Marginal productivity analysis of global inter-sectoral water demand

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Poster paper prepared for presentation at the 26th International Association of Agricultural Economists Conference, Gold Coast, Australia,
August 12 – 18, 2006

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1 0.Introduction

Water use can be broadly divided into three categories; agricultural, industrial and domestic. Water's role in production technologies, unlike labour and capital, has received little attention in econometric studies of natural resource use. Only a few studies have been applied to inter-sectoral water use. Water plays the role of an intermediate quasi-public-good in sectoral production. Most sectoral processes use water as an input, though this purpose varies widely. For example, water is used as a direct input in beverage industries or as an indirect input in cooling, electricity or thermal industries and agriculture, or for transporting other inputs in paper and pulp industry or as a sink for industrial effluents. All these uses make productive water demand a multidimensional phenomenon, hence the difficulty in applying a single modeling procedure to analyze inter-sectoral water demand.

Generally, efforts to model sectoral water demand are confronted with many challenges, including lack of clearly defined information on the price of bulk water sales or purchases, self-supplied water users pay little or nothing for their raw water input in addition to the extraction cost, and much of the expenditure on water is rarely reported, because for most sectors it is an insignificant part of the overall expenditure on intermediate inputs.

There is growing evidence that while freshwater availability is declining, competition among sectors for the withdrawal of this scarce resource is increasing. The need to efficiently use scarce water resources has necessitated a switch from supply to demand management strategies. The pressure on the agricultural sector to improve water use efficiency has been extended to the industrial sector. Projected figures suggest that while irrigation water withdrawal is declining, industrial water use, especially in developing and transitional economies is increasing (Rosegrant et al, 2002). Therefore, the need to improve inter-sectoral water use efficiency is economical. To do this, the understanding of the structure of every sector's water demand is very crucial. Therefore, this article estimates the sectoral water demand functions, computes the output and price elasticities and the sectoral marginal values of water.

Section 2 discusses the empirical method applied to estimate the inter-sectoral water demand functions, while section 3 discusses the data sources and the data extraction method and section 4 presents the empirical results and some policy implications. Section 5 summarizes the findings and highlights further research requirements.

2 Empirical model of inter-sectoral water demand

A number of methods have been used to estimate inter-sectoral water demand functions. These methods range from the traditional demand estimation procedure to the more recent engineering or mathematical programming techniques (Kindler and Russel, 1984). However, because of the availability of data and the lack of funds to collect firm level data from all GTAP regions, this article uses econometric analysis and the marginal productivity approach to estimate the inter-sectoral water demand functions, given the available data. Different econometric techniques have been used to estimate the relationship between water use and other production variables (Renzetti, 2002: 10). The earliest models estimated the single-equation industrial water demand curves. Turnovsky, (1969); Rees, (1969); and DeRoy, (1974) estimated the single-equation water demand functions, in which the ratio of total expenditure to total quantity of water purchased was used as a proxy for water price. The use of average price as a proxy for water price is inconsistent with economic theory. In optimum decision-making, firms equate marginal value to marginal cost (price) of inputs. Also the use of single demand equation to represent the demand function for all the different production sectors might be misleading, because of the differences in the structure of inter-sectoral water demand. For example, beverage industries use more freshwater and recycle less than electro thermal industries.

Subsequent studies extended the analyses of inter-sectoral water demand to the use of the cost function duality approach. The approach assumes that industries' productive technology can be represented by the cost function and therefore uses the Cobb-Douglas' cost function to estimate the derived demand functions for industrial water use (Nerlove, 1965). The assumption is that firms choose input levels to minimize their costs of production and use the estimated cost function to derive the input demand functions, hence the input own and cross price elasticities of demand. The Cobb-Douglas' function is frequently criticized for its imposition of constant returns to scale, which violates the law of diminishing marginal returns and the assumption of strict separability of inputs (Beattie and Taylor, 1993).

An alternative to the Cobb-Douglas' cost function is the translog cost function which introduces flexibility in the returns to scale, hence relaxes the constant returns to scale imposed on the cost function. It also introduces weak separability of inputs. This uses the dual approach in which production technologies are represented by multi-output cost functions.

Grebenstein and Field, 1979; Babin, Wills and Allen, 1982, used the state-level cross sectional observations to estimate the translog cost functions for the American manufacturing industries' demand for water. Renzetti, (1988) used the Cobb-Douglas' cost function and employed the two staged least squares approach to estimate the water demand by manufacturing firms in Canada; and Renzetti, 1992 used the translog cost function and three-stage-least-squares approach to estimate the price effect of intake, treatment and recycled water use in the Canadian manufacturing sectors.

As with the single equation estimation, the major flaw of this method is its use of average cost as a proxy for the price of water. Wang and Lall, 2002 used the translog production function, via the seemingly unrelated regression procedure (SUR) to estimate the demand for industrial water use in China. They developed a model, which used the marginal value of water as a proxy for the price of industrial water. Generally, though the marginal value of water in industries is high, the demand for industrial water use is less responsive to changes in water prices. This article adopts the Wang and Lall, (2002) approach by estimating the translog production function in equation 1, which describes the relationship between the value of output and the value of production inputs including labour, capital, water and intermediate.

$$\ln Y = \beta_0 + \beta_1 \ln L + \beta_2 \ln K + \beta_3 \ln W + \beta_4 \ln I + \beta_5 \ln L \ln K + \beta_6 \ln L \ln W + \beta_7 \ln L \ln I + \beta_8 \ln K \ln W + \beta_9 \ln K \ln I + \beta_{10} \ln W \ln I + \beta_{11} \frac{\ln^2 L}{2} + \beta_{12} \frac{\ln^2 K}{2} + \beta_{13} \frac{\ln^2 W}{2} + \beta_{14} \frac{\ln^2 I}{2} \quad (1)$$

Where; lnY, lnL, lnK, lnW and lnI are the natural logarithms of output, labour, capital, water and intermediate inputs respectively, and the others are the squares and interaction terms of the respective independent variables. To account for the differences in the intercept and slope coefficients of the different sectors, sectoral dummies are imposed on the model. From the estimated equation, the output elasticity (η_y) of water is computed as:

$$\eta_y = \frac{\partial \ln Y}{\partial \ln W} = \beta_3 + \beta_{13} \ln W + \beta_6 \ln L + \beta_8 \ln K + \beta_{10} \ln I. = \frac{\partial Y}{\partial W} . \frac{W}{Y} \quad (2)$$

The marginal value of water (ρ) for each of the sectors is then computed as;

$$\rho = \frac{\partial \ln Y}{\partial \ln W} * \frac{Y}{W} = \eta * \frac{Y}{W} \quad (3)$$

The study assumed that firms in the various industries are perfectly competitive. Economic theory of production asserts that for profit maximizing perfectly competitive firms/ industries, the marginal value of an input is equal to the marginal cost and is the shadow-price of that input (Henderson and Quandt, 1992). Therefore the price of water is assumed to be equal to the marginal value of water. Thus the price elasticity of water (ε_p) is computed as;

$$\varepsilon_p = \frac{\partial \ln W}{\partial \ln P} = \frac{\partial \ln W}{\partial \ln \rho} = \frac{\partial W}{\partial P} * \frac{P}{W} = -\frac{\eta}{\eta - \eta^2 - \beta_{13}} \qquad (4)$$

Once the output elasticity is estimated, the marginal value and price elasticities are computed on the mean values of the variables. The estimation results are presented in Table 1. The computed figures explain how different production sectors and sub-sectors respond to unit changes in the price of water. Price elasticity shows the effectiveness of water pricing as a policy instrument to institute industrial water use efficiency, while marginal value is an indicator of the water productivity in the various production sectors.

3 Description and sources of data

Most of the data used for this study are extracted from the GTAP 2001 cross-sectional data set, which has 66 regions, 57 sectoral outputs and 5 factors of production measured in tens of billions of US Dollars (Rutherford and Paltsev, 2000). The 57 GTAP sectors are aggregated to 13 sectors using the international standard industrial classification (ISIC) codes, which include agriculture (AGR), beverages and tobacco(AGI), chemical(CHM), construction (CON), electricity (ELE), energy (ENG) metal manufacturing (HEV), other manufacturing (MNF), machinery and equipment (MAC), mining (MIN), petroleum (PEC), pulp and paper (PPP), and clothing and textiles (TXT) industries

The sectoral water use data are extracted from the UNIDO database, by converting water use per employee to gross sectoral water intake. To check the consistency of the conversion method, the extracted data are compared with the FAO sectoral water use data and the differences minimized by adjusting the conversion factor.

4.0 Presentation and discussion of the results and policy implications

Table1 presents the regression coefficients, of the three models estimated and the output and price elasticities and marginal values of water for the thirteen industrial sectors. The Cobb-Douglas' estimated coefficients are presented in column 2, while the estimated translog coefficients and the translog with the imposed sectoral dummies are presented in columns 3 and 4 respectively. The estimated translog functions are tested against the null hypothesis that the interaction and square terms were not significantly different from zero. Based on the result, the null hypothesis could not be accepted. Generally, the results show that, water is a significant production input. The other test-statistics in the last three rows confirm the appropriateness of the functional form, the predictability of the model and the absence of auto-correlation among the specified variables.

Overall, the output elasticity of water of 0.20 implies that on the average the value of output increases by US$0.20 for a unit increase in the value of water. Generally, there is not much variation in output elasticity among the various sectors.

The marginal value measures the change in the value of output due a unit change in the level of water use. Overall, sectoral water use has a mean marginal value of US$1.34. The petroleum extraction sub manufacturing sector has the highest marginal value of US$10.17, followed by metal manufacturing, with a marginal value of US$7.47 and the least is agriculture with a marginal value of US$0.39.

The computed price elasticities in column 9 indicate that overall industry-wide water demand is fairly price elastic, with elasticity measure of -1.27. However, there are variations in the responsiveness of different sectors and sub-sectors to changes in water prices. A price elasticity of -0.89 in the agricultural sector shows that a ten percent increase in the price of water leads to about a nine percent decrease in agricultural water use, while industry-wide water use decreases by about 13%. As shown in column 9 of Table 1 price elasticity of water is different for the different sectors and sub-sectors, with pulp and paper industry with the least price elasticity, while the metal manufacturing has the highest price elasticity.

The estimation results have some plausible policy implications. The situation in which a sector's demand for water is price elastic, water pricing could be used to promote water use efficiency. Generally, industrial water use is price elastic. This implies that water pricing policy can lead to water use efficiency in the industrial sub-sectors. However, since some industries are less responsive to changes in water prices than others, water pricing should be complemented with some mandatory policies like water treatment and recycling.

Since the computed elasticities are constant, but the marginal values vary from level of water application to the other, the output elasticity could be used to estimate or predict the marginal value of water in the different sectors of the different GTAP regions.

5 Conclusions and recommendations

This study estimated and analyzed the inter-sectoral water demand functions for thirteen industrial and the agricultural sectors, using the translog production function. The computed price elasticities generally indicate that industrial water demand is fairly price elastic. This suggests that water pricing can be used to improve sectoral water use efficiency. However, for optimum decision, sectoral water prices should reflect the marginal value of water in the various sectors, since this will serve as an incentive for the various sectors to use water efficiently. Production sectors are willing to pay the shadow price of water, which is reflected by the marginal values. When the marginal value equals to the marginal cost (which is the price) of water, sectoral water intake will be optimum. Using the marginal value as the shadow price of water, the price of water should be higher in most manufacturing industries than in agriculture since water commands a higher marginal value in industries than in agriculture. As a policy instrument, water pricing should be combined with some mandatory policies like wastewater treatment and recycling.

There is the need to validate this model, by collecting firm-level data in the GTAP regions and estimating the demand functions to be compared with predicted values from the global model. Also the need exists to investigate whether the computed marginal values are more useful for inter-sectoral water pricing or reallocation.

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Appendix

Table 1: Estimated coefficients, elasticities and marginal values of water

Variables (1)	Cobb-Douglas (2)	Trans-log (3)	Trans-log with sector dummies (4)	Mean values of output (5)	Mean values of water (6)	Out-put-elast-icity (7)	Marginal Value (8)	Price elasticity (9)
Constant	2.242*	2.757*	2.5808*	-	-	-	-	-
lnL	0.083*	0.262*	0.221*	-	-	-	-	-
lnK	0.227*	0.380*	0.344*	-	-	-	-	-
lnW	0.215**	0.150**	0.092***	-	-	-	--	-
lnI	0.633*	0.446*	0.346*	-	-	-	-	-
lnLlnK	-	-0.005	-0.005	-	-	-	--	-
lnLlnW	-	0.0014	0.000	-	-	-	-	-
lnLlnI	-	-0.229*	-0.023*	-	-	-	--	-
lnKlnW	-	-0.002**	-0.002	-	-	-	-	-
lnKlnI	-	-0.024*	-0.024*	-	-	-	-	-
lnWlnI	-	0.011***	0.001	-	-	-	-	-
$0.5\ln^2 L$	-	0.030*	0.277*	-	-	--	-	-
$0.5\ln^2 K$	-	0.046*	0.399*	-	-	-	-	-
$0.5\ln^2 W$	-	0.001	0.016***	-	-	-	-	-
$0.5\ln^2 I$	-	0.051*	0.042*	-	-	-	-	-
S1*ln(W) Beverage and Tobacco	-	-	0.051***	407.85	29.81	0.26	3.50	-1.46
S2*ln(W) Agriculture	-	-	0.011**	81.14	44.53	0.22	0.39	-0.89
S3*ln(W) Basic Chemicals	-	-	-0.002	273.81	13.47	0.20	4.12	-1.39
S4*ln(W) Construction	-	-	-0.037**	1139.29	44.34	0.17	4.31	-1.35
S5*ln(W) Electricity	-	-	-0.010	311.54	87.10	0.20	0.70	-0.78
S6*ln(W) Energy	-	-	-0.137*	22.34	3.55	0.07	0.43	-1.42
S7*ln(W) Metal Manufacturing	-	-	0.358**	312.63	23.56	0.56	7.47	-2.44
S8*ln(W) Machinery & Equipment	-	-	0.269**	19.83	1.91	0.47	4.92	-2.03
S9*ln(W) Mining	-	-	-0.052**	503.87	61.48	0.15	1.25	-1.34
S10*ln(W) Other manufacturing	-	-	0.0001	620.65	30.72	0.20	4.14	-1.39
S11*ln(W) petrol-coal	-	-	-0.029	14.97	0.26	0.18	10.17	-1.36
S12*ln(W) Paper and pulp	-	-	0.017	62.28	10.12	0.22	1.36	-0.87
S13*ln(W) Clothing and textiles	-	-	0.027***	17.36	0.74	0.23	5.47	-1.43
Industry-wide	-	-		368.59	56.32	0.20	1.34	-1.27
Number of observations	727	727	727					
Degrees of freedom	(4, 720)	(14, 710)	(27, 700)					
F Score	608.26*	224.46*	163.09*					
Durbin Watson Test	2.235*	2.014*	1.987**					
R^2	0.7486	0.7255	0.6971					

Source: Extracted from the estimation coefficients

Note: '*', '**' and '***' imply one percent, five percent and ten percent statistical significance respectively.