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# Reduction potential, shadow prices, and pollution costs of agricultural pollutants in China

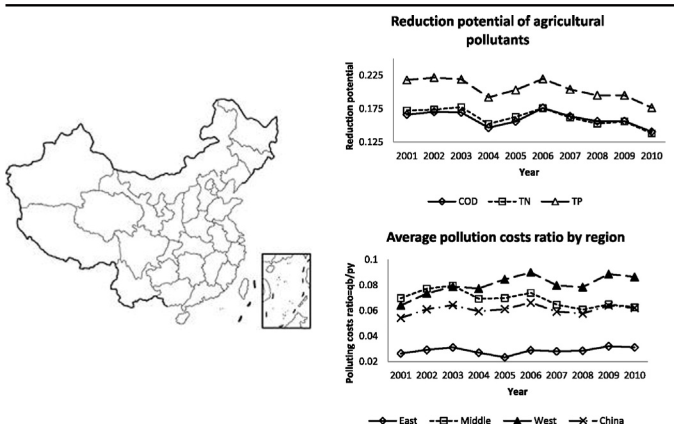
Kai Tang [a,b,c], Chengzhu Gong [a,b,c,*], Dong Wang [c]

[a] Resources Environmental Economic Research Centre, China University of Geosciences (Wuhan), Wuhan 430074, China
[b] School of Economics and Management, China University of Geosciences (Wuhan), Wuhan 430074, China
[c] School of Agricultural and Resource Economics, University of Western Australia, WA 6009, Australia

## HIGHLIGHTS

- Reduction potential and shadow price of China's agricultural pollutants are assessed.
- A parameterized quadratic directional output distance function is used.
- There is scope for further pollution abatement for China's agriculture.
- The regional shadow prices and pollution costs of pollutants are heterogeneous.
- Overall the pollution costs are about 6% of the agricultural gross output value.

## GRAPHICAL ABSTRACT

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## ABSTRACT

This paper analyses the reduction potential, shadow prices, and pollution costs of agricultural pollutants in China based on provincial panel data for 2001–2010. Using a parameterized quadratic form for the directional output distance function, we find that if agricultural sectors in all provinces were to produce on the production frontier, China could potentially reduce agricultural emissions of chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) by 16.0%, 16.2%, and 20.4%, respectively. Additionally, our results show that the shadow price of TN increased rapidly and continuously, while that of COD and TP fluctuated for the whole period. For the whole country, the average shadow price of COD, TN, and TP are 8266 Yuan/tonne, 25,560 Yuan/tonne, and 10,160 Yuan/tonne, respectively. The regional shadow prices of agricultural pollutants are unbalanced. Furthermore, we show that the pollution costs from emissions of COD, TN, and TP are 6.09% of the annual gross output value of the agricultural sector and are highest in the Western and lowest in the Eastern provinces. Our estimates suggest that there is scope for further pollution abatement and simultaneous output expansion for China's agriculture if farmers promote greater efficiency in their production process. Policymakers are required to dynamically adjust the pollution tax rates and ascertain the initial permit price in an emission trading system. Policymakers should also consider the different pollution costs for each province when making the reduction allocations within the agricultural sector.



* Corresponding author at: Resources Environmental Economic Research Centre, China University of Geosciences (Wuhan), Wuhan 430074, China.
*E-mail addresses:* kai.tang@research.uwa.edu.au (K. Tang), chengzhu.gong@uwa.edu.au (C. Gong).

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## 1. Introduction

The environmental cost of China's agricultural sector is enormous, although its food production has successfully fed more than 20% of the global population from only 7% of the world's arable area (Piao et al., 2010). China's agricultural production has caused some negative effects on the environment, such as water pollution (Ulén et al., 2007; Jarvie et al., 2013; Zheng et al., 2015). Excessive emissions of agricultural pollutants, including chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP), have become a critical cause of water pollution in China (Ma et al., 2011). It is estimated that the annual economic losses from water pollution in China are about 150 billion Yuan (World Bank, 2007).

Therefore, it is imperative to reduce agricultural pollutions in China. Since the late 1990s, China's government has attempted to reduce the emissions of agricultural pollutants. The first time that specific emission reduction targets were set was in 2012. These targets included reducing COD and TN emissions by 8% and 10% respectively by 2015, compared with 2010 levels[1]. While policymakers at the provincial level are required to adjust their local agricultural development policies according to the national reduction targets, this may not guarantee that local efforts to reduce agricultural pollutants are in line with the national goal.

Given the diversity in economic, social, and natural conditions in different regions and provinces, it is important to find a suitable way to measure the relevant parameters at the regional level. Such parameters may include reduction potential, marginal abatement costs (MAC), and pollution costs (shadow values). Estimating the MAC and reduction potential is essential to evaluate the cost-effectiveness of the allocation of agricultural abatement obligation among regions. In theory, the MAC of pollutant emissions should be equalized across regions to achieve the most efficient pollution reduction across the economy (Baumol and Oates, 1988). However, in reality this information may not be available because different regions usually exhibit different cost characteristics due to divergent production conditions. Therefore, in practice there are gains to be made from allowing lower cost regions with higher reduction potentials to contribute more to pollution reduction (Wei et al., 2013). Estimating the MAC can also assist the government to identify a benchmark price—the maximum amount to pay per tonne for pollutants reduced. In this case, only bids costing less than the benchmark price would be considered for selection in an auction-based or similar mechanism for the purchase of pollution credits. The pollution costs of agricultural pollutants (shadow values) reflect the opportunity costs for pollution abatement, which can be used for measuring the difficulty level of pollutant reductions (Färe et al., 2006). Regions with lower pollution costs can be identified as key pollution reduction regions in practice. Overall, reduction potential, MAC, and pollution costs are important information for policymakers to design more efficient domestic environmental policies, because they can be used to shape environmental tax and emissions trading systems across regions, etc. (Färe et al., 1993, 2006).

To our knowledge, there is no study that has parametrically estimated the feasible reduction potential, the MAC, and pollution costs of agricultural pollutants in China. The novelty of this paper is that for the first time a parametric directional output distance function, which is differentiable and allows simultaneous expansion of good outputs and reduction of bad outputs (agricultural pollutants), is used to analyze China's agricultural pollution abatement. The differentiability promises the uniqueness of reduction potential, MAC, and pollution cost, while the simultaneous changes mean the potential 'double-dividend' pollution abatement and development in agricultural sector. Policymakers can use these results to design and optimise policies for agricultural pollution abatement.

The rest of the paper is organized as follows. In Section 2, we review the existing literature. We describe the parametric directional output distance function approach in Section 3. Then we present the data and variable specification in Section 4. In Section 5, we report and discuss the estimation results. Finally we conclude in Section 6.

## 2. Literature review

Recent development in distance functions of non-marketed products allows researchers to estimate the MAC of pollutants generated during production without market price and cost information (Hailu and Veeman, 2000, 2001; Färe et al., 1993, 2005, 2006). Generally, the estimation is performed by treating pollutants as bad (or undesirable) by-product outputs under a multi-input multi-output environmentally sensitive production. Then the distance function is used to derive the marginal abatement costs (shadow prices) of pollutants by using the duality between the distance function and the revenue or cost functions.

Existing studies generally use one of three distance functions. The radial output/input distance functions assume a proportional adjustment for all outputs/inputs (Färe et al., 1993; Hailu and Veeman, 2000). By contrast, the directional output distance function describes a simultaneous expansion of good (or desirable) outputs and reduction in bad outputs in a given direction (Chambers et al., 1998). The directional output distance function is thought to provide a more useful and flexible method to evaluate the performance of environmentally sensitive production in the presence of bad outputs (Färe et al., 2005; Du et al., 2015).

There are two ways to estimate the distance function. One is a non-parametric technique called Data Envelopment Analysis (DEA), and the other is a parametric technique. The DEA technique is a data-driven method which establishes the output set as a sectionalized linear combination of observed inputs and outputs. It has been widely used in productivity analysis due to its advantage that no functional form assumption is needed (Hailu and Veeman, 2001; Boyd et al., 2002; Färe et al., 2007). Nevertheless, the distance function using the DEA technique is not differentiable, so it is not well-suited to derive the shadow prices (Färe et al., 2005). In addition, the results estimated using DEA are sensitive to outliers, which may negatively affect the accuracy of results (Hailu and Chambers, 2012; Wei et al., 2013). With the parametric technique, a functional form is specified for the distance function and the parameters of this function are estimated using linear programing. Due to the ease with which theoretical restrictions can be imposed in estimation, this technique has been used in many applications (Coggins and Swinton, 1996; Hailu and Veeman, 2000; Färe et al., 2006; Murty et al., 2007; Hailu and Chambers, 2012; Wei et al., 2013; Du et al., 2015).

However, few existing studies estimate the MAC and reduction potentials of agricultural pollutants in China. Several studies attempt to estimate shadow prices, or equivalently as marginal abatement costs, and reduction potentials of pollutant emissions for the Chinese industrial sector (Aunan et al., 2004; Tu, 2009; Han et al., 2010; Yuan and Cheng, 2011; Yu, 2011). They find that there is considerable heterogeneity in the shadow prices and reduction potentials of industrial pollutants across different regions. However, studies of the Chinese agricultural sector are not present within this literature. To the best of our knowledge, only Li et al. (2013) estimate the reduction potential of agricultural pollutants in China, using a non-parametric approach. So far, no study has estimated the feasible reduction potential and MAC of agricultural pollutants in China using a parametric approach.

As mentioned above, the non-parametric DEA technique is less suited to the analysis of the environmentally sensitive production due to its non-differentiability. Furthermore, the parametric radial input/output distance functions are less flexible than the directional output distance function because of the proportional adjustment of outputs/inputs. Therefore, the directional output distance function estimated

[1] More details can be found in the National Energy-saving and Emission Reduction Project of the 12th Five-Year Plan (http://www.gov.cn/zwgk/2012-08/21/content_2207867.htm).