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Analysis

The Agricultural Water Rebound Effect in China

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ABSTRACT

Although the water productivity of the agricultural sector in China continuously increased over the last twenty years, by improvements in irrigation technology, the total agricultural water use did not decline as expected, mainly due to continuous increases in agricultural output partially derived from technological progress. Thus, agricultural water use in China may experience a rebound effect. This study defines the water rebound effect (*WRE*) using macro-scale indicators of water use and water productivity, establishes a simplified direct comparison method using the contribution rate of technological progress, and evaluates the magnitude of the macro-scale water rebound effect in the Chinese agricultural sector using provincial panel data from 1997 to 2014. The magnitude of the agricultural *WRE* in China (1998–2014) is 61.49%. The northern and western regions of China experience a greater *WRE* than the southern and eastern regions, and the changes in the inter-annual *WRE* are distinct. These observations indicate that much of the expected water savings from efficiency improvement could be offset by increased water use for increased agricultural production due to technology enhancement. The control of water use growth is effective for reducing the water rebound effect. The study confirmed the existence of the agricultural *WRE* in China.

1. Introduction

Due to the limited supply, unbalanced distribution, and excessive consumption of water by the growing population and increasing economic development, China is facing severe water shortages. The northern part of the country has an average freshwater availability of 760 cubic meters per capita per year, 25% less than the internationally accepted threshold for water scarcity (Chai et al., 2014). As shown in Fig. 1, the agricultural sector accounts for > 60% of the water use in China. Improving the efficiency of water use is typically presented as an opportunity for large water savings, particularly in the agricultural sector (Dumont et al., 2013). The Chinese government strongly supports the development of irrigation technology and has implemented many water-saving irrigation measures with the objective of improving water productivity and reducing agricultural water use (Chai et al., 2014). Some progress has been made. As shown in Fig. 2, the water productivity of agricultural sector in China has increased continuously, from 2.93 Yuan/cu·m in 1997 to 5.77 Yuan/cu·m in 2014 (1990 prices). However, total agricultural water use did not decline as expected, mainly due to continuously increasing agricultural output (see Fig. 2). In an increasing number of places on Earth, water resources are used in a very efficient manner – with high agricultural water use efficiency – but water resources are also simultaneously being very quickly depleted (Hoekstra, 2013).

A concept used in energy studies, i.e., the "rebound effect", can help us more clearly quantify the effect of water productivity on water use. The "rebound effect" was first proposed by Jevons (1866), who found that more efficient steam engines not only reduced coal consumption but also resulted in a reduction in coal price, eventually increasing the demand for coal. This positive effect of energy efficiency on energy conservation has been questioned in economic circles (Binswanger, 2001; Sorrell and Dimitropoulos, 2008). The first scholars to study the rebound effect phenomenon in the economics literature were Brookes and Khazzoom (Brookes, 1990, 2000; Khazzoom, 1980). In the Khazzoom-Brookes hypothesis, they proposed that technological progress not only improves energy efficiency but also promotes economic growth and, thus, increases the demand for energy. This energy increment can partially offset the energy saved through improvement in energy efficiency. Following this proposal, theoretical and empirical research on energy rebound effects has developed rapidly and achieved

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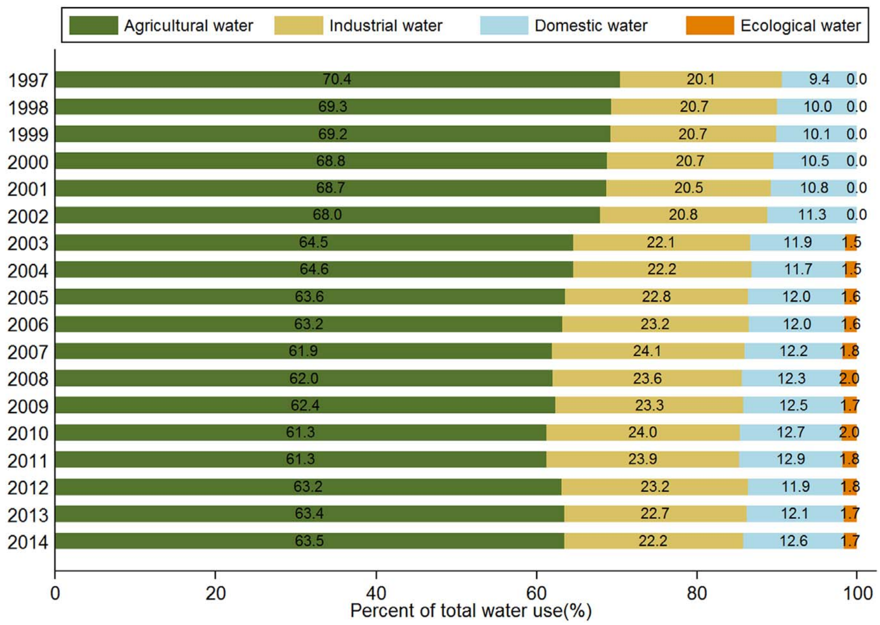

Fig. 1. Water use percentages in China from 1997 to 2014.
Data resources: China Water Resources Bulletin (1997, 1998, 1999) and China Statistics Yearbook (2006, 2015).

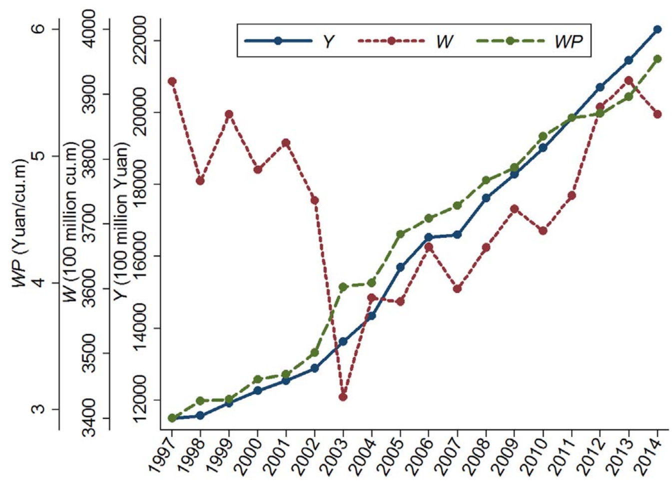

Fig. 2. Agricultural production and water use in China from 1997 to 2014.
Note: 1. *Y*: the gross output value of agriculture in 1990 prices (100 million Yuan); *W*: agriculture water use (100 million cu·m); and *WP*: agriculture water productivity (Yuan/cu·m), WP = *Y* / *W*.
2. Data resources: China Water Resources Bulletin (1997, 1998, 1999) and China Statistics Yearbook (1998–2015).

fruitful results (Alcott, 2005; Berkhout et al., 2000; Greening et al., 2000; Small and Van Dender, 2007). The energy rebound effect is estimated using various econometric methods and sample data. A common method is to estimate the energy rebound effect by estimating price elasticity or efficiency elasticity (Azevedo, 2014; Wang et al., 2012). For some countries or sectors where price does not truly reflect the supply and demand situation, some studies have estimated the energy rebound effect using the direct comparison method and the contribution rate of technological progress (Li and Han, 2012; Shao et al., 2014). Most of these studies confirm the existence of the rebound effect.

Agricultural water supply can also experience its own rebound effect (Berbel and Mateos, 2014). The European (2012) has recently identified this effect as a potential problem. Many researchers have analysed the effects of more efficient irrigation using theoretical model simulation or empirical comparative analysis, demonstrating that water use/consumption do not decrease or even increase following irrigation system improvement(Brinegar and Ward, 2009; Dagnino and Ward, 2012; Dinar and Zilberman, 1991; Ellis et al., 1985; García-Garizábal and Causapé, 2010; Huffaker, 2008; Huffaker and Whittlesey, 2000; Lecina et al., 2010; Peterson and Ding, 2005; Playán and Mateos, 2006; Qureshi et al., 2010; Rodríguez-Díaz et al., 2011; Scheierling et al., 2006; Ward and Pulido-Velazquez, 2008; Whittlesey, 2003). Although Dumont et al. (2013)query the usefulness of the rebound effect as a concept in the better management of water resources, some researchers have focused on water rebound effect in the past few years. Pfeiffer and Lin (2014) found that the shift to more efficient irrigation technology has increased groundwater extraction in western Kansas and indicated it is a rebound effect > 100%. Berbel and Mateos (2014) used a model to systematically analyse the conditions under which improved application uniformity of irrigation may yield increased water use and/or consumption. Water use has been found to decrease in all circumstances unless the irrigated area is expanded. Berbel et al. (2015) reviewed the literature regarding the water rebound effect and illustrate the conditions that may avoid the rebound effect with a case study in the Guadalquivir basin (southern Spain). They suggest that the keys for avoiding the rebound effect are (1) strict limitations placed on the size of the irrigated area, (2) the reduction of former water rights, and (3) the re-assignation of water savings to achieve environmental goals. Gomez and Perez-Blanco (2014) studied the conditions under which Jevons' Paradox in water use appears, building upon basic economic principles. The efficiency elasticity of water use contains three effects, namely the technical effect, cost effect and productivity effect. A positive elasticity indicates that Jevons' Paradox occurs. Loch and Adamson (2015) examined the anticipated impacts of the rebound effect on environmental and private irrigator water availability/use outcomes in the Murray-Darling Basin in Australia. Li and Zhao (2016) studied the role of water rights in limiting the rebound effect of LEPA irrigation in the High Plains Aquifer region of Kansas.

Research regarding the water rebound effect is ongoing; however, key issues remain unresolved. Although many previous researchers have observed the water rebound phenomenon in agriculture, empirical research regarding calculation of the magnitude of the water rebound effect is very limited. Examining and quantifying the agricultural water rebound effect are critical for confirming the existence and severity of the rebound effect in agricultural water use. The greatest difficulty in calculating the water rebound effect is the definition and measurement of the key variables – conservation and efficiency of water use are highly variable with both research purpose and scale. To allow a rough approximation of the agricultural water rebound effect, we define it using macro-scale indicators of water use and water productivity,