Agricultural Water Management 96 (2009) 1560–1566

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Estimating the impacts of water pricing on smallholder irrigators in North West Province, South Africa

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ARTICLE INFO

Article history:
Received 18 August 2008
Accepted 13 June 2009
Available online 22 July 2009

Keywords:
Water savings
Irrigation
Data envelopment analysis
Simulation

ABSTRACT

Worldwide growing water scarcity has increased the call for economic instruments to stimulate rational water use in agriculture. Furthermore, cost-recovery is now widely accepted as a cornerstone of sustainable water management. In many developing countries, where agricultural water use is often still subsidised, water pricing policies are developed for allocating water efficiently and achieving sustainability of water systems. However, the impacts of water pricing policies on irrigation water use and on farm production systems is mostly unknown. We introduce an innovative two-stage methodology that allows estimating these effects at farm level. Applying the method to small-scale irrigators in South Africa, we show that water demand is quite responsive even to small changes in water price. In addition, the introduction of a water price significantly decreases farm profit. This appears to be a problem primarily for the poorer farmers.

1. Introduction

Irrigation is one of the main consumptive uses of water at world level. Due to the growing water scarcity, irrigators experience increasing pressure to release water for other uses and to find ways to improve water productivity (Perry, 2007; Malano et al., 2004). Efficient use of water resources is therefore considered as a fundamental target for farmers and water management (Ortega et al., 2004; Tsur, 2004). In this respect, the apparent misuse and waste of irrigation water, in the context of low and subsidised water prices, induces many authors (Liao et al., 2007; Russell et al., 2007; Bar-Shira et al., 2006; Becker and Lavee, 2002; Perry, 2001) to advocate a more prominent role of economic incentives in encouraging efficient water use. Irrigation water pricing is often regarded as a good tool to achieve efficient use (Singh, 2007). Moreover, this strategy also fits into the picture of cost-recovery, which is now generally considered as a basic requirement for sustainability (Molle et al., 2008; Massarutto, 2007).

In terms of efficiency, increasing the price of irrigation water or simply introducing a price is believed to have two important positive effects. Firstly, it will make consumers aware of the resource scarcity, creating a new respect for water, which should improve management efficiency and secondly it provides incentives to farmers to rethink crop choices, stimulating the shift to more profitable crops (Easter and Liu, 2007; He et al., 2006; Becker and Lavee, 2002). However, according to Tardieu and Préfol (2002) and Liao et al. (2007) rises in water prices are not without risk: they could lead to an overall reduction in a country's agricultural production, endangering the goal of securing food self-sufficiency; they could lead to higher prices for urban consumers resulting in increased import and loss of market share for local irrigating farmers; finally they could lower agricultural income with negative effects on rural development. Abu-Zeid (2001) adds that in many parts of the world increasing or introducing water charges is a sensitive issue, involving historical, social and even religious dimensions. Furthermore, the effect of irrigation charges on agricultural water use efficiency might be insignificant if irrigation water costs represent too small a proportion of the total production costs. Finally the low elasticity of demand for irrigation water reported by Albiac et al. (2007), Gómez-Limón and Riesgo (2004) and Berbel and Gómez-Limón (2000) is still another reason to expect limited water saving effects. Taking into consideration the possible disadvantages and the limited effect water pricing policies might have on water saving, it is clear that methodologies allowing to estimate as accurately as possible, the effects of water prices both on water demand and the agricultural production process are very important (Ortega et al., 2004).

South Africa is one of the countries currently in the process of introducing water charges, imposing a new challenge on the small-scale irrigation sector. Apart from increasing the cost-recovery rate for water supply, an expected benefit of this policy change is that water use efficiency will rise. However, the exact impact on the

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doi:10.1016/j.agwat.2009.06.014

irrigation water use or on the farmers' production system remains unclear. Assessment of these effects is important in South Africa, since small-scale irrigation is identified as a key sector for rural development. This study proposes a novel two-step method, which is applied to a sample of 60 small-scale irrigators in North West Province, South Africa. First technical and economic efficiency levels are calculated, then these are used as a representation of the production technology in a mathematical programming model to estimate the impact of changes in the water price. This method allows estimating the effect of water pricing at farm level and offers insight in the water saving effect of the introduction of water charges. In addition, the environmental effects (use of fertilizers and pesticides) and socio-economic effects (labour use, effect on farm profit and total agricultural output) can be assessed.

2. Methodology

Several authors (Albiac et al., 2007; Manos et al., 2006; Gómez-Limón and Riesgo, 2004; Doppler et al., 2002; Berbel and Gómez-Limón, 2000; Gómez-Limón and Berbel, 2000) have used linear programming models to estimate the effect of water pricing on water demand. A disadvantage of these models is that they use predetermined theoretical ratios between inputs and outputs that are not based on empirical data from actual farms. As a consequence, substitutions between different inputs are not considered. However, based on empirical data Scheierling et al. (2006) and Cai et al. (2006, 2008) reported substitution between water and other agricultural inputs as an effect of increasing water prices. Another shortcoming is that most of these models work at an aggregated level, using average technology. Because of this average technology the models do not describe how policy impacts vary between farms, due to differences in farm conditions and farmer attitudes and behaviour. The more local and farm specific the interventions are, the more the modelling of farm level elements becomes important (Buysse et al., 2007). The combination of the use of average technologies and the simplification of fixing the ratios between inputs and outputs leads to overly abrupt responses to changes in water prices (Jonasson and Apland, 1997). This poses more problems to regional models than to farm models because individual farms are more likely to react abruptly than the sum of all farms in a region (Buysse et al., 2007).

We describe an alternative method that deals with the shortcomings mentioned above. The method uses information from an efficiency analysis as a representation of the production technology. Jonasson and Apland (1997) were the first to incorporate frontier technology and inefficiencies in the mathematical programming of an agricultural sector model. Later Arnade and Trueblood (2002) and Abrar and Morrissey (2006) incorporated technical inefficiency in profit functions to study individual price responses. By incorporating the occurrence of inefficiencies in our model, individual price responses of farmers can thus be studied and the technology representation makes it possible to look at shifts in input use.

2.1. Measuring efficiency with data envelopment analysis (DEA)

The first step in this study consists of determining the current technical and allocative efficiency levels of the farms in the sample using the non-parametric DEA approach. Technical efficiency (TE) is defined as 'the ability of a farm to use minimum feasible amounts of inputs to produce a given level of output' (Coelli et al., 2002).[1] Allocative efficiency (AE) on the other hand refers to the degree to which inputs are used in optimal proportions, given the observed input prices and the value of the outputs produced. Economic efficiency (EE) is the product of allocative and technical efficiency and captures performance in both measures.

A characteristic of DEA is that the relationship between all inputs and outputs is taken into account. A production frontier is constructed and efficiency measures are obtained simultaneously by solving a linear programming (LP) problem (Eq. (1)). In this way the frontier obtained is formed by actual observations and envelops the observed input and output data of all farms. For a case with K inputs and M outputs for N farms, the technical efficiency θ for each farm is searched as follows Coelli (1996):

$$Min_{\theta\lambda}\theta, \tag{1}$$

subject to

$$-y_i + Y\lambda \geq 0,$$
$$\theta x_i - X\lambda \geq 0,$$
$$\lambda \geq 0$$

where θ is a scalar and λ is an Nx1 vector of constants, x_i and y_i, are column vectors with the input and output data for the ith farm. X is a K by N matrix and Y a M by N matrix with respectively all input and output data for all N farms in the sample. Using the variables λ and θ, the model is solved once for each farm, looking for the largest radial contraction of the input vector x_i within the technology set. The first constraint ensures that output produced by the ith farm is smaller than that of peers on the frontier. The second constraint limits the proportional decrease in input use when θ is minimized, to the input use achieved with the best observed technology. The resulting efficiency (θ), is a score always lying between zero and one, with a value of one indicating that the farm lies on the frontier and therefore is efficient.

A second characteristic to capture is the farms' success in choosing the optimal set of inputs given the input prices. This is done by calculating the allocative efficiency. Using the technical and economic efficiency, the allocative efficiency can be determined residually as AE = EE/TE. Economic efficiency itself can be calculated with only minor adjustments to the basic model for calculation of technical efficiency. The calculation involves two steps. First, given the input prices, a cost-minimizing vector of input quantities is determined using the model from Eq. (2):

$$Min_{x_i^*\lambda} w' x_i^*, \tag{2}$$

subject to

$$-y_i + Y\lambda \geq 0,$$
$$x_i^* - X\lambda \geq 0,$$
$$\lambda \geq 0$$

where w_i is a vector of input prices for the ith farm and x_i^* (which is calculated by LP) is the cost-minimizing vector of input quantities for the ith farm, given the input prices w_i and the output levels y_i. The other symbols are defined as in Eq. (1).

In the second step economic efficiency (EE) of the ith farm is calculated as the ratio of the minimum cost to the observed cost (Eq. (3))

$$CE = \frac{w_i' x_i^*}{w_i' x_i} \tag{3}$$

With the allocative and technical efficiency of each farm calculated, a model to estimate the impact of changes in the water price can now be constructed.

2.2. Simulating impact of different water prices

The frontier and efficiency measures will now be used as a representation of the production technology. An underlying assumption for this second step is that farmers will adjust their

[1] Input-oriented measures were chosen to reflect local situations, where a decrease in the use of water is an underlying objective.