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Modelling the marginal revenue of water in selected agricultural commodities: A panel data approach

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Abstract

South Africa is a water-stressed country where water availability is an important constraint to economic and social development, and will become even more so in the future if this scarce resource is not managed effectively. In order to manage this scarce supply of water, we need to value it. This study focuses on the value of water in the agricultural sector, in particular the marginal revenue of water for six irrigation commodities namely avocados, bananas, grapefruit, mangoes, oranges and sugarcane. A quadratic production function was fitted with an SUR model specification in a panel data study from 1975 to 2002 to obtain marginal revenue functions for each of the six commodities. We found that mangoes are the most efficient commodity in its water use relative to revenue generated (marginal revenue of water equals R25.43/m^3 in 2002) and sugarcane the least efficient (marginal revenue of water equals R1.67/m^3 in 2002). The marginal revenue of water is not an indication of the true "market" price. Neither is it an indication what the administered price should be. The marginal revenue of water is rather a guideline for policy makers to determine which industries or commodities within an industry can generate the largest revenue per unit water applied.

1. Introduction

South Africa is a water-stressed country where water availability is an important constraint to economic and social development. This development constraint is likely to escalate in future if water resources are not properly managed as a national asset as well as to the overall social benefit of the nation (Nieuwoudt *et al*, 2004). In order to manage this resource duly we need to value it, but the very nature of this commodity makes valuation difficult. Water is traditionally regarded as a public good, which makes management strategies of water pricing and allocation an extremely sensitive topic.

Supply-side solutions, such as the Working for Water programme, offers limited relief to meeting the increasing demand for water, while demand management programmes, such as the introduction of water efficiency

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technologies and increased water prices, may lead to a reduction in water consumption, but at the cost of reduced incomes, employment and consumer welfare. Rising marginal costs of water provision, increasing scarcity of water, and future threats related to unsustainable water management, require strategies and solutions that focus on demand side solutions which are socially fair and economically viable (Grimble, 1999). The valuation of water in the economy, within the different sectors of the economy or production processes, could be a useful tool for policy makers in the decision-making process regarding these management strategies and solutions.

This study focuses on the valuation of water in the production processes of six agricultural commodities. The agricultural sector - specifically irrigation agriculture - was chosen, since this sector is currently the largest user of water within the South African economy, using 59 percent of water supply in South Africa (DWAF, 2002). Agriculture by its very nature is generally, not only in South Africa, a high water user relative to GDP and employment when compared to other industries. One cubic meter of water adds R1.50 to GDP in agriculture compared to R157.40 in industry, R39.50 in mining and R44.40 in eco-tourism (Niewoudt *et al*, 2004). Even though agriculture generates less output per unit of water, it still is, however, the leader in creating jobs per value of output among the different sectors. In agriculture R1 million creates 24 jobs compared to the 10.9 jobs created by mining (Nieuwoudt *et al*, (2004)).

The main objective of this study is to estimate marginal revenue functions for each of the six commodities chosen. Once these functions have been estimated the respective marginal revenues for each of these commodities can be compared with one another for every year of the study sample. Marginal revenue of water measures the opportunity cost of water, or the forgone revenue at the margin and can thus be defined as the revenue that an additional unit of water will generate. Comparing the marginal value of water for different commodities will allow us to rank commodities according to their revenue efficiency relative to water use in and during the production processes. This information can be helpful to policy makers in the optimum allocation of water rights to agricultural producers in areas where water is relatively scarce.

The structure of the paper is as follows: the first section contains a concise literature review, followed by the methodology implemented in the estimation process in section two. The third section contains the data and empirical estimation results, whilst section four details an analysis of the estimation results, which is followed by a conclusion.

2 Literature review

In many countries, governments, through different pricing and allocation strategies, manages water supplies. These strategies are normally not based on economic efficiency, but rather on social and distribution criteria such as fairness and/or equity. The National Water Act (DWAF, 1998) endorses these principles as well. As an example, many households are granted the first 6kl of water per month free of charge as being a basic human right. Additionally, administered prices (or tariffs), which are based on structures such as flat rates and decreasing block rates, discourage efficient water use even further since it does not reflect increasing scarcity with increasing use of the resource. Small-scale water users are therefore paying more per unit of water use than large-scale users. This is because the water tariff structure is based on cost recovery rather than on managing the resource per se. If tariffs do not reflect the value of the resources, or if they are designed improperly, they will not send the right signals to users, which in turn will discourage conservation (Dinar and Subramanian, 1998).

Conversely, water markets have the ability to allocate water to the most efficient user. Water markets, however, are by no means suited as pricing strategy for all uses, for example water markets in household use will result in high value users bidding up the market clearing prices which will have social costs to low-income consumers whom will be forced to spend large proportions of their income on water.

Shadow pricing serves as a better signal of the value of water than administered prices. A shadow price measures the unit cost as an opportunity cost to society of engaging in some economic activity. Shadow prices are applied in situations where actual prices cannot be charged or where actual prices charged do not reflect the real sacrifice made when some activity is pursued (Bannock *et al*, 1998:378). In a perfectly competitive economy the market will clear where prices are equal to marginal cost, in which case the prices will reflect the true cost to society of producing one extra unit of a commodity. The shadow price (marginal revenue) of water is thus a better indication of the value of water than administered prices (Moore, 1999).

Table 1: South African studies on the marginal value of water

Study	**Year**	**Region**	**Method**	**Marginal value of water**
Conradie	2002	Fish-Sundays river	Econometric Model	R2.40/m^3
Louw	2001	Berg River basin	Mathematical programming model	R0/m^3-R20/m^3
Bate *et al*	1999	Crocodile River catchment	Water Trading	18.76c/m^3-22.75c/m^3

Source: Own summary of results in Nieuwoudt *et al* (2004) and Blignaut and De Wit (2004)

Table 1 lists some of the studies conducted on the marginal value of water in South Africa, in particular for the agricultural industry. It is evident that across regions, as well as methodologies, the marginal values differ significantly.

Louw (2001) evaluated the impact of a potential water market on the efficient utilisation of water in the Berg River basin. He utilised a positive mathematical programming model to develop a methodology to determine the true value of water and found significant differences in the value of water between areas in the basin, with the marginal value of water ranging between as low as R0/m^3 and as high as R20/m^3 in this region. These differences indicate that there are significant gains possible from trade between these areas. Bate *et al* (1999) studied the value of water through actual water trading in the Crocodile River catchment and found much lower values for water than the other studies (Conradie, 2002; Louw, 2001). The outcomes obtained by the Bate *et al* (1999) study correspond with the values of international studies (see Table 2), with water values ranging between 18.67c/m^3 and 23c/m^3. Bate *et al* (1999) also found that the value of water is the highest in tropical fruit production and the lowest in sugarcane.

Table 2: International studies on the marginal value of water

Study	Year	Region	Method	Marginal value of water ($/acre-feet)	Marginal value of water (R/m^3)
Moore	1999	California	Panel data study	$5-$15 per acre-feet	2.6c/m^3-7.9c/m^3
Faux & Perry	1999	Oregon	Hedonic Price Analysis	$9-$44 per acre-feet	4.7c/m^3-23.2c/m^3

Source: Own summary of results in Moore (1999) and Faux and Perry (1999). Conversion: R6.5/US$.

International studies, on the marginal value of water, such as Moore (1999) and Faux and Perry (1999), found values ranging between 2.6c/m^3 and 23.2c/m^3 (Table 2). Moore (1999) estimated a panel data econometric model with a Kmenta-type error structure in order to obtain shadow price (marginal revenue) functions for water. Faux and Perry (1999) applied a hedonic price analysis to agricultural land sales to reveal the implicit market price of water in irrigation.

Building on the general domestic and international frameworks that were reviewed in this section, this study will focus on the agricultural sector, and specifically on irrigated commodities. The agricultural sector was chosen, as it is the largest user of water supply in South Africa.

3. Methodology

A production function approach is used to estimate a revenue function; a marginal revenue function for water is then derived from this estimated revenue function. This study is based on the methodology developed and performed by Moore (1999) on a panel data study of shadow prices for water for 13 water districts in California.

Since water prices are generally set administratively rather than being market-determined; water prices serve neither a rationing nor allocative function (Moore, 1999) and are thus normally modelled as a fixed input. Based on this, the marginal revenue function for water is estimated under the assumption that production is quantity-rationed rather than price-allocated. Farmers are constrained by the availability of water rather than the cost or price of water; one reason could be that the cost of water relative to the total production cost is very small.

3.1 Revenue function

A revenue function is estimated for each commodity, where the revenue function is a function of the price of the commodity, the quantity of water used in the production process of that commodity and a composite variable input factor.

The revenue function is defined as:

$$R(p, w, comp) = \max_{y}\{p \cdot y : y \in Y(w, comp), p > 0\} \tag{1}$$

Where p is a vector of output prices, y is a vector of crop outputs, w is the water used in production and comp is the composite input factor.

3.2 Marginal revenue function or shadow price function

The marginal revenue function of water for each commodity is derived from the revenue function of that particular commodity and is defined as:

$$\frac{\partial R(p, w, comp)}{\partial w} = \lambda(p, w, comp) \tag{2}$$

The marginal revenue function (shadow price function) of water measures the unit cost as the opportunity cost, or forgone revenue at the margin.

The revenue function (equation 1) is estimated econometrically using a quadratic functional form. The quadratic form has been applied often in agricultural production studies (Huffman, 1988; Moore and Dinar, 1995 and Moore, 1999). The marginal revenue function is then derived from the estimated quadratic revenue function.

4. Data and estimation results

The data for the study constitute a panel data set for the period 1975–2002, with six cross-sections namely avocado, banana, grapefruit, mango, orange and sugarcane. The data set contains South African agricultural data has 168 observations. Table 3 contains a list and description of the variables for each cross-section.

Table 3: Variables and description

Variable	Description	Unit	Source
R	Revenue	R ('000)	Agricultural Statistics of the National Department of Agriculture
P	Price of commodity	R/ton	Agricultural Statistics of the National Department of Agriculture
W	Water used in production of commodity	Million m^3	WRC Studies
Comp	Composite input factor	Ha under irrigation	Agricultural Statistics of the National Department of Agriculture

Source: Own summary.

Since the number of cross sections is less than the number of coefficients, a random effects model could not be estimated. Theory places one restriction on the marginal revenue function of water (equation 2) in that the marginal revenue function must be positive. Intuitively we would expect that the function would have a negative slope and a positive intercept. Fixed effects models (Within and Least squares dummy variable) were fitted to the data but yielded positive slope coefficients for the marginal revenue functions of water and were disregarded, as it did not adhere to economic theory.

A quadratic revenue function was subsequently fitted to the data with a Cross-section SUR (Seemingly unrelated regressions) model. Testing for serial correlation indicated the presence of serial correlation in the residuals (LM-statistic = 93.132). Due to strong heterogeneity across cross-sections, individual rho-values were calculated for each of the cross-sections instead of a pooled rho. Large differences amongst the rho-values confirmed that the degree of serial correlation across cross-sections differs. After correction of the data by the individual rho-values, the test for serial correlation failed to reject the null hypothesis of non-serially correlated error terms (LM-statistic = 4.39), indicating that the problem of serial correlation no longer persists. We addressed the problem of heteroscedasticity by imposing a White's cross-section heteroscedastic structure on the error term in the original model. The Cross-section SUR model allows for contemporaneous correlation between cross-sections. A feasible GLS specification was estimated and both cross-section heteroscedasticity and contemporaneous correlation was corrected.

Table 4: Estimates of the quadratic revenue function: An SUR Model

Variable	Coefficient	Std. Error	t-Statistic	P-value
P	36.04	8.20	4.39	0.000
Comp	-4.65	1.31	-3.55	0.001
P^2	-0.01	0.01	-1.55	0.123
$Comp^2$	0.00	0.00	-0.53	0.597
P*Comp	0.01	0.01	0.73	0.465
P*W	4.23	1.08	3.93	0.000
Comp*W	0.18	0.04	4.56	0.000
W^2	-4.29	1.05	-4.07	0.000
W_{ADV}	1148.69	859.85	1.34	0.184
W_{BAN}	-827.13	411.51	-2.01	0.046
W_{GRF}	-900.76	1264.68	-0.71	0.477
W_{MAN}	9917.58	1681.19	5.90	0.000
W_{ORA}	-2603.96	576.36	-4.52	0.000
W_{SUC}	-962.68	345.72	-2.78	0.006
C_{ADV}	-9975.40	2806.10	-3.55	0.001
C_{BAN}	19643.80	8800.02	2.23	0.027
C_{GRF}	15011.20	9266.98	1.62	0.107
C_{MAN}	-12361.20	3060.86	-4.04	0.000
C_{ORA}	136051.90	27933.77	4.87	0.000
C_{SUC}	76438.33	16740.42	4.57	0.000
Adjusted R-squared		0.995		
F-statistic		1661.25		

Note: P = price; Comp = composite input factor; W = water used in production; C = constant, ADV = avocado; BAN = banana; GRF = grapefruit; MAN = mango; ORA = orange; SUC = sugarcane

The final SUR model, after correction for serial correlation and adjustment for heteroscedasticity, is summarized in Table 4. A very high Adjusted R-squared value of 0.99 indicates that the SUR model represents a good fit to the data, supported by a significant F-statistic of 1661.25. The coefficient of W^2 (-4.29), which determines the slope of the marginal revenue function, is not only negative but also significant (t-statistic=-4.07). The coefficients of the interaction variables that contain W, which influences the intercept of the derived marginal revenue function of water, are almost all significant at the 5 percent level, and the combinations of these coefficients yield positive intercepts for each commodity.

5. Analysis of the estimation results

Marginal revenue functions for each of the six cross-sections (commodities) were derived from the cross-section SUR model. Based on the results in section 3, the marginal revenue function (equation 2) can be specified as:

$$MR_{it} = C_i - 8.57W_{it} + 0.18Comp_{it} + 4.23P_{it} \tag{3}$$

The slope coefficients for water, composite factor and price are the same for all cross-sections (commodities) while the intercept differs for each of the commodities. We do not allow for variation in the slope of the marginal revenue function of water among commodities but we do allow for variation in the intercept of the commodities through the SUR model specification. From equation 3 it is now possible to calculate the marginal revenue for a specific year for each of the six agricultural commodities. Table 5 shows the marginal revenue of water for each commodity for the years 1999 and 2002, but it can be calculated for any year in the sample of 1975 to 2002. These years were chosen because it is towards the end of the sample period and the values obtained for 1999 are comparable to the results of Olbrich and Hassan (1999). To compare the two studies we also ranked the commodities according to their marginal value of water from the most efficient commodity in water use relative to revenue generated to the least efficient commodity.

Our results correspond largely to those obtained by Olbrich and Hassan (1999) who made use of a different method (net terminal value). The net terminal value represents the present worth at the end of the cycle or rotation of the stream of net benefits generated in future years (Olbrich and Hassan, 1999). Both studies found that mangoes are the most efficient agricultural commodity among the six commodities evaluated and sugarcane the least efficient. The shadow price of water or the opportunity cost of water in mango production for the year 1999 of R20.64/m^3 is much higher than the forgone revenue in the sugarcane production of R2.67/m^3 for the same year. The results are also similar to the study of Louw (2001) in the Berg River basin, where the marginal value of water ranging between R0/m^3 and R20/m^3 in this area. Louw (2001) also found tropical fruit to yield a higher marginal value of water than sugarcane.

Table 5: Marginal revenue and net terminal value of water

Commodity	Own analysis for the year 2002		Own analysis for the year 1999		Olbrich & Hassan WRC Report 666/1/99	
	MRW (R/m³)	Rank	MRW (R/m³)	Rank	NTV (R/m³)	Rank
Avocado	17.45	2	11.98	2	4–7	3
Banana	8.25	4	6.2	5	4–7	3
Grapefruit	9.92	3	8.7	3	7–10	2
Mango	25.43	1	20.64	1	>10	1
Orange	7.97	5	7.02	4	4–7	3
Sugarcane	1.67	6	2.67	6	1–2	6

Source: Own summary

A result obtained from our model that needs further explanation is the change in the ranks of banana and orange from the year 1999 to 2002. In 2002 bananas outperformed oranges with the marginal value of water equal to R8.25/m^3 and R7.97/m^3 respectively. In 1999 oranges (marginal revenue of water = R7.02/m^3) is ranked more efficient than bananas (marginal revenue of water = R6.2/m^3). Inspection of the raw data showed that the revenue in the orange production is 25.5% higher in year 2002 than in 1999, whilst the revenue in the banana production grew by 20.1%. The growth in the orange production can be contributed to growth in the overall output of 9.4% as well as a price increase of 9.3%. The overall production of bananas decreased by 8.3% from 1999 to 2002 but a growth of 30.9% in the price led to a net growth in the revenue. That said, it should be noted that, firstly, the size of the difference between the marginal value of water for bananas and oranges is relatively small (25c/m^3 in 2002 and 82c/m^3 in 1999), and secondly, Olbrich and Hassan (1999) ranked bananas and oranges as equally efficient.

6. Conclusion

The question now arises: what is the contribution of a study like this one, in which the value of water is estimated? The shadow price or marginal revenue of water is not an indication of what the true trading price or the administered price of water should be. It serves as a guideline for allocation policies, to determine the industries or commodities within an industry in which water can generate the largest revenue per unit of water input. It is also an indication of how market players might react to the presence of pricing strategies such as water markets. It is evident from the large spread in the forgone revenue between the mango and sugarcane industry that the mango industry would be able to bid away water from the sugarcane industry in a region where these two commodities compete for the same scarce water resource.

The pricing strategy for water use charges in terms of section 56(1) of the National Water Act (No 36 of 1998) aims to achieve the efficient and cost-effective allocation of water, equity and fairness in the allocation mechanism, and long-term sustainability of the natural environment (RSA, 1999). Marginal value of water functions can be used as a tool in the evaluation of the efficiency of allocation of water, but should not be regarded as an all-inclusive indicator in the pricing or allocation mechanism, since they do not take social costs such as employment, equity or fairness into account. What it can do is shed some light on the cost of government subsidisation of water-inefficient commodities. Given the fact that the challenge for South Africa is to address poverty, job creation and economic development within the framework of sustainable management strategies of our natural resources, considering the issue of water subsidisation in policy formulation, might prove toe be a good investment for future generations.

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