmental, and economic sciences (Blundell, 2012; Armknecht and Silver, 2014). Among factor decomposition models, the Laspeyres model, which is simple to derive and easily understood, is widely used in various economic and social fields (Whyte et al., 2013; Zhang and Da, 2015). However, it is unable to fully decompose all factors, and the remainder of the decomposition results increases with the number of factors. Where a factor changes greatly in the short term, the remaining items (or residual error) might be very large, and if ignored, they can undermine the model accuracy (Ang, 2004). Sun (1998) optimized the Laspeyres model in accordance with the “jointly created and equally distributed” principle. In the refined Laspeyres model, the residual error can be decomposed, and assigned to sub-items according to sources of error in order to achieve complete decomposition.

Focusing on quantitative analysis, this study explores the application of the Laspeyres model to industrial water use. Further, the driving factors of water use in Tianjin during 2003–2012 are decomposed for industry as a whole as well as individual industrial sectors by using the refined Laspeyres model. Quantitative analysis is conducted for the changes observed for differing periods and sectors, laying the basis for identifying trends in industrial water use and enabling breakthroughs in water savings. In this paper, Section 2 provides an overview of industrial development and industrial water use in Tianjin, where Section 2.1 examines the history of industrial development and industrial structural adjustments, and Section 2.2 conducts a statistical analysis of industrial water use. Section 3 introduces the principles of the Laspeyres model and decomposition models applicable to industrial water use. The data sources and management are presented in this section as well. Model calculations are presented in Section 4, followed by a discussion of the findings and conclusions.

## 2. Overview of industrial development and water use in Tianjin

Tianjin is one of the birthplaces of modern Chinese industry, and became China's second-largest industrial city as early as the 1930s and 1940s. After the founding of People's Republic of China (1949), Tianjin, along with other cities, witnessed rapid industrial development. In particular, after 1978, foreign investment was introduced into the transformation of 748 state-owned enterprises (SOEs) in Tianjin. In 2003, a new round of industrial reform featuring “merge, renovation, and adjustment” was initiated to deepen industrial restructuring. Today, Tianjin has established an industrial pattern underpinned by electronic information, automobiles, metallurgy, chemical, medical and new energy industries, and has created new integrated industrial bases (Statistical Bureau of Tianjin (2013)).

### *2.1. Analysis of industrial output*

Tianjin's industrial output has grown dramatically ever since China's industrial reforms. For example, industrial output quintupled between 2003 and 2012 (from 437.1 billion to 2.41 trillion yuan) (Statistical Bureau of Tianjin, 2004–2013). The proportion of industrial added value in GDP also increased rapidly, up from 47% to