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# Technical and allocative efficiency of irrigation water use in the Guanzhong Plain, China

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## ABSTRACT

Due to increasing water scarcity, accelerating industrialization and urbanization, efficiency of irrigation water use in Northern China needs urgent improvement. Based on a sample of 347 wheat growers in the Guanzhong Plain, this paper simultaneously estimates a production function, and its corresponding first-order conditions for cost minimization, to analyze efficiency of irrigation water use. The main findings are that average technical, allocative, and overall economic efficiency are 0.35, 0.86 and 0.80, respectively. In a second stage analysis, we find that farmers' perception of water scarcity, water price and irrigation infrastructure increase irrigation water allocative efficiency, while land fragmentation decreases it. We also show that farmers' income loss due to higher water prices can be offset by increasing irrigation water use efficiency.

## Introduction

Due to water scarcity, irrigation plays an important role in agricultural production in North China. Huang et al. (2006) points out that widespread irrigation is required to keep up and expand agricultural outputs, particularly wheat and maize, but also to alleviate poverty. However, water scarcity in the region has been worsening due to accelerating industrialization and urbanization, but also because of environmental challenges, such as climate change and water pollution (Jiang, 2009). These developments have led to increased competition among the main water users, i.e. agriculture, industry and households.

Irrigation consumes 60% of total annual water resources in *inter alia* the Guanzhong Plain, which is a region facing severe and increasing water scarcity. In the area, 75% of grain production comes from irrigated land which accounts for 50% of total arable land. Expansion of grain production, and thus of irrigation, is needed to feed China's large and still growing population. However, water has higher marginal returns in industry and the residential sector. Under such circumstances, it is imperative for agriculture to improve its water use efficiency (Lybbert and Sumner, 2012).

This goal of the paper is to measure the efficiency of farmers' irrigation water use and identify its determinants, based on a sample of 347 farmers in the Guanzhong Plain. The paper contributes to the literature in the following three aspects. First, it focuses on both technical and allocative efficiency. Water use efficiency is commonly defined as yield per m$^3$ water. See, for instance, Wang et al. (2010). This measure is biased and inappropriate, however, because it ignores the fact that yield is not produced by a single input, water, but by multiple inputs including water, but also fertilizers, seeds, machinery and labor. Several researches have recognized this and analyzed technical efficiency of irrigation water use, while controlling for the contributions of all other inputs (Karagiannis et al., 2003; Speelman et al., 2008, among others). For instance, based on data on 50 vegetable farms in Greece, Karagiannis et al. (2003) analyzed input-specific technical efficiency as a measure of water use efficiency. However, technical efficiency analysis does not measure a farmer's ability to allocate irrigation water and other inputs to their cost-minimizing input proportions. For that purpose, allocative efficiency analysis is needed. To the best of our knowledge, there are no analyses of allocative efficiency of irrigation water use. This paper fills this gap by simultaneously estimating a production function, and its corresponding first-order conditions for cost

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minimization, to measure this latter kind of efficiency. In addition, it measures technical and economic efficiency.

Secondly, in a bid to get insight into the determinants of technical and allocative efficiency, the paper does not only consider farm-specific characteristics, like farm size, and socioeconomic features, such as farmer's age and education, but also a farmer's perception of water scarcity. As argued by Folmer (2009) and Folmer and Johansson-Stenman (2011), ignoring the latter kind of variables leads to model under-specification, and thus to biased estimators of the coefficients of the standard explanatory variables, like farm and farmer characteristics, and to invalid inference. Furthermore, if perception turns out to be a determinant of efficiency, it is a potential policy handle in that improving perception via e.g. extension, may induce farmers to reduce their water use. (Note that the literature has so far paid little attention to perception of water scarcity and its potential as a policy instrument.)

Thirdly, the paper provides support to water pricing as a policy handle. In China, the use of this policy instrument is still under debate. Huang et al. (2010) argues that the price of irrigation water in China is too low to induce farmers to save water. However, policymakers fear that higher prices will jeopardize farmers' income and further widen the gap between rural and urban residents (Lohmar et al., 2007). Little research has been conducted to quantify the effect of water price on income. We test whether the income loss due to higher irrigation water price can be offset by more efficient use of water.

The structure of the paper is as follows. Section "Methodology" presents the methodological framework. Sections "The conceptual model and the Structural Equation Model (SEM)" and "Empirical results" discuss the data and the empirical results. Section "Discussion and policy recommendations" presents the conclusions and policy recommendations.

## Methodology

### *Single-factor technical, allocative and economic efficiency*

Since Farrell's (1957) pioneering work, the three efficiency measures technical, allocative and economic efficiency, have been extensively used to assess economic performance of various economic sectors. This also applies to agriculture, where a substantial literature on efficiency of agricultural production has developed. Few studies, however, focus on efficiency of a particular input, such as water. To gain insight into the efficiency of the single input irrigation water, we present in this section the notions of *single-factor technical efficiency* (*SFTE*), *single-factor allocative efficiency* (*SFAE*) and *multi-factor economic efficiency* (*MFEE*). These concepts, as introduced by Kopp (1981) and Kopp and Diewert (1982), are illustrated in Fig. 1.

In Fig. 1, there is a single output, $Y$, and two inputs $W$, i.e. irrigation water, and $X$, which denotes all other inputs, such as capital, labor, fertilizers and so on. $F_1$ is an isoquant which represents the production frontier at which a technically, perfectly efficient farmer uses least inputs to produce a given output. Point $P$ is above the production frontier indicating that the farmer who produces at that point is technically inefficient.

Consider the isocost lines $C_1$, $C_2$ and $C_3$. Point $P$ at $C_1$ is the actual cost at which the producer uses $OW_1$ of input factor $W$ and $OE$ of input factor $X$. Point $E^*$ on $C_2$ denotes the cost where the use of $W$ is technically efficient, given $X$ ($OE$) and output. The isocost line $C_3$ is drawn tangent to the isoquant $F_1$ at point $D$ where $W$ and $X$ are both allocatively efficient. The slope of $C_3$ (with negative sign) equals the ratio of the prices of $W$ and $X$. $X^*$ and $W^*$ are intersections[1] of the isocost line $C_3$ and the vertical and horizontal axis, respectively. $C_3$ is the cost at point $D$.

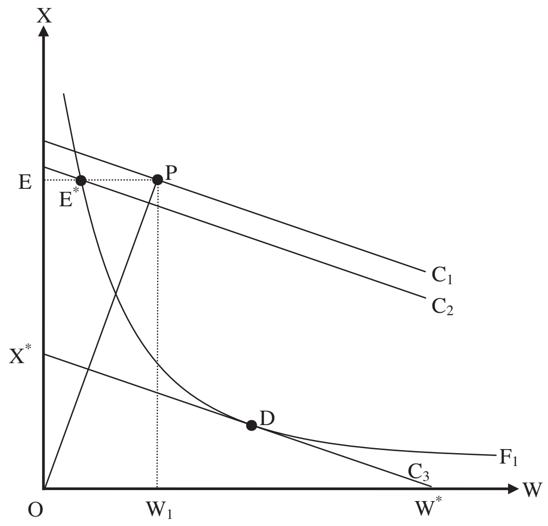

**Fig. 1.** Single-factor technical, allocative and multi-factor economic efficiency. Note: Figure is based on Kopp (1981) and Reinhard et al. (1999).

$EE^*$ is the minimum feasible use of $W$ conditional on a given level of input $X$ ($OE$) and actual output. *SFTE* of $W$ at point $P$ equals $EE^*/EP$. From a cost perspective, single-factor technical cost efficiency (*SFTCE*) of $W$ is the ratio between the cost when $W$ is technically efficient and actual cost, that is, $C_2/C_1$. *SFAE* of $W$ is the ratio between the cost at point $D$ and the cost at point $E^*$, that is, $C_3/C_2$. Finally, *MFEE* is the product of *SFTCE* and *SFAE* and equals $C_3/C_1$. Since *MFEE* is determined as their product, the focus below will be on *SFTE* and *SFAE*. Below we label the three types of single factor irrigation water efficiencies as *IWTE*, *IWAE* and *MFEE*, respectively.

### *Measurement of irrigation water technical efficiency (IWTE)*

Having introduced the concepts of *SFTE* and *SFAE* in the previous section, we now turn to the methodology of estimating these measures. In this subsection we pay attention to *SFTE*, in the next to *SFAE*.

Following Aigner et al. (1977), the general stochastic production function for cross sectional data is:

$$Y_i = F(X_i;\beta)\exp(v_i - u_i) \tag{1}$$

For farmer $i$, production function (1) describes output $Y_i$ as a function of a vector of inputs $X_i$ and an error term made up of two components: $v_i \sim N(0,\sigma_v^2)$, representing the standard error term, and the non-negative error term $u_i$, which follows a half-normal distribution, reflecting the shortfall of a farmer's output from the production frontier, due to technical inefficiency.

A translog stochastic frontier production function is usually chosen for (1). For the $i$th farmer, the translog stochastic frontier production function with 4 inputs, reads:

$$\begin{aligned}\ln y_i = \beta_0 + \beta_w \ln w_i + \sum_{j=1}^{3}\beta_j \ln x_{ji} + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3}\beta_{jk}\ln x_{ji}\ln x_{ki}\\ + \sum_{j=1}^{3}\beta_{wj}\ln w_i \ln x_{ji} + \frac{1}{2}\beta_{ww}(\ln w_i)^2 + v_i - u_i\end{aligned} \tag{2}$$

where $y_i$ is output (wheat in the present study). The 4 inputs considered in the application below include: (1) $x_{1i}$, the sown area (*Land*); (2) $x_{2i}$, *Labor*; (3) $x_{3i}$, *Other inputs*; and (4) $w_i$, *Water*.

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[1] $X^*$ is the quantity of $X$ when cost ($C_3$) is incurred to purchase $X$ only, while $W^*$ is the quantity of $W$ when cost ($C_3$) is incurred to purchase $W$ only.