CHAPTER TWO

ECONOMIC VALUATION OF WATER RESOURCES: AN OVERVIEW OF METHODS AND APPLICATIONS

2.1 INTRODUCTION

Water resources, like other natural resources are limited in supply. Studies show that at the global level, per capita water availability is declining due to population growth, urbanization, industrialization, climate change and poor governance. Additionally, the nonagricultural (domestic, industrial and environmental) demand for the scarce water resource is rapidly increasing (Rosegrant *et al.* 2002c). In the past, the need to meet the growing demand for scarce water resources was solved in part, by new investments in irrigation and water supply systems and through improved water management (Rosegrant 2003). Thus, the supply-side management of water resources received considerable attention in meeting the growing demand for scarce water resources. However, because of the rapid growth in the demand for water and the dwindling per capita water availability, investment in new water infrastructure and the heavy reliance on groundwater sources have become expensive. So water supply is projected to be inelastic in the future, due to the limitations put on the potential for expansion of new water supplies (Rosegrant and Cline 2003). Therefore, the switch from supply-side to demand-side management is now viewed as a viable option in water management policies. To efficiently institute demand-side management of the exiting water sources, users should pay its fair price, which reflects the scarce nature of the resource. Prices which reflect the marginal value of water are assumed to institute allocative efficiency of water use. With this development, water pricing policy is now viewed as an effective tool which can be used to stimulate socio-economic development. Nonetheless, there are major controversies over the socio-economic methods used to estimate inter-sectoral water prices, either because of distortions in water markets due to government intervention, or because existing prices do not reflect the scarcity value of the resource. Therefore, this chapter is designed to describe and analyze some of the existing methods of estimating the value of water in inter-sectoral economic activities. Agudelo (2001) categorized water valuation methods into three:

i) methods that infer value from information regarding markets of water and water-related benefits

ii) methods that estimate values from the derived demand for water, where water is used as an intermediate good, and

iii) methods that estimate the value of water from a direct consumer demand, as in the case where water is used as a final good.

As a market good, value is derived from rentals and sales of water rights or land in case of a riparian ownership of water. As an intermediate good, value is derived from the producers' demand function, residual imputation, value added or alternative costs of water use. If used as a final private good, the value of water is determined from the consumers' demand function. If water is used as a public final good, its value is derived from the embedded travel costs or as bundle of other goods in a hedonic property value or the use of contingent valuation method to determine the value consumers place on the its use (Agudelo 2001). This study focuses on the use of water as an intermediate good, used as an input in the production of other goods and services. It also attempts to analyze the benefits of inter-sectoral water use in a country where water markets are ill-defined and prices are distorted, because of government intervention or because of the absence of completely defined user rights.

When used as an intermediate good, the value of water must be assessed from the producers' point of view. The conceptual valuation framework for the welfare benefits of increases or decreases in water use is provided by the producers' demand for inputs, including water. The following valuation methods are among the many that could be used to assess the value of water as an intermediate input in an ill-defined or dysfunctional water market: i) estimating the producers demand function, ii) the residual imputation method, iii) the value added method and iv) the alternative cost method. Each of these methods is discussed in turn in the succeeding sections.

2.2 ESTIMATING THE PRODUCERS' DEMAND FUNCTIONS FOR WATER

In this approach, water demand function can be deduced from historical water use statistics or calculated from the analysis of optimum water consumption patterns, by mathematical programming to determine the schedule of increases or decreases in net income accruing from changes in the level of water use (Agudelo, 2001). From the estimated demand curve, the quantity of water demanded can be determined. If there are any changes in the level of water consumption, the area below the curve for the specified increase in the quantity of water demanded represents the maximum amount the producer is willing to pay to obtain the resource input. Where no information about the entire demand function exists, the price of water is used as the best estimate of the maximum willingness to pay for unit increase in the level of water use. The slope of the demand curve shows how the producer adjusts to changes in water price and this price indicates the marginal benefits of water use to the producer.

In estimating the producers' demands function, other variables such as the prices and quantities of other inputs are included. These variables generally cause the demand curve for water to shift over time, because the demand for water depends on the degree of variability in the demand for other inputs. The various methods that can be used to estimate the producer's demand function include the production function, assumed price elasticity, econometric modeling and mathematical programming.

2.2.1 Production function approach

In this approach the functional relationship between output and all the inputs including water is estimated.

$$Y = f(K, L, N, I \ldots, W) \tag{2.1}$$

Where Y is output, K is capital, L is land, N is labour, I is any other intermediate input except water and W is water. In an attempt to maximize profits, the producers select inputs such that the value of the marginal product is equal to the price of the product. That is;

$$\begin{aligned} &P_K = P_Y x \frac{\partial Y}{\partial K}, \quad P_L = P_Y x \frac{\partial Y}{\partial L}, \quad P_N = P_Y x \frac{\partial Y}{\partial N}, \\ &P_I = P_Y x \frac{\partial Y}{\partial I}, \; P_W = P_Y x \frac{\partial Y}{\partial W} \end{aligned} \tag{2.2}$$

The above implies that the level of water W is increased until the value of the additional unit of water used ($P_Y x \frac{\partial Y}{\partial W}$) just equals the cost of using an additional unit of water (P_W). Optimum condition requires that this must hold for all the inputs used and that the ratios of the marginal value to the marginal cost of an input must be the same for all inputs. As one of the main empirical estimation methods used in the study, this method will be fully discussed in chapter three.

2.2.2 Assumed price elasticity approach

This method assumes that the price elasticity of water is constant over a time and space. With constant elasticity, if the initial price (P) and quantity (Q) of water are specified, and assuming that the quantity of water changes to (Q_1) in response to a change in price from P to P_1, then the relationship between percentage change in the quantity of water demanded and the percentage change in the price of water could be integrated to obtain a demand function/curve for water within the specified range (Agudelo, 2001 and Young, 1996).

$$\int \frac{dP}{P} = \frac{1}{E}\int \frac{dQ}{Q} \Rightarrow \ln P = \frac{1}{E}\ln Q + C \tag{2.3}$$

By taking the exponentials of both sides of equation 2.3 and setting the constant, the equation becomes;

$$P = P_1 \frac{Q_1^{1/E}}{Q^{1/E}} \tag{2.4}$$

Therefore, the benefit gained by increasing the quantity of water used in response to an increase in the price of water is computed as;

$$B = \int_{Q_1}^{Q_2} PdQ = \int_{Q_1}^{Q_2} P_1 Q_1^{1/E} \frac{dQ}{Q_1^{1/E}} \tag{2.5}$$

$$B = \frac{P_1 Q_1^{1/E}}{1-\frac{1}{E}}\left[\frac{Q_2}{Q_2^{1/E}} - \frac{Q_1}{Q_1^{1/E}}\right] \tag{2.6}$$

If the assumed elasticity is not equal to unity, the integration becomes:But if the assumed elasticity is equal to unity, then the integration becomes:

$$B = P_1 Q_1 \ \ln\frac{Q_2}{Q_1} \tag{2.7}$$

Equations 2.6 and 2.7 represent the area under the demand curve for a change in the quantity of water demanded from Q_1 to Q_2, which is the value of incremental change in quantity of water demanded. King (2002) in Blignaut and de Wit (2004) used the constant elasticity concept to estimate the demand for, and the marginal value of domestic water use in South Africa.

The assumption of constant elasticity of water demand or supply over a period of time has been criticized. Water is an intermediate good used in the production of other goods and services. Therefore, the demand for water is dependent on the demand for the final goods or services produced. As such, assuming constant elasticity for a good that has a derived demand may be unrealistic and does not make economic sense (Kindle and Russel, 1994)

2.2.3 Econometric approach to estimating water demand functions

The econometric approach to estimating water demand functions involves making inferences from actual observation on quantities used and prices of water, along with corresponding data on other explanatory variables (Renzetti 2002; Agudelo 2001; Young 1996). In addition to the price of water, the prices of the other factors of production, type of technology, product mix and output levels are also required for a sound econometric modeling technique.

Many empirical studies apply econometric modeling techniques to estimate water demand functions for domestic, agriculture, industry and mining water uses. Earliest econometric methods used in modeling the demand for industrial water use focused on the estimation of single-equation demand functions/curves. Turnovsky (1969); Rees (1969) and DeRooy (1974) were among the first set of studies to estimate the demand for water use by the manufacturing sub-sectors. These studies estimated the single equation water demand functions, in which the ratio of total expenditure to the 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 not consistent 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 categories of industries might be misleading. Some industries can treat and recycle water, while others often rely on freshwater intake for their production activities. The structure of water demand in different industries depends on the type of activities. For example, beverage industries use more freshwater and recycle less than electro thermal industries.

Subsequent studies extended the analyses of industrial water demand to the use of the cost function duality approach. The approach assumes that an industry's productive technology can be represented by the cost function. Therefore, it uses the Cobb-Douglas' cost function to estimate the derived demand functions for industrial water use (Nerlove, 1965). This approach assumes that manufacturing firms choose input levels to minimize their costs of production and use the estimated cost function to derive the input demand functions, from which the own and cross price elasticities of demand for the inputs can be computed. The Cobb-Douglas' production 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. This relaxes the constant returns to scale constraint imposed by the Cobb-Douglas' cost function. It also introduces weak separability of inputs and uses the dual approach in which production technologies are represented by multi-output cost functions.

Grebenstein and Field (1979) and Babin *et al.* (1982), used the translog cost functions to estimate the American manufacturing industries' demand for water using state-level cross-sectional observations. Renzetti (1988) used the Cobb-Douglas' cost function via the two-stage 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 industry.

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 (SUR) procedure to estimate the demand for industrial water use in China. The authors developed a model, which used the marginal value of water as a proxy for the price of industrial water. Generally, the results of these studies indicate that although the marginal value of water in industries is high, the demand for the input by the manufacturing firms is less responsive to changes in water prices.

2.2.4 Mathematical programming approach

The mathematical programming approach follows the linear programming model, which is an optimization model that combines unit processes of water utilization systems in the form of linear inequalities. The variables are the levels of the systems' operations and the inequalities express constraints of the overall system (Kindler and Russell, 1984; Carmichael and Strzepek, 1987). These models are developed to represent the optimum allocation of water and other inputs so as to maximize profits, subject to constraints on resource availability and institutional capabilities. The procedure usually follows the construction of a flow diagram of sectoral activities, linking up the components of the flow diagram, algebraically formulating linear inequalities and constraints, and estimating the coefficients of the decision variables. This approach articulates the links between water input alternatives, their prices, other input choices and output, and identifies the best or optimal input strategies or the profit maximizing production path that could be followed by firms. In effect, it identifies the most efficient water utilizing options by the production sectors in terms of cost effectiveness and output maximization. The objective function for a mathematical programming model is usually written as;

$$\begin{aligned} &\max\ f(\pi, X) \\ &\textit{subject to}\ \ A'X \leq B \end{aligned} \tag{2.8}$$

Where 'π' represents the net return per activity, 'X' is a vector of production activities, the elements of the 'A' matrix are the production coefficients and 'B' is the vector of production inputs such as labour, capital, natural resources including water, intermediate inputs and so on (Young 1996). The parameter ‘π’ is a measure of the marginal return to water in activity ‘X’. The use of mathematical programming is quite advantageous in a situation where a wide range of technological options is to be studied. In such a situation, it is important that the marginal productivity, which is represented by the net profit coefficients, is accurately calculated. However, this valuation method requires detailed data at the firm/industry level and is most suitable for the individual sector or country level inter-sectoral water use analysis; but it is expensive and time consuming. Carmichael and Strzepek (1988) explained the use of mathematical programming in modeling and forecasting industrial water use and treatment practices.

2.3 THE RESIDUAL IMPUTATION METHOD

This method requires the subtraction of the economic cost of all the other production inputs except water from the sales revenue. The difference becomes the value of water in the production of commodity.

In the case where just one commodity is produced, the use of the residual imputation method is based on the theory that the sales revenue exactly equals the total cost of production. This implies that the sales revenue (price multiplied by the quantity sold) exactly equals the sum of the inputs used, multiplied by their respective prices. This relationship is expressed below as:

$$PQ = \sum K_i N_i + WP_w \qquad (2.9)$$

Where ‘P’ is the competitively determined commodity prices, ‘Q’ represents the quantity of the commodity produced and sold, while ‘K_i’ is a vector of competitively determined prices (equal to the marginal value product) of non-water factors, and 'N_i' is a vector of non-water inputs employed in the production process and 'W' and 'P_w' are the quantity and price of water respectively. If all the inputs, including water are exchanged in a competitive market and employed in the production process, the value of water (price multiplied by its volume used) will be;

$$WP_w = P_i Q_i - \sum K_i N_i \tag{2.10}$$

This method can be extended to a multi-input and multi-product situation, in which different sectors compete for the use of the scarce resources (production inputs) and sell their products in a non-differentiated market. This implies that the firms are in perfect competition. The residual value of water in the i^{th} sector producing the j^{th} commodity is;

$$W_{ij} P_{w_{ij}} = \sum_{i=1}^{n} P_{ij} Q_{ij} - \sum_{i=1}^{n} W_{ij} N_{ij} \tag{2.11}$$

Renwick (2001); Hussain *et al.* (2000) and Bakker *et al.* (1999) used this method to estimate water productivity in irrigated agriculture and reservoir fisheries. Renwick (2001) used the concept expressed in equation 2.11 to estimate both the implicit and explicit costs of securing water and the scarcity value of the resource use. Thus equation 2.11 can be broken into:

$$W_{ij}(P^* + \lambda) = \sum_{i=1}^{n} P_{ij} Q_{ij} - \sum_{i=1}^{n} W_{ij} N_{ij} \tag{2.12}$$

Where 'P*' reflects both the implicit and explicit costs of securing water and 'λ' reflects the scarcity value of the resource use, hence:

$$P^* + \lambda = \frac{\sum_{i=1}^{n} P_{ij} Q_{ij} - \sum_{i=1}^{n} W_{ij} N_{ij}}{W_{ij}} \tag{2.13}$$

However, Young, (1996) cautioned that the residual imputation method is only valid if i) all inputs and outputs are exchanged in markets that are both competitive and unregulated and ii) the production function is 'well behaved'.

Using the residual imputation method, Renwick, (2001) calculated the shadow price of water and by using discounting method, estimated the present value of water in irrigated agriculture and reservoir fisheries in Sri Lanka.

2.4 VALUE ADDED APPROACH

This approach could be used in any situation that requires the estimation of economic benefits derived from the use of water as an intermediate input in sectoral production activities. Value added refers to net payments to the primary factors of production such as wages and salaries, rents and other natural resources, interest or depreciation on capital. Value added is measured on a sector-by-sector basis through an input-output model representing the economic structure of a country, region or water management area. The framework of the input-output model, which is a static model, is used to estimate the direct and indirect impacts. This framework based on the linear structure of inter-industry production linkages, pioneered by Wassily Leontief in the 1930s. In it, the total input requirements matrix, also known as the coefficient matrix, is computed. The input-output coefficient matrix is used to calculate the direct and indirect intermediate inputs requirements per extra unit of output or value added in a specific sector. This coefficient matrix, which is also referred to as the Leontief inter-industry transactions matrix, defines the amount of the output from each production sector which is required as an intermediate input used to produce a unit of an output in a specific sector. The model illustrates the interdependence nature of the production sectors in an economy, hence the inter-sectoral forward and backward linkages. With the incorporation of water into the inter-sectoral production framework, the input-output model can be used to investigate the economy-wide contribution of water to inter-sectoral production activities and the impact of investment in water infrastructure on output growth and value added. It can also be used to evaluate the economy-wide impact of inter-sectoral water pricing, re-allocation and other managerial policies. Hassan (2003) used a quasi-input-output model to analyze the contribution of irrigated agriculture and cultivated forestry in the Crocodile River in South Africa. Despite its advantages, its ability to capture the forward and backward benefits of inter-sectoral activities, the use of the input-output model has been criticized for its exclusion of institutional framework inherent in an economy. It significantly fails to account for the equitable distribution of benefits derived from production activities.

To adequately address these limitations, the input-output or the Leontief model can be extended to the social accounting matrix (SAM) model by the inclusion of most of the final demand sector into the endogenous accounts. This inclusion facilitates the computation of an extended Leontief inverse, which aims at incorporating the feedbacks from rents to consumption, to new production that originates from an exogenous flow (Boughanmi *et al.*, 2002; Juana, 2006; Juana and Mabugu, 2005 and Sadoulet and de Janvry, 1995). From the coefficient matrix both the input-output and the SAM based production multipliers can be computed. Economic multipliers estimate the economy-wide impact of exogenous changes in related economic variables or policies in a specified economy. Four types of multipliers can be found in existing literature: the direct, indirect, induced and total impact multipliers. These are fully discussed in chapter five. These direct and indirect impacts of exogenous changes in final demand on output, employment and income are measured both in aggregate terms and for each sector of an economy. Kumar and Young (1996) incorporated water supply and demand functions into SAM framework for Thailand and investigated the economy-wide impact of water pricing policies on the economy of the country.

The SAM model can also be extended to computable general equilibrium (CGE) models, by imposing demand and supply functions and equilibrium conditions to the model. These relax the linearity conditions and introduce non-linear functions into the valuation framework. It also relaxes the assumption of constant prices in the factor and product markets and allows the market mechanism process to solve for competitive equilibrium. Berrittella *et al.*(2007) did a global CGE analysis of the economic impact of restricted water supply using the modified GTAP-E (Energy) version. The authors generated a GTAP-W (Water) model which is aggregated to include 17 sectors and 16 regions and included water as a non-marketed resource. Also, Letsoalo *et al.*(2007) used the CGE approach to analyze the benefits of water consumption charges in South Africa.

2.5 ALTRERNATIVE COST APPROACH

The alternative cost approach is appropriate when estimates of direct demand schedules or functions are difficult to be computed because of data unavailability or other reasons. This approach is based on the assumption that the maximum willingness to pay for a publicly supplied good or service is not greater than the cost of providing it. That is, if a given project, with a specified output costs is less than the next best project with the same output level, then the former is preferred to the alternative. The present value of the total costs of each alternative is calculated on the basis of commensurate planning period, price level, and discount rate (Agudelo, 2001). The analysis must verify that the highest-cost alternative would actually be constructed in the absence of the project under consideration.

The alternative cost approach is very useful when the demand for water is price inelastic and when the objective of a public project is to reduce the cost of producing an output which could otherwise be provided at a higher cost to the consumer. The approach has the advantage of permitting benefits evaluation without actual estimation of the demand curve.

2.6 OUTLINE OF THE APPLIED METHODS USED IN THIS STUDY

Given the above analyses of methods used to estimate the economic value of water, this section briefly discusses the methods applied in this study.

In Chapter Three, the study estimates the global inter-sectoral water demand functions for thirteen production sectors. Using the marginal productivity approach, the study estimates the output and price elasticities and marginal values of water for the different water user-sectors. The data for the global level analysis are extracted from the GTAP (2001) and UNIDO (2000) data bases. The modeling procedure follows the Wang and Tall (2002), by estimating the Cobb-Douglas’ and translog production functions. Using the two-staged model the study estimates the elasticities and marginal values for the different aggregated sectors. The study uses the marginal productivity approach because the price of water is not shown in the available data. Therefore, the computed marginal values are used as a proxy for the price of water. In Chapter Four, the study extracts data from the census of manufacturing, agricultural, construction and services activities on the one hand

(STATSA, 2002), and from water resource accounts (STATSA, 2004) to estimate the sectoral water demand functions for South Africa. This is done in order to validate the global model. The regional water demand functions are computed by using the 1996 census of manufacturing activities data, and the DWAF's economic information system (EIS) and other regional data, to validate the national level parameter estimates.

In chapter five, the 1999 social accounting matrix (SAM) developed by Thurlow and van Seventer (2002) is updated to reflect 2003 entries by using data from TIPS (Trade and Industry Policy Strategy, 2004) and Statistics South Africa 2000 Water Accounts (STATSA, 2004). This SAM is used to compute the multipliers, which are interpreted to show the contribution of water to economic activities in South Africa. The multipliers are used to examine the economy-wide impact of water reallocation from agriculture to the non-agriculture sectors on the basis of the computed marginal values in Chapter Four. This shows how sectoral water reallocation based on the sectoral marginal contribution of water impacts output growth, factor payments and household income generation. If economic efficiency is mainly determined by marginal values, the study then examines the extent to which the equity criterion is also met. If not, then the study generates scenarios to find out which allocation strategy maximizes both economic and social welfare. However, when the assumptions of the SAM analysis are relaxed in a CGE model, the simulation results are usually significantly different from the SAM results. Therefore, the study uses the computable general equilibrium analysis to investigate various water policies on households' welfare.

2.7 SUMMARY AND CONCLUSION

This chapter surveyed the various methods for valuing water as an intermediate good. Four main valuation methods were briefly discussed. Among the various methods discussed the econometric demand estimation and the value added approaches will be extensively applied in this study.

The study applies the econometric approach to estimate the global inter-sectoral water demand functions and compute the output and price elasticities and the marginal value of water for specified sectors. Specifically, the study adopts the marginal productivity approach to estimate the translog production functions. This approach is preferred to the other econometric methods because of it being consistent with economic theory of optimum pricing. Since water prices are distorted either because of government regulations that favour one sector's use of water over the others, or because of the quasi public good nature of the resource, this study uses computed marginal values as the shadow price of water. Also, since water pricing is a controversial issue in water resource economics, policy analysts would like to recommend sectoral water prices that reflect the economic value of the resource to policy makers. The marginal productivity approach ensures that the marginal value of water is equal to the price of water. This method facilitates the estimation or computation of sectoral price and output elasticities and marginal values in water markets have distorted prices. It applies the duality approach which computes output elasticities directly from the estimated functions, and uses the estimated output elasticity to compute the marginal value, hence, the price elasticity of demand for water by the different sectors (Wang and Lall, 2002). Therefore the model is called the two-stage model. This approach is used because of the available data reports values of inputs and outputs, and not their prices. The method can be intuitively used to extrapolate the marginal value of water for the different sectors, which is then used as a proxy for water price in the different production sectors in the absence of global water markets. The data used for the global inter-sectoral water demand analysis is extracted from the Global Trade Analysis Project (GTAP) 2001 and UNIDO data sets. To validate the global model, the same method is used to estimate inter-sectoral water demand functions in South Africa. In this country-specific study, the marginal productivity approach is preferred to other approaches because water prices are currently distorted in the country, due to the extensive government intervention in the allocation and other policy implementation processes in order to protect the rights of the historically disadvantaged individuals. The study assumes constant price and output elasticities. This assumption is used to estimate the provincial inter-sectoral marginal values of water. The results obtained are used to compare and analyze cross-regional difference in inter-sectoral marginal values of water. The marginal productivity approach is discussed in details in chapter three.

To investigate the policy relevance of the computed or estimated marginal values, there is the need to ascertain the policy option for which the estimated figures are more appropriate: either for inter-sectoral water pricing policy or inter-sectoral water reallocation. To gauge the policy viability of the estimated inter-sectoral marginal values the study updates the already existing social accounting matrix of South Africa and uses this updated SAM to compute the coefficient and multiplier matrices, which are used to analyze the economy-wide impact of reallocating water among the production sectors on the basis the marginal value of water in each of these sectors in South Africa. The SAM multiplier analysis approach is used because the model is capable of explaining inter-sectoral linkages. Therefore, it can explain how changes in water allocation can impact sectoral production and value added on one hand, and how these impacts are transmitted to the institutions that own the factors of production on the other hand (Juana and Mabugu, 2005; Boughanmi *et al.*, 2002). Thus, the model accounts for both changes in output due to policy alterations and the distributional aspects of these impacts; hence, its appropriateness in assessing the economy-wide contribution of water and policy implications of investments and reallocation decisions. This method is discussed and applied in Chapter Five.