

**SHORT RUN IRRIGATION WATER DEMAND :
AN EMPIRICAL EVALUATION OF THE ROLE OF
PRICE, CROP AND TECHNOLOGY CHOICE**

Submitted by

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Abstract

Considerable interest has arisen regarding irrigation water use in, especially, arid areas where competition for this scarce but crucial commodity is likely to intensify. The immediate implication is that user sectors, of which irrigated agriculture is the largest, must ensure efficient and conservative use of scarce water resources, using it sparingly and in high value / return economic activities. Central to the desire for efficient use, in a free market, is the role that proper pricing of water (so that its scarcity value is accurately reflected) could play in limiting farmers' derived short - run irrigation water demand, crop choices, and their choice of technology for irrigation. Using a multi- product firm framework, we have here constructed and modelled four central farm decision functions: the short - run demand function for irrigation water demand; the farmer's' crop choice decision; the choice of irrigation technology; and lastly, a crop output equation. We conclude that irrigation water price does not influence short - run irrigation water demand, neither does it affect the farmer's choice of crops or technology. Our fourth equation, the crop output equation, however, demonstrates the important role water plays in irrigation agriculture. Using farm budget data from Orange Free State and Transvaal, which are collected by the Directorate of Agricultural Economics for short - term planning purposes, we conclude that the apparent inefficacy of water costs as a tool for ensuring the efficient and conservative utilisation of irrigation water is due to the relatively negligible weight water inputs have relative to the farmers' capital and operating costs. Water prices alone can not, therefore, be relied upon as an effective tool for efficient water utilisation in irrigated agriculture in the study area.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is crucial to life. The importance accorded water can be seen from the fact that it not only composes 70% of the human body, but also plays an important role in the production of the food and fibre that keeps man alive and in the industries that produce a myriad of products which are important to his sustenance. This statement, in effect, summarises the often - competing uses of water in domestic, industrial and agricultural uses, all of which uses have a bearing on the well - being of man. Perhaps the following quote best illustrates the value, competition and the differing efficiency amongst competing sectors regarding water.

"About 98% of food consumed by man is derived from cultivated crops, principally cereals that occupy about 10 per cent of the earth's land surface. The production of food and fibre consumes more water than any other - 80 per cent of man's uses. Further, water forms about 63 per cent of the dietary constituent of man's food. In industrial manufacturing, about 98 per cent of the water withdrawn is returned for reuse whereas only about 40 per cent is returned from irrigated agriculture."
(Framji, 1983)

It is perhaps the realisation of this that important word forums and treatises on water resource management have found a rooting. For example, *Agenda 21*, the policy statement on the United Nations Conference on Environment and Development (UNCED) addresses the need for integrated water resources management.

A number of reasons could be advanced to explain the seemingly sudden surge in the urgency for adoption of appropriate policies related to water resource utilisation and management. First, the recognition of the economic value of resources and the need to protect the environment for sustainable development has led to general awareness and stress on conservation and reallocation of resources, including water, with appropriate pricing policies increasingly being relied upon as a measure for limiting waste and inefficient water use.

Secondly, the failure of centralised, government irrigation water delivery systems to keep pace with expanding requirements for irrigation water facilities, against a backdrop of a less-than-optimal water pricing, coupled with pervasive subsidisation of irrigated agriculture, has led to a new emphasis on cost - sharing

and decentralisation in agricultural, sanitary and domestic water provision more than previously. Central to this concern for cost - sharing, is the need for proper pricing for irrigation water. Wastage of irrigation water, even in areas of acute water scarcity, is commonplace and examples thereof abound in the irrigation literature. Wastage often takes the form of over - application, undue losses in the delivery system and uneconomic choice of crops (UN ,1976) and is often worsened by lack of monitoring, use of improper technology and is expressly encouraged by a pricing system that does not well reflect the scarcity value of the water resource. In other words, efficiency in use of water resources is simply lacking in a majority of the world's irrigation schemes.

Thirdly, substantial doubt has been cast on the belief, all-too-common amongst policy makers, that water is 'a different good', a belief which formed the basis for price distortions where prices do not reflect the social marginal cost of its production and or delivery. Over time it has come to be realised that water is not so much 'different from other goods' so that distorting water prices do matter just as they do with any other inputs. Further more, economists working in the field of irrigated agriculture have often based their analyses in terms of 'crop water requirements' or 'demand' rather than 'farmers' demand for irrigation water, thus essentially reversing roles with agronomists. While the farmer's demand for water is a derived one -- derived from the final demand for his crops -- such analyses give the impression that the farmer has no choice over water application decisions but, rather, must simply agronomically determine what the crop's water requirements are and apply it regardless of underlying costs. This is, of course, not true. For example, (Vaux H.J., 1983) contends that a number of studies have indicated that the application of water by farmers is often in excess of the optimal application rates required to ensure that water is non - limiting in plant growth. This implies that carefully managed moisture stressing management and proper water scheduling might reduce the use of water for irrigation while having minimal impact on yields. The effect of such a strategy would be to substitute additional increments of irrigation for farmers' management and control of water use. It also implies that water savings can be achieved if the timing and quantity of irrigation applications are managed with a degree of precision not customarily observed if the farmer is sufficiently and effectively induced to do so.

Fourth, legal developments have added impetus to the need to deal with irrigation water in a free market and thus avoid distortions, especially in water scarce regions of the world. The adoption of riparian rights and the increased attention being accorded the sale of water rights, is increasingly leading to the emergence of water markets, a trend which South Africa will not be immune to indefinitely. To the extent that this phenomenon will find footing in South Africa, water will increasingly be put into use in those activities in which its value are high and a way from the 'water - is - a - different commodity' type uses, users and sectors. The evolution of property rights from the early common law's "regime of natural flow" doctrine in the pre - Industrial Revolution era, when there was relatively limited competition, and towards a "reasonable use" doctrine during the Industrial Revolution is perhaps an indication of what might be expected in terms of legal developments pertaining to water rights. Moreover, the issue of water rights must be addressed in tandem with any land reform policy process if programmes are to be balanced and lasting.

Fifth, the great strides accomplished by science over the past three decades in inventing and implementing water - saving irrigation technologies is clearly waning. Perhaps the pace with which irrigation technology improvements have been led to increased efficiency in water utilisation in irrigation agriculture might not be repeated. Whereas it took long to advance irrigation technology since the invention of river - basin - flood - irrigation basin by the Babylonians in the Euphrates and the Egyptians on the banks of the Nile, the rapid developments that have culminated in more modern and efficient irrigation techniques, such as micro-jet systems, most probably will not be repeated. What this suggests is that irrigation water resource management will rely less and less on new technological innovations and more and more on the economic tools of pricing and integrated management.

Whatever the explanation for the recent heightened interest in sustainable water resource management and the central role that proper pricing can play, it is surely true that agriculture will continue to rely on water as a key input. Water, in the form of precipitation, is correctly viewed as one of the most important factors determining the performance of the agricultural sector in any country at a given time. While precipitation is critical for arable farming, irrigation water is the single most important input in irrigated crop production. For areas with adequate

rainfall, agriculture is simply another on-site water use with no special considerations, apart from quality and quantity. Where water is scarce and rainfall generally low and the area arid, agricultural production has to rely on irrigation. Under such circumstances, virtually all irrigation water has to come from off-site sources such as rivers, dams and underground water. It is the severity of the rainfall scarcity problem that determines the combination of on-site and off-site water sources in agricultural production.

Agricultural production requires various inputs and water is but one of them. For regions that are arid, availability of irrigation water becomes the most decisive single input in agricultural production (UN., 1976). Agricultural water demand¹ is a function of several factors which includes the arable and irrigable land size, agricultural techniques, crop mix on irrigated land, substitutability of irrigated farming for dry-land farming, irrigation techniques, soil characteristics, political and economic policy, projected food and industrial crop demands, internal and world market signals for agricultural output / exports, macroeconomic policy, agricultural input price policy, legal structures controlling irrigation water, presence or absence of water markets, among others. Each of these and other factors, singly or together, determines agricultural water demand for irrigation purposes.

1.2 Summary of South African Irrigation water situation

Agriculture is the single largest consuming sector of South Africa's water resources. It is estimated that on average, 7, 877 m³ of water is applied per hectare annually to the more approximately 1,231 million hectares under irrigated agriculture." (Backeberg, 1993). The situation in South Africa with regard to irrigation water is perhaps best illustrated by Backeberg (1993). He reports that South African exploitable surface, underground and return flow volume of water is assessed at 38,666 million cubic metres in the year 2010. However, given the present state of technical knowledge, this volume of water is relatively fixed. Due to topographical and climatic factors, there is a skewed area distribution and seasonal variability of water supply. It is estimated that consumptive and non -

¹ Agricultural water demand denotes all consumptive use of water related to either crop, livestock, fish ponds and even forestry. Irrigation water demand is thus a subset of agricultural water demand and refers to actual water utilisation in irrigated crop production. (See UN, 1976)

consumptive use will increase to a level of 25 888 million cubic metres by the year 2010, with the share of irrigation water rising to 11, 885 million cubic metres. Furthermore, total desired utilisation is expected to increase above the available supplies after the year 2020. This means that solutions are urgently required to conserve and efficiently use the available water resources. Water savings, through more efficient irrigation techniques, proper pricing and integrated management will have to be adopted. Backeberg adds a dimension that helps focus attention not only on government irrigated schemes, with their subsidised rates, but also private irrigation schemes. Backeberg, (1993) notes that approximately 53 per cent of total water resources are utilised on private schemes, 25 per cent on co-operative schemes and 22 per cent on government schemes. If the quest for water savings in agriculture is to be effective, efficient and effective strategies for use by the private irrigator are required.

1.3 Dissertation focus and Presentation

This dissertation addresses short - run irrigation water demand in South African agriculture and farmers' propensity to economise on water use via their response to water prices / cost, and crop and irrigation technology choice. To make the study more focused, and the results usable in a policy setting, only two regions, the Transvaal and the Orange Free state - the two regions for which data were available - are included in the analysis. The approach adopted in this paper is largely empirical, using 1994 farm budget data from the Directorate of Agricultural Economics. The paper is organised as follows: Chapter 2 reviews the irrigation water use literature and models. Chapter 3 begins with a review of the theory of the multi-product firm; this forms the theoretical basis for our subsequent analysis, and enables us to develop the short - run water demand, crop and irrigation technology choice, and output models. The data and study area are described in Chapter 3. Empirical estimation and analysis of results is contained in Chapter 4, while Chapter 5 briefly addresses the policy implications of the results of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The role of water in promoting agriculture has increasingly attracted the attention of many researchers within the scientific community in South Africa and elsewhere. These interests and research findings have contributed to the understanding of the role of water in irrigated agriculture. Many have contributed to the development of successful irrigation management strategies, improving agricultural productivity in arid areas as well as general water policy formulation. The literature on water - irrigated agriculture relations can broadly be divided into two groups. First is the work of agronomists and other production - oriented scientists whose focus is on establishing the level of water inputs necessary to achieve maximum yield per acre. They are mainly interested in the effect of water on plant growth and yield. The second group, who are more recent entrants into the field, are economists who focus largely on water - use efficiency, returns and on pricing considerations.

This section reviews some of the literature that is related to the focus of the dissertation. Whereas it would have been more interesting if most of the literature reviewed pertained directly to the study area, there seems to be a general dearth of literature on the topic that directly discusses South Africa and that focuses on the microeconomics of water utilisation in agriculture in particular. Thus, most of the literature referred to and specifically the ones reviewed in this chapter are either drawn from, or uses data from, the western US, Australia or Israel. It is no coincidence that the US dominates much of the literature on water economics generally. This can be readily understood, given the arid nature of much of the western U.S. and the corresponding competition for, and value, of scarce water resources, coupled with the free market orientation of the US. This is, however, not a serious limitation of the present study since the reviewed literature provides methodologies and models that are relevant to the South African situation. The approach adopted in this section is to provide a detailed insight into a few of the more relevant models. Eleven such models are presented in the remaining sections of this chapter. Even though these models, and others, could be extended to analyse many of the decisions farmers must make with regard to their variable inputs, the focus in these studies on water as a variable makes these models particularly relevant to the present study.

2.2 Multicrop Inputs Allocation Model

Moore, Gollehon and Carey (1992) have evaluated water prices as a determinant of producer decisions for four western regions of the USA. Their work attempts to analyse the importance of water prices in the choice of crops and the total acreage of land under irrigated agriculture using a multicrop model of irrigated agricultural production. They analyse farm firms in the western United States in which field crops are produced as a multi-output farm enterprise faced with a fixed allocable land constraint which forms 'jointness - in - production.' In this context, the farmer has four decisions to make: first he decides which crops to grow from the number of crops common to that area. This is a discrete choice which can be estimated independently using dummy variables. The second decision is how much of the total land surface is to be allocated to the crops chosen after the first decision is made, which decision may conveniently be summarised as 'land use choice.' With the crop choice and land utilisation decisions made, the farmer / irrigator makes a 'water supply decision' ('estimates' his water supply function) and, finally, a 'crop level water supply decision' that is dependent upon and influenced by among other things his land allocation decision. The crop choice decision may be depicted as:

$$d_i = f_i(p, r, b, N; x) \quad i = 1, \dots, m. \quad (1)$$

where

d_i is a discrete choice variable equal to 1 if crop i is grown and zero otherwise.

p is a vector of crop prices, with p_i equal to the price of crop i , $i=1, \dots, m$;

r is a vector of variable input prices except for water price;

b is the irrigation water price;

N is the land constraint;

n_j is the land allocation to crop i ; and,

x is a vector of other variables exogenous to the farm or the crop²

However, the farmer must decide not only what crops to grow, as seen above, but also how much land to make available for each crop. In other words, the farmer has the problem of optimally allocating land amongst all the crops that he could possibly cultivate, subject to a land constraint. The land allocation function is thus a constrained optimisation problem of the form:

² Agricultural production, unlike that of manufacturing, is prone to the vagaries of weather, soil quality, irrigation technology, farm management, disease and the like, all of which are captured by this variable.

$$\begin{aligned} & \Pi(p, r, b, N; x)^3 \\ & = \max_{n_1 \dots n_m} \left\{ \sum_{j=1}^m \pi_j(p, r, b, N; x) : \sum_{i=1}^m n_i = N \right\} \end{aligned} \quad (2)$$

Moore *et al* (1992) have shown that, given the normalised quadratic form for the profit functions the optimal land allocation function $n_i^*(p, r, b, N; x)$ that solves (2) is linear in its parameters and thus the estimable form of the land allocation function is of the specification below:

$$n_i^* = \alpha^i + \sum_{j=1}^m \beta_j^i p_j + \sum_{z=1}^z \gamma_z^i r_z + \delta^i b + \psi^i N + \sum_{s=1}^l \eta_s^i x_s \quad i = 1, \dots, m. \quad (3)$$

where $\alpha, \beta, \gamma, \psi$ are parameter estimates and the other notations are as described previously. The multicrop profit function as specified in (2) may be written as:

$$\begin{aligned} & \Pi(p, r, b, N; x) \\ & = \sum_{i=1}^m \pi_i(p, r, b, n_i^*(p, r, b, N; x); x). \end{aligned} \quad (4)$$

The crop supply and water demand functions are derived by applying Hotelling's lemma to (4). This yields the following supply functions⁴:

$$\begin{aligned} y_i(p, r, b, N; x) &= \frac{\partial \Pi(p, r, b, N; x)}{\partial p_i} = \frac{\partial \pi_i(p_i, r, b, n_i^*; x)}{\partial p_i} \\ &= y_i(p, r, b, n_i^*; x) \quad i = 1, \dots, m. \end{aligned} \quad (5)$$

Applying Hotelling's lemma to the firm's crop-specific profit function gives the short-run water demand as formulated below:

$$-\frac{\partial \pi_i(p, r, b, n_i^*; x)}{\partial p_i} = w_i(p_i, r, b, n_i^*; x), \quad i = 1, \dots, m \quad (6)$$

³ This is the firm's multi-output profit function

⁴ The authors note that two forms of supply functions are possible from the Hotelling's lemma application above but have opted to use (5) in their analysis since (5), unlike the alternative, treats crop prices explicitly.

By normalising the quadratic form of the profit function, $\pi_i(p_i, r, b, n_i^*; x)$, both the crop allocation function $[y_i(p, r, b, N; x)]$ and the water demand functions $[w_i(p_i, r, b, n_i^*; x)]$ take a form that is not only estimable, but also linear in the exogenous variables. The two estimable equations take the following forms:

$$y_i = \theta^i + \sum_{j=1}^m k_j^i p_j + \sum_{v=1}^z \xi_v^i r_v + t^i b + p^i N + \sum_{s=1}^t v_s^i x_s \quad i=1, \dots, m \quad (7)$$

and

$$w_i = \mu^i + v^i p_i + \sum_{v=1}^z \omega_v^i r_v + \psi^i b + \vartheta^i n_i + \sum_{s=1}^t t_s^i x_s \quad i=1, \dots, m \quad (8)$$

Regression equations are estimated using primary, cross section data from the 1984 and 1988 Farm and Irrigation Ranch Survey (FRIS), a survey of operators of irrigation farms by the US Department of Commerce. American irrigators use both ground and surface water, with ground water assumed to be the marginal source when both sources are used. Where the former source is used, an engineering formula that calculates ground water pumping lift is used to compute the marginal pumping costs in dollars per hectare foot unit. This is then used as the proxy for price with an additional assumption that government ground water institutions / sellers of water, and their agencies, do not impose binding constraints for water on irrigators.

The variables used in estimating the four equations, correspond to the four choices already outlined and include the number of farms, farm area, water applied per acre foot, water price (normalised), pumping depth, pumping pressure, cooling degree days, growing season precipitation, normalised wage rates, bulk gasoline prices, count of farms in which each of the crops in the region was cultivated, mean water applied and mean output per crop in units per acre-feet per farm. Equations (3) and (7), corresponding to the land allocation and supply functions are estimated using the *Tobit* procedure while the water demand equation is estimated using the

Heckman model.⁵ The crop choice model, being a qualitative variable analysis, logically requires that a *Probit* model be used.

Their empirical findings indicated that the water price coefficient was significant at the extensive margin, but statistically insignificant with regard to short - run, crop level, water demand. This, most importantly, implies that once farmers in the region have made their land allocation decisions, water price does not feature effectively in their decision about short - run water use. In other words, the price elasticity of demand for irrigation water is low. This important finding supports those of Just *et al* (1990b), Alouze C.M (1991), Antle and Hatchett (1986), and Zilberman *et al* (1990) and Clayton *et al* (1989). Water price thus 'affects' only the firm's profit function, and its crop-choice, irrigation technology and land allocation decisions. The conclusion from their research is that once decisions regarding crop choice and land allocation are made at the beginning of the planting season, water price is largely irrelevant. They also conclude that the farm level demand for water is highly price inelastic for every region.

2.3 Just *et al*'s Behavioural input allocation model

Just *et al* (1990) use two approaches for allocating variable input allocations among production activities (multicrop decisions.) One approach relies on behavioural rules for input allocations and notes that farmers follow some acceptable 'rule of thumb' in deciding on input allocation decisions. The second approach is based on profit maximisation. The model implies that input use responds instantaneously to changes in input and output prices. The exact structures of the models are explained, and their empirical findings are reported below in this section and in section 2.4.

The motivation of the authors for designing the model was to develop acceptable techniques for examining the input allocation issue in a multi - output framework. In this model, farmers are portrayed as behaving as if their production functions followed constant returns to scale with fixed input/land ratios. The ratios employed

⁵ This is an econometric, qualitative choice model akin to the *Tobit* model but which is more suited for discriminant analysis. See Madalla G.S. for an in-depth review of the procedure.

are based on regional averages modified for season and for farm specific - conditions. The behavioural input allocation model may be formally developed and expressed as follows;

$$X_{jit} = \sum_{k=1}^k x_{kjit} \quad (9)$$

where

i = number of farmers ($i=1,2, \dots, I$);

k = crops ($k=1,2,\dots,K$);

j = inputs ($j=1,2,\dots,J$);

t = years ($t=1,2,\dots,T$);

X_{jit} = the aggregate quantity of input j used by farmer i at time t .; and,

X_{kjit} = is the unobserved quantity of input j allocated by farmer i at time t to crop k .

Since the model assumes farmer's production functions exhibit constant returns to scale, the individual farmer's decisions consist of the choice of the particular variable input / land ratios to adopt and how much land to allocate to each crop. It follows that since $X_{kjit} = X_{jit} / L_{kit}$ is the quantity of input j per unit of land used at time t by farmer i in producing crop k ; thus:

$$x_{kjit}^* = \alpha_{kj} + \beta_{ji} + \gamma_{ji} \quad (10)$$

where

α_{kj} is the average regional use of variable input j per unit of land in the production of k throughout the period of analysis;

β_{ji} are deviations from for use of j at time t ; and,

γ_{ji} , are deviations of i from the regional average for use of input j .

From (9) and (10) the components of x_{kjit}^* which may be estimated are:

$$x_{jit} = \sum_{k=1}^k (\alpha_{kj} + \beta_{ji} + \gamma_{jt}) L_{kit} + \varepsilon_{jit} \quad (11)$$

where

ε_{jit} is a random deviation associated with farmer i and input j at time t and is normally and independently distributed.

The empirical estimation of (11) involves regressing each variable input on the area of the farm allocated to each of the crops. The parameter estimates $\hat{\alpha}_{kj} + \hat{\beta}_{ij} + \hat{\gamma}_{jt}$ give a per acre estimate of variable input j to crop k by farmer i at time t . The product of this estimate and the total land area allocated to a particular crop is the behavioural estimate of the allocation of input j to crop k by farmer i at time t . This can be formally depicted as:

$$\hat{X}_{kjit}^b = (\hat{\alpha}_{kj} + \hat{\beta}_{ij} + \hat{\gamma}_{jt})L_{kit} \quad (12)$$

where the subscript b denotes the behavioural model. The model was empirically applied and tested with Israeli data to determine the effect of two inputs: water (the most scarce local input and the major constraint to development in the region) and 'other' inputs (derived as aggregated normalised expenses on other inputs) Just *et al* (1990.) Ordinary least squares parameter estimates of (12) were reported for five crops (outputs): bell peppers, tomatoes, onions, melons and egg plant. The important conclusion which is relevant to the focus of this dissertation is that whereas water use per area did not seem to differ between the regions, all farmers responded to water price stimuli by using less water over the period reviewed. The model thus confirmed the importance of prices as a policy tool in water conservation and utilisation among farmers. This is a significantly different result from their own model (Just *et al* (1990b) reviewed in section 2.4, in which water prices are portrayed as largely irrelevant in the farmers' input decision. The conclusion also contrasts those of Carrey *et al* (1992), Alouze C.M (1991), Antle and Hatchett (1986), Zilberman *et al* (1990) and Clayton *et al* (1989) but concurs with the conclusions of Howitt *et al* (1980), Burt *et al* (1990) and Kim *et al* (1989.)

2.4 The Profit maximisation Approach to Allocation of inputs

Just *et al* (1990b) have an alternative model that they have used to empirically estimate the allocation of inputs (and specifically, water) by farmers. This is what they call the "profit maximisation approach" to allocation of inputs or, simply, the 'profit maximisation model.' In this model, farmers are assumed to be driven by

profit maximisation objectives. As such, the short - run profit maximisation problem of the farm firm may be formally expressed as:

$$\begin{aligned} \max_{x_{kjit}} \quad & \sum_{k=1}^k P_{kt} Q_{kit} - \sum_{j=1}^j W_{jt} X_{jit}, \\ \text{s. t. } \quad & Q_{kit} = f_{kit} (X_{k1it}, X_{k2it}, \dots, X_{kjit}, L_{kit}, \\ & k = 1, 2, \dots, k \\ & X_{kjit} = \sum_{k=1}^k X_{kjit} \end{aligned} \quad (13)$$

where

- Q_{kit} is output of k by farmer i at time t .
- P_{kt} is the price of output k at time t ;
- W_{jt} is the price of input j (water) at time t ; and,
- f_{kt} is i 's production function for output k at time t .
- X_{kji} is the unobserved quantity of input j allocated by i to crop k .

The first order condition (F.O.C.) that determines the variable input is

$$j_t = P_{kt} \frac{\partial f_{kit}}{\partial X_{kjit}}, \quad k = 1, \dots, K; j = 1, \dots, J \quad (14)$$

Converting the F.O.C. expression (14) into elasticities gives:

$$X_{kjit} = P_{kt} \frac{R_{kit}}{W_{jt}} e_{kjit} \quad (15)$$

where $e_{kjit} = (\partial f_{kit} / \partial x_{kjit})(x_{kjit} / Q_{kit})$ is a non-constant elasticity (at its optimal solution) of variable input j in the production of k by farmer i at time t . Assuming that the elasticities vary amongst i, k, t and can be decomposed as:

$$e_{kjit} = a_{kj} + b_{ji} + c_{jt} \quad (16)$$

where

a_{kj} is a crop effect;
 b_{ji} the farm effect; and,
 c_{jt} is the time (or technology) effect.

Then, one can merge (16) into (15) and aggregate over crops, yielding an estimable form:

$$X_{jit} = \sum_{k=1}^K (a_{kj} + b_{ji} + c_{jt}) \frac{R_{kit}}{W_{jt}} + \xi_{jit}, \quad (17)$$

$$\begin{aligned} j &= 1, \dots, J; \\ i &= 1, \dots, I; \\ t &= 1, \dots, T; \end{aligned}$$

where

ξ_{jit} is an iid random deviation associated with farmer i , variable input j and crop k at time t .

The model then uses the parameters estimated in the above equation (17) to translate revenue data into profit - maximising estimates of variable input allocation among the different crops. This is accomplished by the equation below:

$$\hat{X}_{jit}^P = \hat{a}_{kj} + \hat{b}_{ji} + \hat{c}_{jt} \frac{R_{kit}}{W_{jt}} \quad (18)$$

where

\hat{a}_{kj} is crop effect parameter estimate of (17)

\hat{b}_{ji} is a farm effect parameter estimate of (17)

\hat{c}_{jt} is the time (or technology effect) parameter estimate of (17)

The parameter estimates of equation (17) on the Israeli data, using OLS, led to two conclusions: first, while the 'time' and 'crop effects', as previously defined, are significant, the 'farmer effects' are not significantly different from zero; and secondly and more importantly, the elasticity of the water variable was found to be very low amongst crops ranging from 0.011 for bell peppers to 0.046 for melons. These low elasticities could be interpreted as implying that water prices had minimal influence on the farmers' water use decision. This finding contrasts their own model reviewed in section 2.3 Just *et al* (1990a), as it does those of Howitt *et*

al (1980), Burt *et al* (1990) and Kim *et al* (1989.) This finding is, however, similar to those arrived at by Carrey *et al* (1992), Alouze C.M (1991), Antle and Hatchett (1986), Zilberman *et al* (1990) and Clayton *et al* (1989.)

2.5 Antle and Hatchett's Dynamic Input Decision model

Antle J.M and Hatchett S. A. (1986) have used a dynamic model which employs sequential decision - making on irrigation water use by farmers. They adopt the plausible argument that intermediate output decisions may be endogenous to final output and that intermediate inputs are likely to be correlated with one another and with variables such as acreage. This implies that a single equation estimation of input use (such as the last three models reviewed) is inherently biased and thus econometrically undesirable. In this dynamic approach, crop production and decisions regarding input usage are regarded as constituting a dynamic optimisation problem. The model assumes a three - stage decision problem.⁶ With this assumption, the sequential decisions model is formally specified as:

$$\text{Max}_{(x_1, x_2, x_3)} E[\pi : \Omega] = E[py_3 : \Omega] - \sum_{t=1}^3 E[r_t x_t : \Omega] - rz, \quad (19)$$

where

π = profit;

p = output price;

y_3 = final output;

r_t = price of input x ;

r = price of output z ; and,

Ω = information on which input decision is based.

Further, technology is represented by the following equations, each representing production functions at each stage:

⁶ Dynamic programming models normally assume multi-stage decision points where decisions are optimised. The present model assumes three such decision stages.

$$y_1 = f_1(x_1, z_1, \epsilon_1) \quad \text{and} \quad (20)$$

$$y_t = f_t(x_t, y_{t-1}, \epsilon_t) \quad \text{for } t = (1, 2, 3.) \quad (21)$$

where

e_t is a random component⁷

y_{t-1} is the previous state of the crop⁸ and which embodies the impact of all previous inputs applied

Given the embodiment of the previous input allocation decisions (water applied in stages 1 and 2) in the later stage (in this case stage 3 because $t = 1, 2, 3.$), the composite production function may be written as;

$$y_3 = F(x_1, x_2, x_3, z, \epsilon_1 \epsilon_2 \epsilon_3) \quad (22)$$

At stage 1, a variable input x_1 and a fixed input z (land) are chosen, with the choice dependent on the farmer's price expectations, future crop states and decision rules for future optimal levels of subsequent outputs in the next two stages denoted as x^*_2 and x^*_3 and which themselves are:

$$x^*_2 = x^*_2(r_2, y_1, w_2) \quad (23)$$

$$x^*_3 = x^*_3(r_3, y_2, w_3) \quad (24)$$

where w_t is a parameter that reflects the farmer's subjective evaluation, at time t , of future output and prices. The farmer's decision at stage 1 is to choose levels of x_1 and z to solve:

$$\text{Max}_{x_1} E\{[py_3 - r_1x_1 - rz - r_2x^*_2 - r_3x^*_3]\}; \omega_1\} \quad (25)$$

subject to (20) and (21)

⁷ In agricultural production, the random error component could be explained by factors such as weather, diseases, etc.

⁸ For example, if the farmer is currently at the beginning of last stage, 3, since $t=1,2,3.$, the farmer looks at the state of the crops y_2 , at the end of last decision stage, 2, before making a final decision about how much water to apply in this final stage. Y_1 and y_3 are defined in a similar manner.

At the end of stage 1, the farmer, having applied x_1 to z , now knows y_1 and ε_1 . Technically speaking, it is not possible for the farmer to literally observe ε_1 . Neither is y_1 , the intermediate crop stage and end of stage 1, directly observable. It, however, does contain information about stage 1 output which the farmer uses as a base in deciding input usage at stage 2. Based on this information, the farmer is ready for stage 2.

At the beginning of stage 2, the farmer observes y_1 and makes his decision about x_2 based not only on his observation of y_1 but also his expectation of x_3^* . Thus, he confronts an optimisation problem which may be denoted as:

$$\text{Max}_{x_2} E\{[py_3 - r_1x_1^\circ - rz^\circ - r_2x_2 - r_3x_3^*]; \omega_2\} \quad (26)$$

With this information, the farmer is set for stage 3. At the start of the third stage, the farmer observes the crop state, y_2 and chooses the final level of input, x_3 , to solve his optimisation problem which is:

$$\text{Max}_{x_3} E\{[py_3 - r_1x_1^\circ - rz^\circ - r_2x_2^\circ - r_3x_3]; \omega_3\} \quad (27)$$

subject to (19) and (20)

The intuitive appeal of this dynamic model results from the fact that it allows for the effect of input use at stage 1, through its influence on output y_1 (crop state at end of stage 1) to influence the input use at stage 2, with the sequence ending at stage 3. Obviously, the number of stages would vary from one crop to the next as well as on farm managerial decisions.

To empirically apply the model, Antle and Hatchett (1986) estimated two equations using data for irrigated wheat production in the Imperial Valley of California. Data used in the analysis included, yield, variety, planting date, acreage and field locations, date and amount of water applied, an index of soil quality, a variable capturing evaporation and a set of management dummy variables to account for differences across farms. Their results give different water demand elasticities for the stages used in the analysis. They conclude that the elasticity of demand for water was high in stage 1 but low in stage 3. In terms of this model, therefore, the efficacy of prices as a policy tool for the analysis of farmer's response

or as a conservation tool depends on the type of crop and the differing water requirement across the various growth stages of the crops in question.

2.6 The inter - temporal irrigation water demand model

The inter - temporal irrigation water demand model formulated by C.M. Alouze (1991) seeks to provide a theoretical framework and empirical test of farmers' response to water scarcity signals between seasons and years. The logical underpinning of the model is based on the observation that water is most valuable during drought (when it is scarce) and that rationality dictates that farmers not only save water for use during such drought periods (an inter - temporal allocation) but also choose to grow only valuable crops (the crop choice response to the water scarcity signal.) The model thus addresses one of the focal points of this study, viz., do water scarcity signals (price or otherwise) determine or shape farmers' crop choice decisions? The issue of land / acreage allocation per crop is, however , not explicitly addressed by the model.

Alouze postulates that the demand for water in irrigated agriculture is a derived demand. As such, the quantity required by farmers depends on, amongst other things, the value of the crop it produced, as measured by product (crop) price, the nature of technology employed in the production of the output, the prices of competing and complementary inputs, and the soil moisture content at the beginning of the irrigation season. The importance of inter-temporal water allocation in irrigation water demand management is based on the fact that hydrological drought and agricultural drought need not coincide.⁹ It is this distinction that makes inter - temporal transfers (and with them temporal pricing and farmer response) tenable and dam construction necessary. Although the model uses a single crop irrigation farm firm's response to water scarcity signals by using a two period inter-temporal allocation decision framework, the methodology can be used in a multi-crop context. The model's single crop inter-temporal production function may be written as:

$$y = q(w,x) \tag{28}$$

⁹ Hydrological drought refers to periods of below average water levels in reservoirs and streams and low levels of soil moisture in catchments while agricultural drought is characterised by rainfall and soil moisture deficiencies.

where

- y is the output in each period ;
- w is soil moisture (it is a random variable in the second period W and a known variable (w) in the first period); and ,
- x is the level of applied water (x_1 for period 1 and x_2 for period 2.)

The farmer's decision is the choice of levels of x_1 and s_1 (defined below) so as to maximise:

$$E[\pi] = p.q(w, x_1) + bE[p.q(w, x_2)] - bP_w(s_1 + E[S]) - F(1+b) \quad (29)$$

subject to:

$$\begin{aligned} x_1 - s_1 &\leq x_0(1+1/a) \\ s_1 &\leq s \\ x_1 &\geq 0 \\ s_1 &\geq 0 \end{aligned}$$

where

- x_0 is the farmer's water right (allocation) for each period;
- F is the fixed cost paid for x_0 for each period;
- S is the sales water purchasable by the farmer in each period;
- P_w is the price of S ;
- s is the sales water available in first period and is known but random, S , in the second period;
- p is output price (known in first period) but random $,P$, in the second;
- a is a storage loss discount factor in storing water from period 1 to 2; and,
- b is a discount rate applicable for second period's revenues and cost.

Expressing (29) as a Lagrangean function results in (30)

$$L = p.q(w, x_1) + bE[p.q(w, x_2)] - bP_w(s_1 + E[S]) - F(1+b) + y_1(x_0(1+1/a) + s_1 - x_1) + y_2(s - s_1) \quad (30)$$

Assuming, as the model does, that the price of sales water (P_w) is low relative to its value in production, and further that all water offered for sale is purchased ($s_1 = s$), then the first order condition with respect to output becomes:

$$P.\partial q/\partial x_1 = abE[p.\partial/\partial x_2] \quad (31)$$

where

ab is the product of the discount rate due to time preference (b) and the discount factor due to storage loss (a .)

Equation (31) can be interpreted to mean that the value of water applied in Season 1 is chosen so as to maximise the marginal product of water applied in the first season, which should be equal to the discounted expected value of the marginal product of water applied in the second season.

The model was applied in the context of a farm in the state of Victoria, Australia, during the 1982 - 1983 period. The important conclusion, given the assumptions of the model, was that there is a zero probability that the farmer's annual allocation of water (both $x_0 + s$) will correspond to the optimal water requirement of period 1 when climatic variability, economic factors (water input and agricultural output prices) and inter - temporal decisions are taken into account. The reason for this conclusion is that the cost of water is so low relative to its value in production that farmers largely ignore prices in making water application decisions. This implies a low price elasticity of demand for water. This conclusion supports those of Carrey *et al* (1992), Just *et al* (1990b), Caswell *et al* (1990), Antle and Hatchett (1986), and Clayton *et al* (1989.) It contrasts the findings contained in the studies by Just *et al* (1990a), Howitt *et al* (1980), Burt *et al* (1990) and Kim *et al* (1989.)

2.7 Caswell *et al*'s (1990) Conceptual Farm Level Model

Caswell M, Litchenberg E. and Zilberman D (1990) address the issue of cost - effective alternatives to addressing the resource scarcity, and externality problem in what they have called a 'conceptual farm level model.' In particular, and of special relevance to this dissertation, they examine the impact of increased water prices and the adoption of water - conserving irrigation technologies on water use efficiency, yields and profitability, among other things. Cotton production in the Western San Joaquin Valley in California is investigated. Their per acre production function is given as:

$$q = f(e) \quad (32)$$

where

q is output per acre ; and
 e is 'effective water' ¹⁰.

Likewise the irrigation cost function is given as:

$$C_i(\alpha) = I_i + a (V_i + w) \quad (33)$$

where

I is fixed cost per acre ;
 w is price of water per acre foot ;
 i denotes technology used ; and
 V_i is land quality parameter.

Given the production and cost functions above, the farmer's optimisation problem can be stated as:

$$\Pi_i(\alpha) = \max_{a_i} \{ pf(h_i(\alpha).a) - I_i - a(v_i + w) - x.a.g_i(\alpha) \}^{11} \quad (34)$$

where

P is the price of the crop ;
 x is an anti- pollution tax ;¹²
 $\Pi_i(\alpha)$ is quasi rent per acre associated with technology i ; and
 $x.a.g_i(\alpha)$ is the internalised cost of pollution.

The optimal water application level ($a_i(\alpha)$, which is itself a function of land quality and the technology used) is determined by solving:

¹⁰ 'Effective water' is defined as the amount of water actually taken up by the crop's root system. It is seldom the case that 'applied water' is the same as 'effective water' even though improved, water conserving technologies such as drip irrigation tend to reduce, not eliminate, the disparity between the two.

¹¹ The last term of this equation, i.e. internalised cost of pollution, even though an important consideration in water resource utilisation has been dropped from subsequent analysis since it neither addresses the focus of the dissertation nor is does dropping it compromise the structural specification of the model.

¹² The model introduces an anti- pollution tax as a means of dealing with externalities associated with water use in irrigated agriculture. Even though it is not directly relevant to the focus of the dissertation, their treatment of water use response to prices is especially relevant.

$$Pf(h_i(\alpha).a_i(\alpha)).h_i(\alpha) = v_i + w + xg_i(\alpha) \quad (35)$$

Denoting the cost of 'applied water' as $u_i^a(\alpha)$ and that of 'effective water' as $u_i^e(\alpha)$, both water prices may be written as :

$$\begin{aligned} u_i^a(\alpha) &= w + v_i + xg_i(\alpha) \quad \text{and} \\ u_i^e(\alpha) &= u_i^a(\alpha) / h_i(\alpha) \end{aligned} \quad (36)$$

This implies that (35) can be re-written simply as:

$$Pf(e_i) = u_i^e, \quad (37)$$

which is the marginal efficiency condition for resource allocation.

The estimated model is formulated as

$$\varphi(M, S, P) = \prod_{n=1}^N \prod_{j=1}^J M_n! (M_n S_{nj})!^{-1} P_{nj}^{M_n S_{nj}} \quad (38)$$

where

n denotes the region for $n = 1, \dots, N$;

M_n denotes a sample size of plots in sub - region n ;

S_{nj} denotes the number of farms adopting water - conserving technologies;

$M_n S_{nj}$ is the number of plots using technology j in sub - region n ;

M is a 1 by N vector of M_n ; and

P is a N by J matrix of P_{nj} .

The log-likelihood function for estimating equation (38) becomes

$$\log \dot{\ell}(M, S, P) = \sum_{n=1}^N M_n \sum_{j=1}^J S_{nj} \log P_{nj} \quad (39)$$

Caswell *et al* (1990) have demonstrated that when the data from the sample is of equal size, i.e. S_{nj} and P observations are equal to M_n' , the log-likelihood function (39) simplifies to a form (40) that is estimable:

$$\log \dot{\ell}(S, P) = \sum_{n=1}^N \sum_{j=1}^J S_{nj} \log P_{nj} \quad (40)$$

Water cost, on the other hand, is given as the product of water use per acre and the cost of water (as measured in dollars per acre foot unit). More formally:

$$W_{nj} = U_{nj} \cdot Z_{nj} \quad (41)$$

where

U_{nj} water use per acre ; and

Z_{nj} cost of water per acre foot¹³.

It is important to note that, in a sense, California presents a classic case of a water scarce region in which competition for, and value of water in, production has become increasingly high. That is, agriculture in California is susceptible to water supply shortages much as are several regions of South Africa. The extent of the adoption of water - conserving technologies and high value tree crops is a logical response by profit maximising farmers to water scarcity signals.

The study used primary data collected by farm advisors from six counties of the San Joaquin Valley. Data was collected for five perennial crops: grapes, deciduous fruits (apricots, nectarines and peaches), walnuts, pistachios and almonds in each of the regions. The model was estimated using the maximum likelihood procedure, i.e. it estimated the log-likelihood, or probability, of adopting water - conserving technologies, as opposed to traditional (non-water efficient) techniques, given crop choice and farm location (i.e. where, amongst the three counties of the San Joaquin Valley the farm is situated). Specifically, the model gives particular attention to the effect of crops and location on the odds that a particular technology will be adopted. Other variables included in the model are the water-cost differential between the traditional and modern water - conserving technologies, and a dummy variable which captures the use of ground water versus surface water.

The authors arrived at four major conclusions. First, the results rejected the hypothesis that the elasticity of the odds of adoption of water - conserving techniques with respect to its water-cost saving (calculated to be .028) is equal to zero. Secondly, the results indicated clearly that farmers who use underground water (the more expensive source option) are more likely to adopt water - saving techniques than are their counterparts who use surface water. This is an important finding given that surface water, which is often in the domain of public authorities, is often sold at less than its market value in contrast to underground water which

¹³ The cost of water used by a sub - region is the sum of the cost of obtaining the water (the pumping cost for ground water or the price paid to a water district for surface water) and the cost of pressurisation.

has to be pumped at great cost and which price, therefore, closely approximates its marginal value. Thirdly, they failed to reject the hypothesis that there are no regional differences in the odds of adoption. This suggests that farmers rationally adopted water - conserving technologies across each of the sub-regions. Their fourth finding, which is also relevant to this paper, concerns the differences among crops (analogous to the 'crop - choice decision' issue) in the acceptability of water conservation technologies. Their results demonstrated that growers of relatively less valuable crops, almonds and pistachios, have a higher likelihood of adopting water - conserving technologies than those farmers who grew the other, more valuable crops in the sample. This finding concurs with those of Howitt *et al* (1980), Kim *et al* (1989), and Clayton *et al* (1989).

2.8 Howitt *et al*'s Quadratic programming model

In their review of the analyses of various derived demand functions for irrigation water as estimated for California by several authors, Howitt *et al* (1980) show that most derived - demand and linear programming models used to estimate derived irrigation water demand models underestimate elasticities. To demonstrate their contention, and as an alternative estimation procedure, they develop and empirically apply a quadratic programming model for the derived demand for irrigation water, which they estimate and compare with linear programming models. The quadratic programming problem is specified as

$$\begin{aligned} \max & [d - \frac{1}{2} Dx]'x & (42) \\ \text{s.t} & Ax \leq b \quad x \geq 0 \end{aligned}$$

where

- A is an nm vector of coefficients from linear production functions relating each of the m input factors needed to produce a unit of output;
- d contains elements of the demand intercepts;
- D is an n by n matrix of own price slope coefficients; and
- x denote outputs

The optimal basic solution is then derived as

$$x^* = B_Q^{-1}b \quad (43)$$

where

B_Q is the subset of A which is the basis matrix for the quadratic solution.

Formulating (43) in terms of a Lagrangean and applying Kuhn - Tucker conditions, the constraint for the dual quadratic problem is derived as:

$$\lambda'A + Dx \geq d \quad (44)$$

where

λ' is interpreted as the value of the marginal products of the constraining resources¹⁴

Assuming that the farmers are profit maximisers, the quadratic dual values (a vector of marginal revenue products) can be written as:

$$\lambda' = (d* - D*x*) B_Q^{-1} \quad (45)$$

Substituting (43) into (45) and differentiating with respect to b yields;

$$\frac{d\lambda}{db} = -B_Q^{-1} D_* B_Q^{-1} \quad (46)$$

The above equation forms the basis of the model. It indicates that within any given set of crops, the farmer's valuation of water resources "changes in response to changes in the quantities available and that they will do so in an expected direction." Howitt *et al* (1980).

The model was applied to annual crops in California. It is, however, assumed that for short - run optimal agricultural water allocation decisions, the capitalised loss to the individual grower who prefers tree and bush crops (on the grounds that they are relatively more drought resistant), exceeds the annual opportunity cost of water used for the alternative, i.e. field crops. Fourteen regions were chosen, based on homogeneity of climate, soil types, water costs and availability. Alternative farm

¹⁴ λ' is itself defined as $\lambda' = c_*' B_I$ where c_* is defined as an m by 1 partition of the output price vector c associated with the basis of activities x_* .

activities (crops) are considered in the analysis where water, land and energy costs, among others, are the constraints the farmer faces. It is clear that the model is a short - run irrigation water demand model for California's agriculture, and it specifically attempts to accounts for shifts in production mix, surface / ground water ratios, and for price effects relating to 'California's volatile but valuable vegetable crops' Howitt *et al* (1980). This corresponds to the crop choice and the water supply decisions that this paper addresses.

Two striking conclusions are made by the authors. First, they conclude that the demand for irrigation water in the study area is significantly elastic, especially in the \$25-35 per acre - foot price range. This contrasts with the findings by Carrey *et al* (1992), Just *et al* (1990b), Alouze C.M (1991), Antle and Hatchett (1986), Caswell *et al* (1990) and Clayton *et al* (1989) but concurs with the results of studies by Just *et al* (1990a), Burt *et al* (1990) and Kim *et al* (1989). Secondly, they conclude that, for a given uniform irrigation technology, farmers respond to water scarcity signals implicit in high water costs in the study area, by choosing more valuable 'water economising' crops. In their own words, "it can be seen that the value of the marginal product (VMP) or marginal revenue product (MRP), respectively, will be equated to the aggregate water cost." Howitt *et al* (1980, page 627). This finding concurs with those of Caswell *et al* (1990), Clayton *et al* (1989) and Kim *et al* (1989).

2.9 Burt *et al*'s Sequential decisions irrigation model

Burt's study deviates slightly from the others reviewed in that it analyses irrigation in a subhumid climate. It thus offers a contrast to the predominantly dry - region - centred studies and underscores the fact that irrigation agriculture is not exclusive to arid regions. Farmers in such areas may be driven by *other* considerations in making decisions regarding investments in irrigation, water use, water conservation, irrigation technology type, crop choice, land allocation and related. As the authors note, "irrigation development is likely to be dominated by individual farm or relatively small community developments as contrasted to the large reclamation projects characteristic of arid regions." Burt *et al* (1990, P. 16). The need for irrigation, however, is necessitated by the fact that although precipitation is fairly high in such climates, its variability presents a grave risk to farmers. Temporal considerations are thus important.

The formal statement of the model begins with the premise that farmers wish to maximise their returns to investments in irrigation and will therefore strive to allocate their limited funds to the various investment categories that comprise a working irrigation system. These components are:

- x = water storage capacity;
- y = distribution capacity;
- z = acres developed for irrigation;
- $N_t(x, y, z)$ = expected value measure; and
- $I_t(x, y, z)$ = investment cost.

The problem that the farmer faces is well summarised by the following statement :

" Thus for a given developed acreage and at a particular point in the irrigation season, either water supply as determined by x or distribution capacity, y , may limit the total amount of irrigation water applied. Distribution capacity will be a limitation predictable with certainty but, but for a given supply constraint, will be a random variable when looking ahead at time t ." Burt *et al* (1990, P. 34).

The study thus analyses the intraseasonal, short period allocation decision, and the interseasonal (annual) decision. The dynamic model uses the following general class of production functions:

$$\psi(Y) = h\left(\sum_{i=1}^M \theta_i(W_i)\right), \quad (47)$$

where

- Y = crop yield;
- ψ = is a monotonic transformation of Y ; and,
- h & θ are arbitrary functions.

The specific formulation of the sequential model adopts the usual convention of dynamic programming, in which growth stages are counted from the end, and is of the form:

$$\begin{aligned} f^1(s_1, s_2) &= \max_u [-c(u) + Ef^n(h(s_1 + \theta(u + v^1)))] \\ f^n(s_1, s_2) &= \max_u [-c(u) + Ef^{n-1} \cdot (s_1 + \theta(u + v^n), s_2 - G(u))] \\ \text{for } n &= 2, 3, \dots, M \end{aligned} \quad (48)$$

$$\text{Subject to. } G(u) \leq s_2 \\ u \leq D$$

where

s_1^M = a partial sum of terms for the production function that measure crop condition;

s_1^n = water in storage;

u^n = net irrigation water applied;

v^n = precipitation ;

$G(u^n)$ = gross amount of water that must be withdrawn from storage or pumped;

$c(u^n)$ = expected costs associated with the decision to apply u^n units of water;

$f^n(s_1^n, s_2^n)$ = expected net return from an n stage process under an optimal policy when where the initial state is that defined by s_1^n and s_2^n (the criteria is maximum value of expected net returns) $n= 1,2,\dots,M$;

$f^0(s_1^0, s_2^0) = R(s_1^0)$, the net harvest value of the crop; and

W_i = a vector of climatic and cultural variable but which is assumed to be made up of the sum of precipitation and net irrigation water denoted w only.

This model was empirically applied to corn irrigation in central Missouri. The study focused on farm level investment in corn irrigation. The authors selected water and temperature as the most critical 'climatic' factors affecting corn yield. Apart from these two climatic factors, agronomic variables, fertiliser and plant population were added to the model to explain the yield response surface. Four discrete states were used in the analysis. The variables used in the analysis are given below as:

v_t = precipitation;

u_t = irrigation water applied;

w_t = sum of irrigation water and precipitation truncated from below 0.35";

T_t = sum of daily maximum temperatures;

T_t^* = sum of the proportion of daily maximum temperature exceeding 85°F and 90°F ;

$I_t = T_t^* \sqrt{\text{Max}(0, w_t - .35)}$ an interaction variable between water and high temperatures for $t = 1,2, \dots,6$.

The actual equation estimated is :

The actual equation estimated is :

$$y = B_0 + B_1 U + B_2 U^2 + \sum_{t=4} C_t T_t + C_4' T_4^{**15} \quad (49)$$

where

$$= \sum_{t=1}^6 (a_t w_t + b_t w_t^2 + c_t I_t) \quad (50)$$

The important conclusion from the study was that the greater the price of water, the more the conservation of water is an optimal policy among farmers. In other words, water prices *do* influence the amount of irrigation water applied. In their own words "at higher values (higher water prices) successively smaller and smaller applications of water are made at a given stage and state; also applications are made at fewer states." Burt *et al* (1990, P. 11) This finding corroborates those of Just *et al* (1990a), Howitt *et al* (1980) and Kim *et al* (1989) but contrasts the findings of Carrey *et al* (1992), Just *et al* (1990b), Alouze C.M (1991), Antle and Hatchett (1986), Caswell *et al* (1990) and Clayton *et al* (1989).

2.10 Clayton *et al's* Pumping Costs Response Model

This model is based on data from the western USA and presents a water demand analysis based on a sample of 1927 farm observations in sixteen western states drawn from the 1984 Farm and Ranch Irrigation Survey (FRIS). The authors contend that as the water scarcity problem intensifies, competition is likely to increase between urban and industrial water users, and agricultural water users. This is likely to lead to higher water cost being reflected in either higher annual charges or capitalised into higher land costs. Since all the farmers in their sample irrigated exclusively with groundwater, the study uses farmers' estimates of energy costs as a proxy for the price of water. Furthermore, farmers in the survey planted various field crops and used various water conservation methods. The essence of this model and the central thrust of their investigation which is relevant to the focus of the present dissertation, is that of farmers' per hectare water use response to price changes. The study also addresses the changes in the acreage of widely grown

¹⁵ The authors actually deleted the first and last time period and found out that the difference is trivial and therefore simplified the model to include only four periods, $t=2,3,4$ & 5.

crops¹⁶ in response to perceived water pumping cost variation, which was a proxy for water price. This is quite similar to the present paper's focus on farmers' allocative decisions (i.e., the area of land per crop) as a response to changes in water prices. The following equation was estimated, using ordinary least squares, for each of the three climatic regions¹⁷ and then for all the climatic regions combined:

$$\ln(Q) = \beta_1 + \beta_2 \ln(p) + \varepsilon^{18} \quad (51)$$

where

Q = the producer's water application (centimetre per land unit);

P = Energy costs used in pumping in dollars per 1000 m³ ;

β_s = parameter estimates; and

ε = a stochastic error term.

The authors arrived at four important conclusions. First was the finding that water use per hectare (Q), was quite unresponsive to its price. This supports the conclusions of Carrey *et al* (1992), Just *et al* (1990b), Alouze C.M (1991), Antle and Hatchett (1986) and Caswell *et al* (1990) who found water prices did not feature prominently in farmers' irrigation water application decision. This study reported a price elasticity of -0.26. This is in contrast to the findings of Just *et al* (1990a), Howitt *et al* (1980), Burt *et al* (1990) and Kim *et al* (1989).

Secondly, farmers in the high CIR¹⁹ region were more dependent on irrigation throughout the growing season and tended to substitute cotton for small grains grown in the other two regions' (Clayton *et al*, 1989, Page 770) . This conclusion

¹⁶ The crops studied were corn grain, corn for silage, grain sorghum, wheat, barley, soybeans, dry edible beans, other small grains, alfalfa, other hay, cotton, sugar beets, and Irish potatoes.

¹⁷ The study divided the sixteen states covered in the sample into three regions based on the consumptive irrigation requirement (CIR) of a reference crop, alfalfa. The CIR considers both the evapo-transpiration need of a 'well watered' alfalfa and rainfall. A high CIR meant that the region relied on or needed irrigation more.

¹⁸ The study actually estimated linear, log-log and quadratic forms of this equation. However, they report only on the log - log functional form giving the justification that neither the theory of demand nor the literature provided evidence of a functional form, *a priori*. The log- log functional form was, however, chosen because it consistently had higher coefficients.

¹⁹ See footnote 16 for meaning of CIR

concluded with the findings of Caswell *et al* (1990), Howitt *et al* (1980), and Kim *et al* (1989), all of whom concluded that farmers generally switched to high value crops as water costs increase.

The third finding, and which should not be confused with, or interpreted as contradicting the previous one, is that although farmers shifted to water - saving (hardy) crops with high value, this shift has less influence on agricultural water demand than the crop mix already existing in the three regions. In their own words "comparability between past elasticity estimates by crop and current estimates by region also suggest that farmers shift to water - saving crops have less influence on water demand than the crop mix existing within most regions. In other words, regions depend heavily on certain mixes of field crops which, themselves, have somewhat specialised water needs " (Clayton *et al*, 1989, Page 771). This is a unique finding, contrasting sharply with the other studies reviewed. They stress the point that although, in general, farmers studied in the sample responded to higher water costs by switching to higher value crops, the effect of that switch on the water demand for the region as whole is limited. In other words, farmers do not go out of their way to introduce new high value crops that are exotic to the region but which could be as water - saving as they are valuable. Instead, they choose from the crop - mix or bundle which *is* characteristic to the region. This does not, however, contradict the finding that farmers respond by switching from low to high value crops. It only suggests that the search for the alternative is limited to the region specific crop mix.

Fourthly, their results *do* indicate statistically significant differences in groundwater demand relationships associated with climate. The regions with lower irrigation water requirements had a more responsive demand for irrigation water than the rest of the west (Clayton *et al*, 1989, Page 771). However, in spite of differences in climate, crop mix and irrigation requirements (as delineated by CIRs) across the three climatic regions, the relatively low elasticity of demand estimates for groundwater did not vary significantly across the climatic regions. This finding is in sharp contrast to the expectation that the dry areas in which water scarcity is more acute should be more responsive to water price. In an attempt to offer an explanation to this extraordinary finding, the authors state that "fixed well yields, large fixed investments in irrigation equipment, or the domination of a few crops may all reduce water price influences on water application per hectare" (Clayton *et al*, 1989, Page 771) . This point seems to lend credence to their contention that

even the shift to water - saving crops only has minimal effect on the overall water demand relative to the crop mix that pervades the region.

2.11 Kim *et al's* Dynamic response model

Kim *et al* (1989) developed and applied a dynamic model in the context of ground water mining for irrigated agriculture. The model hypothesises that there exists an inter - temporal depletion path with respect to ground water mining for irrigated agriculture. As a response to the depletion and the high cost of ground water mining, the model postulates that farmers respond in two ways: first, by re-examining and adjusting the relative allocation of groundwater among the crops being irrigated, and, secondly, via endogenous switch points in time, a phenomenon that describes a systematic transition from production of crops with relatively low water demand. The model is empirically applied using information from the Texas High plains, which is part of the Ogallala aquifer in the western USA. In the context of this dissertation, the study is relevant in so far as it analyses farmer's allocative and water supply decisions in response to resource depletion and higher pumping costs i.e., higher water cost.

The model is constructed not on the basis of the farmer's aggregate groundwater demand for irrigation but on the disaggregated categories, i.e. crop specific demand curves.²⁰ This allows for the inter - temporal relative allocation of water among categories of crops as a result of increases in water cost. Specifically, the agricultural demand for ground water is disaggregated into crop - specific linear demand curves with the objective of capturing the inter - temporal relative groundwater allocation among crops and the reduction in the number of crops that are cultivated under irrigation as a response to scarcity and higher groundwater mining cost. Given these objectives, the model posits a disaggregated, crop-specific inverse groundwater demand for the i th crop of the form below²¹:

²⁰ The decomposition / allocation of aggregate demand into the crop specific demands and pumping costs employed the Blaney-Criddle methodology the details of which are not presented but merely cited by the authors. Our search for this methodology was fruitless.

²¹ Those interested in going through a rigorous mathematical development of the model can consult the reference directly. Attempting to do so here would be beyond the scope and purpose of this chapter. As such, only the equations relevant to the thrust of attention and the application of the model for Texas high plains sorghum and cotton cultivation have been included herein.

$$P = \frac{a_i}{b_i} - \frac{1}{b_i} \cdot W_i, \quad i = 1, 2, \dots, n, \quad (52)$$

where

- W_i = measurement of acre-feet of groundwater pumping for crop i ;
- P = is the price (marginal extraction cost) in dollars per acre-foot
- a_i and b_i (> 0) are demand parameters estimated for crop i .

The marginal pumping cost function, MC, is given by;

$$MC = k_1 * (SL - h) = k_2 * h \quad (53)$$

where

- k_1 = a positive constant representing pumping cost per acre-foot of lift;
- SL measures of irrigation surface level elevation above sea level; and,
- h measures the water table elevation in feet above sea level.

The model introduces a groundwater hydrological equation under a multicrop water demand situation and which is specified as:

$$\dot{h} = \frac{R + (k_3 - 1) \sum_{i=1}^n W_i(t)}{A \cdot S}, \quad (54)$$

where

- \dot{h} = time derivative of h ;
- R represents the average aquifer recharge rate in acre-feet per year;
- A = size of the aquifer in acres; and,
- S = a storativity coefficient.

Total pumping costs is given by the following function with the terms as defined previously:

$$TC = \sum_{i=1}^n k_1 (SL - h) W_i. \quad (55)$$

The region under study is characterised by the chronic 'mining' of groundwater. Irrigated agriculture accounts for a large proportion of all pumped groundwater in the region. The empirical application of the dynamic model uses economic and hydrologic parameters for the seven counties in there region of study. Producers in

this region largely rely on pumping groundwater for their irrigation water requirements. Ninety - five percent of irrigated acreage in the counties is planted in cotton and grain sorghum. (Kim *et al*, 1989, page 80) Two equations were estimated for cotton and sorghum water demands and include as independent variables real cotton prices (dollars per pound), real sorghum prices (dollars per bushel), real pumping cost (dollars per acre-foot) , number of centre - pivot irrigation systems in the country, pre-plant rainfall, summer rainfall and six dummy variables to account for six of the seven counties included in the study. Prices were in 1967 dollars. Since the estimates involved pooled cross section - time series data, the demand equations were estimated using a model that assumed a first - order autoregressive structure that takes account of the inherent problems of heteroskedasticity and serial correlation.

The two important conclusions were that short - run irrigation water demand decreases in cotton prices but increases in sorghum prices. In other words, a positive correlation existed between cotton water demand and its own price while the reverse was the case for sorghum prices. This conclusion implies that farmers respond to water scarcity signals, as represented by pumping costs, by not only reducing the water applied but also switching to higher value crops. The producer prices of both sorghum and cotton were significant, indicating that farmers in the High Plains take into account producer prices in making their irrigation water application decisions. The second conclusion is that both cotton and sorghum water demands (despite the relatively high value of cotton relative to sorghum) decrease as pumping costs (the surrogate for water price) increases.

2.12 Wade's (1990) " Corruption Model for Irrigation Water Pricing"

The response of farmers to water scarcity signals have traditionally been estimated using prices of water. In a study of canal irrigation in Southern India, Wade (1990) provides an interesting, non -empirical case study of farmers response to water scarcity signals in a canal irrigation project as measured by the amount of bribery given to the irrigation engineers. Contextually, therefore, the price elasticity of demand for water could be viewed, then, as the 'bribe elasticity of demand' for irrigation water. He documents that the actual area of land available or under irrigation is a function of the size of the bribe the irrigation engineers demand. This was especially the case for those farms in the southern parts of India where vast

areas of land are being irrigated despite its illegality. In the context of this dissertation, the 'bribe price', an irrigation water scarcity signal, not only determines the total area of land brought under irrigation but is also one of the key issues in the present paper i.e., crop choice. This is perhaps more evident from the quote below:

"A second reason why irrigators may approach Irrigation engineers has to do with the zoning of land for irrigation. Very large areas of land under most South Indian canals - often running into tens of thousands of acres per canal - are being irrigated (sic) unauthorisedly, in the sense that they are not entitled by crop zoning arrangements to any irrigation at all, or are intended for non-paddy but are growing (water intensive) paddy crops." (Wade, P. 296).²²

2.13 Conclusion

The literature reviewed thus far demonstrates that a wide variety of models have been used to investigate a large number of issues relating to water use in irrigated agriculture. Amongst the issues investigated were farmers' response to water prices in terms of amount of water used; their decisions regarding land allocation per crop; the effect of irrigation water prices on choice of crops to cultivate under irrigation; choice of technology; and output response to irrigation water application. Whereas all these issues are relevant for those interested in the economics of irrigated agriculture, we shall focus here on short - run irrigation water demand, crop choice, technology choice and crop output response to irrigation water use in a specific region(s) of South Africa. It is clear from the varied results contained in these surveys that no *a priori* evidence exists to indicate what the likely situation would be in South Africa. This is left for empirical enquiry and is the subject of Chapter 4. The works of Just *et al* (1990a) and 1990(b) offer an additional insight; viz that the results are quite responsive to the model specification and functional forms adopted. This is also the conclusion one draws from Moore C.V (1990) and Martin *et al* (1982), both of which are not reviewed in detail in this dissertation. It is also clear that most of the literature concurs with regard to the propensity of farmers to shift to higher valued crops in response to water prices, even though the authors differ widely with regard to the price elasticity of demand for irrigation water.

²² In this southern Indian state studied, paddy (unhasked rice) is the main irrigated crop while groundnuts, hybrid sorghum and cotton are irrigated crops. If the 'bribe price' is reasonable, irrigators (farmers) may as well cultivate cotton under irrigation as opposed to paddy.

CHAPTER 3

REVIEW OF MULTIPLE PRODUCT FIRM THEORY AND MODEL FORMULATION

3.1 Introduction

This chapter begins with a review of the theory of the multi - product firm which forms the theoretical base of this dissertation. We then adapt it to farm firms' choice of crops and input utilisation decisions. In section 3.4, the four equations that are empirically estimated in Chapter 5 are modelled and the variables explained. Section 3.5 describes the data and study area.

3.2 The theory of Multi - product Firm

This section briefly reviews the theory of the multi - product firm as it forms the theoretical basis for the dissertation and the econometric model specified and estimated below, and analysed subsequently in later chapters. It offers, then, a theoretical basis for the subject of this dissertation. The first parts of this section offer a textual and diagrammatic explanation of the multi - product firm theory which are then presented more formally towards the end of this chapter.

The theory of the multi - product firm is an extension of the more conventional text - book presentation of the single output product firm. Firms combine factors of production to produce various forms of output or products, given an existing technology²³. Whereas it is true that goals of firms differ and are varied, the profit maximising motive has traditionally been accepted to approximate the objective of most firms.²⁴ Since firms have to combine factors of production (inputs) and transform these into outputs, they inevitably and obviously have to incur costs. The firm's objective may thus be revised as maximising profits subject to various cost constraints. Whereas costs need not be the only constraints, (e.g. others such as technological ones often do exist) we will assume away the existence of such constraints for the present purpose so as to focus on cost constraints alone.

²³ It is assumed that technology is fixed in both the short and the long run such that it is only in the very long run that technology is to be varied with respect to output.

²⁴ The classical assumption that firms are driven by profit maximisation as their prime motive has been the subject of lively debate amongst economists. In the process, alternative theories have been put forward, such as maximisation of sales or even managerial benefits as per agency theory. While there are elements of 'truth' in these varied assumptions, this paper adopts the Neo-classical view without attempting to dismiss the validity of alternate thought.

A two - product, two - input firm framework can be used to explain the theory of the multi - product firm. This analysis can, however, be easily extended to firms producing more than two products and employing a larger number of inputs. Assuming the two -product, two - input scenario holds for purposes of illustration, a farm firm (henceforth farm) produces each crop (product) x and y by combining two factors L and K. The farm thus chooses various combinations of inputs for the desired levels of production of x and y such that its profits are maximised. In functional notation:

$$X = f_1(L, K)$$

$$Y = f_2(L, K)$$

This can also be demonstrated diagrammatically. The various combinations of inputs that yield different levels of outputs are best illustrated using an Edgeworth box whose sides measure the total available levels of each input on either axis, as illustrated in Figure 1 below (Koutsoyannis, 1985). Any point within the Edgeworth box gives combinations of x and y produced by the available factors of production. If we let the production function for commodity x be represented by the set of isoquants labelled A, which are convex to the origin O_x , while the isoquants labelled B, and which are convex to origin O_y , represent the production function of commodity y, then it is evident that the further away isoquant B lies from its origin O_y , the greater the quantity of commodity y that the firm is producing. A similar explanation can obviously be extended to those isoquants labelled A. The firm's decision is that of where to produce within the Edgeworth box. For efficient production and profit maximisation, it is obvious that the firm will produce along the contract curve, O_xO_y , derived by joining the several points of tangency of isoquants A and B. This is due to the fact that while any point of production outside the contract curve, such as point N is feasible, it is not efficient (i.e. Pareto Optimal) because the firm can reallocate resources to the production of one or both products by producing somewhere along the contract curve, such points as M and P. The actual point of production along the contract curve, is however, a function of the relative prices of the inputs.

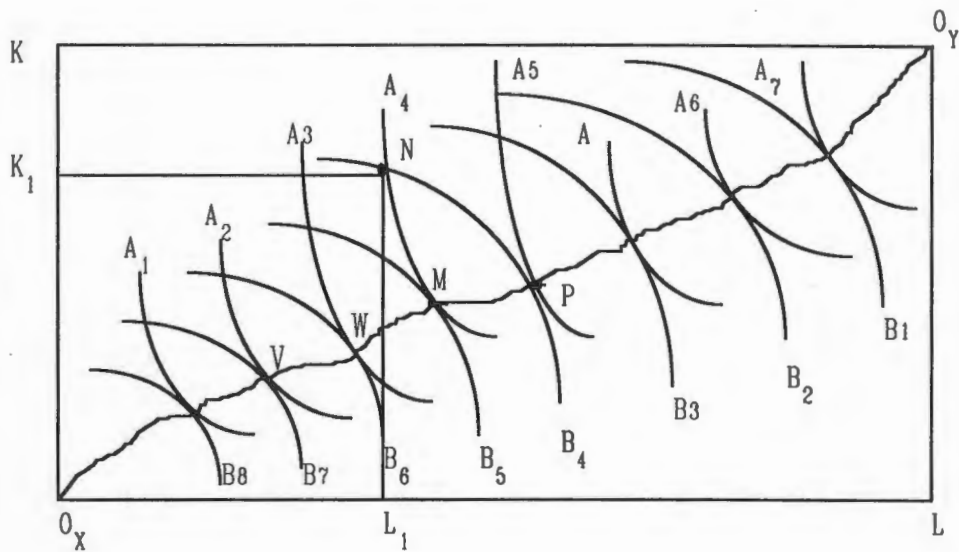


FIGURE 1

From Figure 1, above, the line O_xO_y is the Edgeworth contract curve. The choice of levels of inputs A and B that the firm will employ in producing x and y can be derived from the Edgeworth illustration by using the production possibility (or product transformation) curve of the firm. The PPC gives the locus of points of x and y that consume all the firm's resources. However, the PPC itself is nothing more than the contract curve derived from the Edgeworth box framework for each point of tangency between the isoquants and defines a combination of output levels of x and y that lie on the production possibility curve. Figure 2, below, illustrates this.

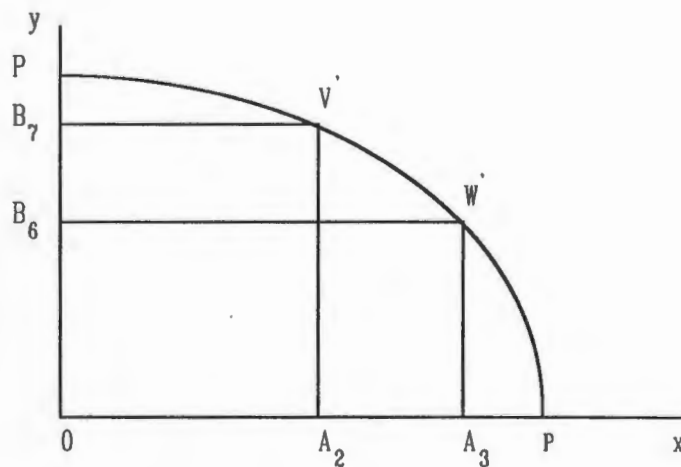


Figure 2

3.3 Formal derivation of the Production Possibility Curve

Since an isoquant measures the combination of inputs A and B that produce a specific level of a product, x, the slope of any of the isoquants measures the marginal rate of technical substitution (MRTS) of the inputs K and L ; thus

$$MRTS_{L,K}^x = \frac{MP_{L,x}}{MP_{K,x}} = \frac{\frac{\partial x}{\partial L}}{\frac{\partial x}{\partial K}} = - \frac{\partial K}{\partial L} \quad (56)$$

where $MRTS_{L,K}^x$ is the marginal rate of technical substitution of factors K and L in the production of commodity x. This can be extended to the production possibility curve B for product y, viz:

$$MRTS_{L,K}^y = \frac{MP_{L,y}}{MP_{K,y}} = - \frac{\partial K}{\partial L} \quad (57)$$

At the points of tangency between the two series of isoquants A and B, i.e. on the contract curve, the slopes must be equal implying that

$$- \frac{\partial K}{\partial L} = \frac{MP_{L,x}}{MP_{K,x}} = \frac{MP_{L,y}}{MP_{K,y}} = - \frac{\partial K}{\partial L} \quad (58)$$

Likewise the slope of the production possibility curve for the firm is given by

$$- \frac{\partial y}{\partial x} = MRPT_{x,y} \quad (59)$$

where $MRPT_{x,y}$ is the marginal rate of product transformation.

Movement along the production possibility curve from the y axis towards x means, essentially, that inputs are released to the production of x which then experiences a corresponding gain in inputs. These two conditions can formally be represented respectively as

$$\begin{aligned} \partial L_y (MP_{L,y}) + \partial K_y (MP_{K,y}) &= \partial y \\ \partial L_x (MP_{L,x}) + \partial K_x (MP_{K,x}) &= \partial x \end{aligned} \quad (60)$$

Totally differentiating the production possibility curve, i.e. its slope, yields

$$-\frac{\partial y}{\partial x} = \frac{\partial L_y(MP_{L,y}) + \partial K_y(MP_{K,y})}{\partial L_x(MP_{L,x}) + \partial K_x(MP_{K,x})} \quad (61)$$

An important condition for efficient production is that the firm must 'produce on' the curve and not inside it. Moreover, since the slopes of isoquants A and B are equal at tangency then

$$MP_{K,x} = MP_{K,y} \left(\frac{MP_{L,y}}{MP_{K,y}} \right) \quad (62)$$

and

$$MP_{K,y} = MP_{K,x} \left(\frac{MP_{L,x}}{MP_{K,x}} \right) \quad (63)$$

Dividing the total differential by $\partial L_y (= -\partial L_x)$ yields

$$-\frac{\partial y}{\partial x} = \frac{MP_{L,y} + MP_{K,y} \left(\frac{\partial K_y}{\partial L_y} \right)}{MP_{L,x} - MP_{K,x} \left(\frac{\partial K_x}{\partial L_y} \right)} \quad (64)$$

Substituting (62) and (63) into (61) gives

$$-\frac{\partial y}{\partial x} = \frac{MP_{K,y} \left(\frac{MP_{L,x}}{MP_{K,x}} + \frac{\partial K_y}{\partial L_y} \right)}{-MP_{K,x} \left(\frac{MP_{L,y}}{MP_{K,y}} + \frac{\partial K_x}{\partial L_y} \right)} \quad (65)$$

However, since the terms in the brackets are equal by definition and the second bracketed terms are equal by the condition $\partial K_y = \partial K_x$, then the bracketed functions fall away and are cancelled out; thus, the slope of the production possibility curve is given by

$$-\frac{\partial y}{\partial x} = \frac{MP_{L,y}}{MP_{L,x}} = \frac{MP_{K,y}}{MP_{K,x}} \quad (66)$$

The optimal combination of the quantities of y and x, is that combination the sales from which yield the same revenue to the firm, i.e., the isorevenue condition. This can be obtained from the equation

$$\bar{R} = P_x \cdot (x) + P_y \cdot (y) \quad (67)$$

And, solving for y yields

$$y = \frac{\bar{R}}{P_y} - \frac{P_x}{P_y} \cdot (x) \quad (68)$$

Given product prices (and agricultural produce prices are often given as an example of products closely approximating the competitive firm's price - taking behaviour in the absence of statutory boards) the values of \bar{R} can be derived by assuming different values of x.

The formal elaboration of the multi - product firm's equilibrium condition described above may be re-stated as follows: firms seeks to maximise profits subject to the constraints set by the factors of production, the transformation curve, the prices of the commodities (P_x, P_y) and the factors of production (w, r). In the context of the subject matter of this dissertation, rational farmers are expected to choose output and input combination that make profit maximisation tenable. As such, rationality dictates that farmers will choose crops with high per hectare returns, minimise on input usage (such as that of water), choose irrigation technologies that minimise costs and maximise profits and apply inputs up to a point where their marginal revenue products equals the marginal cost of the additional unit of the input applied. These four concerns form the essence of our empirical analysis and correspond to the crop choice, short run water use, technology choice and crop output equations formulated in the next section and which are estimated in Chapter Four.

3.4 Model Specification, Variable Selection and Justification

This section delineates the equations that will be empirically estimated in the following chapter using the multi - product firm theory discussed above and the literature on water input usage and models reviewed in Chapter Two. Using the multi - product firm framework and the models reviewed earlier, we construct four equations which are subsequently estimated in Chapter Four. The first is a crop choice equation that will be empirically estimated in an attempt to test whether farm firms are guided by relative product (crop) values per hectare in their choice

of crops cultivated. The second equation is the short run irrigation water demand equation. In the context of the multi - product firm model and given our expectation that farm firms will use input combinations up to a point where their marginal product per unit costs are equated, it is desirable to test whether water input use by farmers is responsive to its cost. Thirdly, we formulate a technology choice equation which builds on the theoretical premise of the second equation. The argument is that farm firms that respond to input scarcity signals (water costs or prices) are more likely to respond by using water-saving technologies. The fourth and last equation is conveniently referred to as the output equation. This equation seeks to capture yield or output response to water and other variable inputs applied in the production process.

3.4.1 Crop Choice equation

The crop choice equation is modelled as a variant of the multicrop inputs allocation model used by Moore, Gollehon and Carey (1992), herein after MGC, for the Western regions of the USA. It should be noted that the variations from the MGC model have been necessitated by data constraints and the need to remain as theoretically and practically relevant to South African conditions as possible. We formulate the crop choice equation as follows;

$$d_i = f_i(p, g, w, l, r) \quad i = 1, \dots, m \quad (69)$$

where

d_i is a discrete choice variable equal to 1 if crop of profitability class i is grown and zero otherwise;

p are normalised crop prices;

g is the per hectare profit margin for each crop i ;

w is amount of water applied per hectare

l is the labour input requirement per hectare for each i ; and

r is a measure of other variable input requirements other than water;

Perhaps the most significant modification to the MGC model is the fact that the dependent variable in our case does not consist of the four dummy variables representing the five crops as used in their study. Instead, we have classified the crops in the sample into two categories depending on whether they fall above or below the mean of their reported per hectare value. The plausibility of this

transformation is not difficult to understand. From the perspective of the multicrop firm model, we are simply substituting specific crop classification with a profitability level classification. In terms of econometric considerations, it is not the inclusion of specific product types that matters, but whether there exist variations in profitability associated with a particular line of production. This transformation does not violate that requirement. Another motivation for the transformation has to do with data availability and the form in which it is presented. As will be noted later on in the description of the data, the *combud*²⁵ data set provides information relating to fifteen crop types. Attempting to include all of them would create problems with sample size and degrees of freedom in our subsequent estimation.

The inclusion of price as an explanatory variable in the crop choice equation may be justified on the premise that farm firms normally respond to price signals in their choice of crops to cultivate. Consequently, to the extent that higher crop prices determine farm profitability and influence crop choice, the variable clearly belongs in the model. It is hypothesised that crop choice, as defined previously, is positively related to individual crop price. This is in conformity with theory as well as the econometric specification adopted here, where the higher - value crops take the value 1 in the dummy variable formulation while lower valued crops take zero. If the specification were reversed, we would expect a negative correlation.

The variable *g* is included as a measure of profitability amongst the specific crops in the sample. While high crop prices can be seen as a necessary condition for farm profitability and an attraction for farmers, it is not a sufficient condition for farm profitability since this depends on the per hectare crop output, crop prices and the other variable costs of production. Certain crops have higher prices per ton but lower gross margins owing to the fact that their production costs are higher. This is a strong justification for including the variable in the crop choice equation. We hypothesis, *a priori* , a positive correlation between crop choice and gross margin per hectare.

²⁵ The data set, *combud*, is annual farm budget statistics gathered by the Directorate of Agricultural Economic for short term planning purposes. Details of this data presented in Chapter 4.

The variable w is the amount of irrigation water applied per hectare. For crops grown under irrigation, water becomes an important input not only for agronomic considerations but also for the expectation that expenditures on irrigation water not only necessarily form a high proportion of pre-harvest costs, but also importantly determine the gross margin per hectare. It is therefore postulated that rationality will dictate that farmers will, *ceteris paribus*, choose those crops with low irrigation water requirements in lieu of those that require higher irrigation water application rates for a given technology. Plant water requirement is, itself, a function of peculiar agronomic considerations and will thus vary by crop, length of growing season, climate and similar variables. Delving into such considerations are, however, neither relevant to, nor within the scope of, this equation. We therefore expect *a priori* that the correlation between the per hectare water requirement / application and crop choice to be is negative.

Labour is an important factor in agricultural production. Just as with water requirements, labour requirements vary from one crop to the next. The amount of labour that a farm hires depends on the type of crop, and the ease and desirability of factor substitution between labour and capital, i.e. the desirability and ease with which labour can be substituted by machinery. Available literature suggests that South African agriculture is over - mechanised and this is frequently attributed to two factors: first is the rise in farm wages, a factor that has made labour expensive relative to machinery; second is the fear of a potentially negative impact on agricultural production as a result of hostile agricultural labour relations during the apartheid regime a part from other reasons such as the concessionary terms at which machinery was availed to the farmers and the short period within which such machinery were 'written - off' for tax purposes. The inclusion of the labour variable, l , in the equation is thus justified. We expect crop choice to be negatively correlated with the labour input per hectare.

The last variable in the equation, r , is a measure of the per hectare requirement for other inputs in crop production. In the farming sector, generally, farmers use operating capital in the purchase of complimentary inputs such as seeds, fertilisers, herbicides and other chemicals that help raise healthy plants and therefore enhance output. How much the farmer spends in purchasing these inputs will influence his overall production costs and, thus, the farm margins. Given that profit-maximising firm farms are to be guided by rational decision - making, one way a farmer can

influence his gross margin is to choose crops that are non-intensive in the use of inputs (e.g. crops that have less water requirement) and which are, therefore, less demanding in terms of their per hectare operating capital requirements. In the **combud** data set used in this dissertation, we have used interest payments on funds borrowed from credit institutions as a proportion of operating capital as a proxy for the relative per hectare operating capital requirement for each observation in the sample. We anticipate *a priori* a negative correlation between the dependent variable and this proxy for operating capital requirements which are used in the purchase of farm inputs.

3.4.2 Water demand equation

The short run irrigation water demand may be written as follows;

$$w_i = f_i(p_i, pc_i, gm_i, fcost_i, T_i, lgs_i, r_i) \quad i = 1, \dots, m \quad (70)$$

where

w_i is the per hectare quantity of water applied in farm i ;

p_i is the price of crop cultivated by farm i ;

pc_i is the per hectare irrigation power cost;

gm_i is the per hectare gross margin on farm i ;

$fcost_i$ is the per hectare fixed cost ;

T_i is a discrete choice for the technology applied in farm i ;

lgs_i is the length of crop growing season in months for the crop in farm i ;

and

r_i is the interest payment on operating capital by farm i

The **combud** data set records the amount of irrigation water, in cubic metres, applied per hectare for each of the observations in the sample. As explained in more detail in section 3.4.4 regarding the data used here, only observations that report the use of irrigation technologies and the actual amount irrigation water applied and irrigation power costs were recorded have been included in our analysis. This leads to the exclusion of all observations that reported using flood irrigation techniques since, in such cases, water price is exogenously determined (i.e. set by the water authorities or irrigation board) and invariant with respect to volumes used. On the other hand, those farms that report using sprinkler and centre pivot schemes had to undertake their own pumping and pressurising of

water flow and thus energy, or power, cost represents a close proxy for the actual water price.

The variable pc refers to the costs incurred per hectare for power cost used in pumping and pressurising water flow for irrigation purposes. Both the centre pivot and sprinkler systems involve power costs which provide a good proxy for water prices. The amount spent varies with the type of motors and engines installed, the water-saving attributes of the technology adopted, as well as the intensity of irrigation envisaged among other considerations. Like all costs, we expect the unit power cost variable to be negatively correlated with per hectare water use.

Gross margin, gm , is included in our equation as one of the independent variables as a measure of profitability. It is postulated that the higher is the gross margin for a particular farm activity, the greater the probability that the farm will be in a position to adequately cover those costs involved in pumping and pressurising irrigation water. Such farms are thus expected to be less constrained in their application of water given optimal crop water requirements, prevailing climatic conditions and particular soil characteristics. We therefore expect a positive correlation between the amount of water used and the farm's per hectare gross margin.

The variable $fcost$ is the irrigation fixed costs per hectare. This includes the sunk costs of investment in irrigation equipment and irrigation-related farm structures. The extent of fixed cost varies across farms, irrigation technologies and crop types. It is postulated that those farms with heavy investments in irrigation equipment and machinery will be less responsive to the variable pumping or energy costs involved in putting such equipment into use. The correlation between the amount of water applied and the magnitude of fixed investments per hectare is thus expected to be positive. Therefore, farmers who have the financial resources to put into place expensive irrigation systems are less likely to be constrained in the amount of water they apply.

The type of technology used in applying water to the crop root system is included as an explanatory variable in the water demand equation. Irrigation technologies are diverse with respect to their efficiencies, where efficiency is defined to refer to the difference between the irrigation water that is pumped and which actually

reaches the crop root system. Flood irrigation techniques are obviously less efficient in this regard than are either sprinkler or centre pivot system. It is assumed that irrigation water use per hectare is inversely related to the efficiency of the particular irrigation technology. Since there are only two techniques inquired of in this study, the impact of irrigation technology in the short run irrigation water demand equation is modelled using a dummy variable, taking the value 1 if sprinkler technology is employed and zero otherwise. The sign of the coefficient is indeterminate since there is no *a priori* evidence that sprinkler irrigation is more efficient than centre pivot irrigation technique or conversely.

The length of a crop's growing season, *lgs*, is included as an explanatory variable in our short-run water demand equation as it determines the length of crop-irrigation-days for a particular crop. For example, whereas vegetables take a short period to maturity (often about three months), maize and cotton may take longer while yet others like Lucerne may have to be irrigated most of the year. The *combud* data gives the length of the growing season (in months) when irrigation water was actually applied. We postulate that crops or farm firms that produce crops with longer periods irrigation water requirements will use more water than will those that take relatively shorter periods from sowing to harvesting. The coefficient of the variable *lgs* is thus expected to be positive.

The last variable included in the equation is interest payments on working capital as a proportion of pre-harvest costs, *r*. Farm inputs are normally purchased from the farm firm's working capital and the extent to which interest payments on working capital forms a high proportion of the total pre-harvest costs indicate that particular farm's ability to meet its input cost obligations, including paying for energy needed to pump and pressurise water for irrigation. Given this, we would thus expect a negative correlation between irrigation water application and the level of a farm's operating capital indebtedness as represented by the proportion of interest payments to the total pre-harvest costs. On the other hand, one could argue convincingly that those farms that are heavily reliant on borrowed working capital have no constraints in their supply of inputs (including water) since such borrowed working capital often provides the farmers the finances with which input purchases are made. In fact farmers who are heavily reliant on borrowed working capital in a particular crop season are more pressed financially and are, therefore, often more likely to make sure that they apply all required inputs that would

maximise per hectare output since that would ensure a larger gross farm income and an enhanced ability to meet debt obligations. Given this scenario, therefore, one would expect a positive relationship between the amount of irrigation water applied and the level of the farms' operating capital indebtedness. We, therefore, have no *a priori* expectation about the sign of the coefficient of the variable r .

3.4.3 Technology Choice Equation

The type of irrigation technology adopted by the farmer has ramifications for irrigation water use as irrigation technologies differ with respect to their water-saving attributes, i.e. irrigation efficiency. Drip irrigation is, for example, more efficient than is flood irrigation as the latter loses more irrigation water applied per hectare in run-off, percolation and evaporation. Likewise centre pivot irrigation technology and sprinkler irrigation do not have the same levels of efficiency. Profit maximisation thus envisions that rational farmers will choose irrigation techniques after taking due cognisance of their relative irrigation water-saving efficiencies. Since all observations included in the sample either have sprinkler or centre pivot schemes, it is desirable to investigate whether water-saving considerations do play any role in irrigation technology choice by farmers. Perhaps the following quote from a study of the history of irrigation technology adoption in the western USA provides insight as to the importance of technology choice for cost minimisation in irrigated agricultural production.

"The centre pivot system became extremely popular, probably because it required only one fourth the amount of labour that a furrow or a hand moved system needed. The centre pivot has several other advantages over conventional furrow systems because it can be used on a hillier land and sandier soil with higher application efficiency.²⁶ One draw back of the centre pivot system was its relatively high energy requirements... the total energy cost of a gravity distribution system with a 50% application efficiency exceeds that of a centre pivot system with an 80% application efficiency for pumping depths of 250 feet or more. Thus, centre pivot were more likely to be water-saving rather than energy saving." (Nieswiadomy, 1988, Page 64)

²⁶ Application efficiency is defined as the ratio of the amount of water that is retained in the root zone divided by the amount of water delivered to the soil surface.

This observation seems to fit well the South African situation where the centre pivot technology is more energy-intensive in operation, but relatively labour - saving as compared to the sprinkler irrigation technique. This is evident from Table 3.1, below, which gives descriptive statistics for energy use, labour and machine hours per hectare for the sprinkler and centre pivot technologies included in the sample.

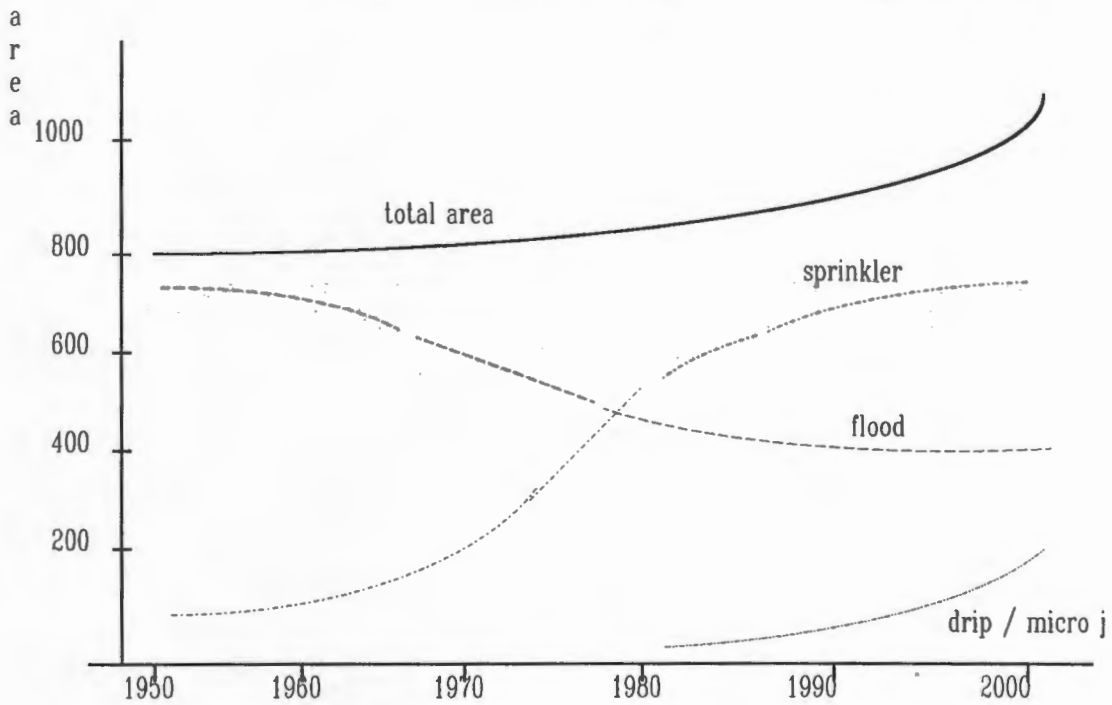
Table 3.1: Descriptive Statistics

	Power Kw/hr		Machine Hrs		Labour Hrs	
	Sprinkler	Pivot	Sprinkler	Pivot	Sprinkler	Pivot
Mean	2.6	338	96.8	62	99.7	40
Median	0.7	0.7	83	45	57	28
Minimum	0.5	0.14	37	18.3	4	10.1
Maximum	35	10461	312	392	420	340
St. Deviation	1.2	337	9.9	12	18	10

Source : Computed from combud data set

That South African irrigators have been moving rapidly towards more efficient, lower cost irrigation technologies is further clearly indicated by Figure 3.1, below, which illustrates that there has been a decided switch from flood, to the relatively more efficient sprinkler, irrigation technique over time.

Figure 3.1 : Trend in Irrigation Technology Adoption



Source : Macdonalds I.A.W (1988)

Irrigation technology choice may thus be modelled as:

$$d_i = f_i(p, g, w, l, r, R) \quad i = 1, \dots, m \quad (71)$$

where

d_i is a discrete choice variable equal to 1 if sprinkler technology and zero otherwise;²⁷

p = crop prices;

g is the per hectare profit margin for each i ;

w is the per hectare water application for each i ;

²⁷ For purposes of this dissertation, the choice is restricted to either sprinkler or centre pivot. This has been necessitated by data constraints i.e. the combud data set contained information based largely on these two. This is not insinuate that they are the only two technology options adopted by farmers in the two regions.

l is the labour input requirement per hectare for each i ;
 f is the per hectare irrigation fixed cost for each i ;
 R is a dummy that captures climatic and topographical differences between the two regions described in section 3.4.5 dealing with data set and the study area.

It is evident, then, that the **technology choice equation** may be modelled as a discrete choice equation where the dependent variable takes the value 1 if sprinkler technology is in use, and zero if it is a centre pivot type. The data used in this dissertation contain nearly equal observations that use either system. Our *a priori* expectation is that the coefficient of water cost, is negatively correlated to the independent variable while f , l , and g have a positive correlation with the dependent variable. We have no *a priori* indication of the signs of the coefficients of the crop prices, p , and the regional dummy, R .

3.4.4 Crop Output equation

The crop output equation is modelled as:

$$Q_i = f_i(p, w, l, e, c,) \quad i = 1, \dots, m \quad (71)$$

where

Q_i is normalised per hectare crop output.;
 p is crop prices;
 w is the per hectare water application ;
 l is the labour input employed per hectare;
 e is the per hectare energy utilisation;
 c is the per hectare preharvest costs for inputs other than water and energy

The crop output model is specified as dependent on the amount of irrigation water, w , applied. The theoretical justification for including this variable in the model is that where water is a constraint in agricultural production, its application

to crops via either irrigation method should result in higher output. We thus expect a positive relationship between the amount of water applied and the output that the farmer actually harvests.

The amount of labour hours used per hectare, l , has been included in the model as it is an important input in crop production. This variable captures the actual labour input, i.e. the number of labour hours actually employed in the production process per hectare. Labour is required promptly at critical stages of plant growth such as sowing, weeding, harvesting and harvesting, among other chores. Farms with inadequate, or less than optimal, labour inputs are expected to have lower productivity and hence lower output. We therefore expect a positive relationship between output per hectare and the amount of irrigation labour hours employed per hectare.

The variable, c , denotes total pre-harvest costs. Pre-harvest costs are defined to include the per hectare expenditures on chemicals, fertilisers and herbicides which the farmer uses in crop production. Farmers who apply fertilisers and chemicals as recommended are likely to have higher pre-harvest costs but also greater output than those farms that ignore, or use fewer of such inputs and in less than the quantities recommended. We therefore anticipate a positive relationship between output and the per hectare pre-harvest expenses.

The variable, e , refers to the amount of kilowatt hours used per hectare. All farm enterprises in the sample used electricity for their pumping and pressure requirements. The higher the pumping requirements for the particular crop, the more pumping hours and hence energy used. To the extent that this variable reflects irrigation intensity, we expect a positive correlation between output and energy as defined above. Interest payments are included in the model as proxies for cost of operating capital. Different farm crops have different operating capital requirements. The *Combud* data set used in this analysis gives interest payments on operating capital borrowed by farmers for the crop season. Higher interest payments effectively reduces farm profitability as reflected in the gross margin and therefore reduces farmers' ability to employ other inputs which are required. The propensity of the farmer to reduce his costs compromises the optimal or desirable input application and with it, crop output. To the extent that this is true, we expect a negative correlation between output and interest payments.

The last variable in the model, p , refers to normalised crop price per ton. The theoretical justification for including this variable is that output prices determine the gross margin per hectare. For the same input costs, farms that produce high value (price) crops will, by definition, have higher gross margins. The point is, to the extent that prices determine gross margins, farmers experiencing higher gross margins are more likely to spend on inputs and techniques that enhance productivity and are therefore likely to have higher output than their counterparts. We therefore expect a positive correlation between output and crop prices.

3.4.5 Data and Study area

The data used in this analysis comes from annual farm budget series, *combud*, for the year 1994. The series is published annually by the Directorate of Agricultural Economics largely in the form of income and cost budgets for use as short term planning aids. Even though the Annual Reports referred to above only contain summarised information and tables, the raw data collected and updated annually is available on-line in the Department's computer system. While compiling the statistics, the Department brings together 2 or 3 farmers who successfully follow acceptable management practices in a specific area, for a particular crop, and who provide information relating to various output and input variables. The data is collected by experienced extension staff and are believed to be reasonably accurate.²⁸ Even though the *combud* data set contains 941 farm budgets, the focus of the present dissertation meant that only those farm budgets that contained information on at least one form of irrigation could be used in our analysis. This was again "filtered" so that only those entries from either the Transvaal or Orange Free State were included. The rationale for doing so is that other regions of the country either had adequate rainfall, e.g. winter rainfall areas, or were not as important in terms of agriculture. Yet, others such as those in Natal and the Eastern Cape, were excluded not only on the grounds that they had few observations but, more importantly, because of the desire to have a better defined and focused analysis. Including a wide region with perversely diverse topographical, climatic and management practices would risk having blunt and non

²⁸ One very helpful officer boasted during our visit to their offices that if the information were not accurate, commercial Banks and other lending institutions wouldn't be using them in assessing fixed and operating loan applications by farmers.

focused results. Even though our desire would have been to focus on a much smaller area within either region, doing so would have resulted in insufficient degrees of freedom in the empirical analysis undertaken in the next chapter. The data set was, accordingly, narrowed down to 63 observations, with each region contributing roughly one half of the total observations.

CHAPTER 4

MODELS' ESTIMATION AND ANALYSIS OF RESULTS

4.1 Introduction

In the previous chapter, we developed the foundation for the empirical estimation of the four equations for crop choice, short - run irrigation water demand, technology choice and crop output. In this chapter, those equations are estimated and analysed. Section 4.2 discusses the crop choice equation while the water demand, technology choice and crop output equations are dealt with in sections 4.3, 4.4 and 4.5 respectively. All the regression equations were estimated using the Windows version of *TSP* i.e. *Eviews*. Since the equations' formulation has been discussed and the economic criteria for the selection of variables explained, this chapter will focus exclusively on the interpretation and analysis of the results.

It is important to note that, while the short - run water demand and crop output equations have been estimated using an ordinary least square (OLS) estimation procedure the crop choice and technology choice equations have been estimated using the *Logit* model. This has been necessitated by the econometric consideration that the latter set of equations have discrete dependent variables. The *Logit* procedure, based on the cumulative logistic probability function, describes the logarithm of the odds that either choice (i.e. of the discrete dependent variables) will be made, given a set of independent variables. Using OLS procedure under such circumstances is tantamount to subjecting the equation to a linear probability function where the slope of the regression line, in effect, would measure the effect on the probability of making either choice of a unit change in either one of the independent variables, while holding all others constant. Since some of the right - hand side variables in the two equations are, themselves, qualitative the use of *Logit* model in such circumstances is econometrically superior to OLS. The specific difficulty with the linear probability model is that the error terms are inherently heteroscedastic and are not normally distributed even though these problems do not cause a bias. The greatest problem with the probabilistic linear model is, however, that the expected value of the dependent variable (a dummy variable) is not limited to 1 or 0. One thus often gets expected value estimates that are outside the requisite probability range. Such an estimate does not make statistical sense and is therefore intuitively unappealing.²⁹

²⁹ For a thorough treatment of qualitative variables, see Pindyck and Rubinfeld chapter, 10. Whereas the use of ordinary least squares under the circumstances has certain statistical drawbacks, the relative ease of

4.2 Crop Choice Equation

The formulation of the crop choice model was described in Chapter Three and need not be repeated here. The equation to be estimated is:

$$Hvcrop = \beta_1 Price - \beta_2 Water + \beta_3 Gmargin - \beta_4 Lhours - \beta_5 Propint + e_i \quad (72)$$

The variables are as previously defined and e_i is an independent, normally distributed error term. The regression results of the *logit* model are presented in Table 4.1 below.

Table 4.1 : Regression output for crop choice equation

LOGIT // Dependent Variable is Hvcrop
 Date 08/05/95
 Sample: 1 63
 Included observations: 63
 Convergence achieved after 8 iterations

Variable	Coefficien t	Std. Error	T-Statistic	Prob.
C	-7.054652	3.507477	-2.011318	0.0490
Price	-1.110556	0.831507	-1.335595	0.1870
Water	-4.989315	4.053366	-1.230906	0.2234
Gmargin	10.87124	4.483536	2.424701	0.0185
Lhours	0.176830	0.507306	0.348566	0.7287
Propint	1.199074	14.18843	0.084095	0.9333
Log likelihood		-5.43		
Obs with Dep=1		15		
Obs with Dep=0		48		

The regression results presented above have the "correct" signs, as previously hypothesised. The most significant single result from the above regression output is that the coefficient of the per hectare water application variable is statistically

interpreting its coefficients and related statistics is one reason why most researchers assume such difficulties away.

insignificant. This importantly implies that the relative per hectare irrigation water application requirement among crops does not influence farmers' crop choice decision. It is also apparent from these results that the per unit crop price, the per hectare labour hours and the working capital requirement proxy variable (*propint*) seem not to feature or are not important considerations in crop choice as reflected by their statistically insignificant coefficients. Thus, the only important variable in explaining crop choice is the per hectare gross margin as reflected by the statistical significance of the *gmargin* coefficient.

For qualitative choice models, such as the equation estimated above, an overall measure of goodness-of-fit such as the R^2 in the OLS estimates is not readily available from regression outputs of most statistical packages.³⁰ Instead, the likelihood ratio index is adopted as an alternative measure of goodness-of-fit. The index is normally specified as :

$$\rho = 1 - \frac{L(\beta^*)}{L(0)}$$

Note that the denominator of the right hand side is the restricted model while the numerator is the unrestricted model. The statistic computed above falls in the 0 to 1 range and thus offers an alternative to the normal R^2 . It is worth noting that ρ is difficult to interpret in the same sense that one does R^2 . It however gives an indication of the overall performance of the coefficients in explaining the model. An alternative to the above is the more familiar likelihood ratio test which can be used to test the hypothesis that either one, a group or all the coefficients in a particular equation are zero. The Likelihood ratio test is normally specified as:

$$-2[L(\beta_R) - L(\beta_{UR})] \sim \chi_m^2$$

³⁰ It is possible, however, to generate 'Pseudo R^2 ' using packages like LIMDEP and STATA. These, however, were not immediately available for such statistics to be generated.

where

m is the number of restrictions;

$L(\beta_R)$ is the log likelihood estimate of the restricted equation; and

$L(\beta_{UR})$ is the log likelihood estimate of the unrestricted equation.

Since the Log - likelihood ratio index and the associated ratio test involve estimating both the log - likelihood of the unrestricted model, as presented in Table 4.1 and a restricted model³¹, we implement the restriction by omitting all the right hand side variables in the unrestricted equation. The log likelihood estimate for the unrestricted model is -34.6. Substituting these log - likelihood estimates from the unrestricted and the restricted equations into the likelihood ratio index formular presented previously yields:

$$\rho = 1 - \frac{L(\beta^*)}{L(0)} = 1 - \frac{-5.43}{-34.6} = 0.84$$

As mentioned earlier, the above value is a pseudo R^2 but may not be interpreted in the same manner one does normal R^2 . It however gives an indication of the explanatory power of the explanatory variables.

Further, an estimation of the likelihood ratio test as previously explained is necessary. The goal of this procedure (likelihood ratio test) is to allow testing of the hypothesis that the coefficients of the right hand side variables are zero. Again, using the log-likelihood estimates and substituting these values into the likelihood test formula yields:

$$-2[-5.4 - 34.6] \sim 40$$

Since the *chi square* statistic computed above is greater than the critical value of *chi square* with five degrees of freedom at 5 per cent significance level (11.07) we can reject the null hypothesis that the restrictions do not apply implying that the coefficients are not equal to zero. This implies that the variables are included in the equation are important explaining crop choice as formulated in the model.

³¹ This figure is estimated using Logit with the four restrictions. The coefficients and other regression statistics are however not reproduced.

4.3 Short - run Water demand equation

The short - run irrigation water demand equation, as noted in the previous chapter, can be functionally expressed as follows:

$$Lwater_i = \chi_1 + \chi_2 Lpowerco_i - \chi_3 Lprice_i + \chi_4 Lfcost_i + \chi_5 Tech_i + \chi_6 Gmonths_i + \chi_7 Lpropint_i + e_i \quad (73)$$

where the variables are as specified in Chapter Three and e_i is an independent, normally distributed error term with zero mean. The short - run irrigation water demand equation as formulated above was estimated in log - log form using OLS estimation procedure. This formulation allows the coefficients to be interpreted as elasticities. The regression output is presented in Table 4.2 below.

Table 4.2 : water demand equation's regression output

LS // Dependent Variable is LWATER

Date: 08/14/95

Sample: 1 63

Included observations: 63

Variable	Coefficient	Std. Error	T-Statistic	Prob.
C	4.778833	0.516677	9.249162	0.0000
Lpowerco	-0.046344	0.028176	-1.644845	0.1057
Lprice	-0.072592	0.045053	-1.611254	0.1128
Lfcost	0.383699	0.070233	5.463238	0.0000
Tech	0.244375	0.090339	2.705080	0.0091
Gmonths	0.110391	0.028514	3.871474	0.0003
Lpropint	0.157076	0.075291	2.086253	0.0416
Lngmarg	0.028268	0.036381	0.776990	0.4405

R-squared	0.610325	Mean dependent var	6.413587
Adj.R ²	0.560731	S.D. dependent var	0.459142
S.Error	0.304307	Sum squared resid	5.093166
L. likelihood	-10.16322	F-statistic	12.30620

The F-statistic for the short - run irrigation water demand equation of 12.3 is significant. This indicates that the variables included in the model are collectively significant in explaining short - run irrigation water demand; in other words, the model has explanatory power. The R-square statistic calculated for the output equation is 0.61, which implies that the model explains 61 per cent of the variation in short - run irrigation water demand across the 63 observations included in the analysis. All the coefficients do take the expected signs as hypothesised earlier except for the variable *lpropint* for which signs could not be determined *a priori*. As previously mentioned, given that the equation was estimated in log - log form, the coefficients may be interpreted as elasticities.

The variable for the costs of pumping, *Lpowerco* (i.e. the proxy for water cost) takes on a negative sign as expected and has a coefficient of -0.04 but is, nonetheless, not-statistically significant at the 10 per cent level. The coefficient is only significant at the 11 per cent level which is slightly above the conventional 5 to 10 per cent limit. Interestingly, this implies that water prices, or cost, is not a major determinant of irrigation water use. If the confidence limit were to be relaxed the coefficient would signify the modest inelasticity of water demand with respect to water costs as reflected by the proxy, irrigation power costs. This result is a critically important one for policy purposes.

The coefficient of the crop price variable, *lprice*, takes on the hypothesised sign and is significant at the 15 per cent confidence level. The coefficient could be interpreted to mean that the elasticity of short - run irrigation water demand with respect to crop price is low, i.e. 0.06.

The coefficient of the fixed irrigation costs, *lfcosts*, not only has the hypothesised sign but is also statistically significant. This is an important finding for irrigation water - saving policy consideration. It indicates that once farmers have invested in irrigation outlays, which are often very costly, they will make good the use of such investment by applying as much water as the crops and climatic conditions will dictate with no significant attention or motivation to limiting irrigation water use. The coefficient may be interpreted that the higher the initial investment cost in irrigation outlays, the less inclined the farmer would be to limiting his per hectare irrigation water application.

The coefficient of the technology variable, *tech*, is statistically significant at the 1 per cent level. The coefficient may be interpreted to mean that the elasticity of water demand with respect to the technology adopted -- sprinkler -- is low; it is relatively inelastic at 0.24. Since the variable was estimated in a dummy form taking the value 1 if sprinkler technology and 0 otherwise, the coefficient could be interpreted to imply that the short - run elasticity of water use for sprinkler irrigation systems is positive, but relatively inelastic. The low elasticity signifies the water - saving attributes of the technology in question, and thus provides an important consideration for policy purposes.

The length of the crop - growing season, as represented by the variable *gmonths*, has a statistically significant coefficient and takes on the correct sign. As postulated earlier, crops that have longer growing seasons have higher irrigation water application requirements in both absolute and relative terms than do those with shorter period requirements; hence the positive relationship. The coefficient, 0.11, may be interpreted to mean that the elasticity of short - run irrigation water demand with respect to the length of crop - growing season is inelastic.

The variable *lpropint* was explained as reflecting the relative position of the individual farms with respect to their ability to cover their working costs. We noted that there was no *a priori* evidence for hypothesising either sign or direction of correlation. From the regression results, it is apparent that the relative farm indebtedness with regard to operating capital is positively correlated to irrigation water use. The coefficient of 0.15 can be interpreted to suggest that the short - run elasticity of irrigation water demand is quite low with respect to the farm's operating capital status.

The variable, *gmargin*, does not influence short - run irrigation water demand as exemplified by its statistically insignificant coefficient. It does, however, take the hypothesised sign.

4.4 Technology choice equation

As suggested in Chapter Three, the technology choice decision by irrigators is influenced by: the cost of the technology as reflected in the per hectare irrigation fixed cost; the per hectare power expenditure; the per hectare gross margin; water use; a region dummy taking the value 1 if Free State and 0 if Transvaal; and the per hectare irrigation labour hours. The equation may be written as:

$$Techs_i = \lambda_1 + \lambda_2 fcost_i - \lambda_3 price_i + \lambda_4 gmargin_i - \lambda_5 powerco_i + \lambda_6 region_i + \lambda_7 lhours_i + e_i \quad (74)$$

Table 4.3 : Logit regression output : Technology choice equation

LOGIT // Dependent Variable is TECHS

Date: 08/07/95

Sample: 1 63

Included observations: 63

Convergence achieved after 8 iterations

Variable	Coefficient	Std. Error	T-Statistic	Prob.
C	-12.24439	3.863546	-3.169210	0.0025
Price	-0.348143	0.301219	-1.155780	0.2527
Gmargin	0.509731	0.358186	1.423092	0.1603
Region	5.357385	1.692518	3.165334	0.0025
Lhours	1.086472	0.518510	2.095374	0.0407
Fcost	1.826037	0.856265	2.132559	0.0374
Powerco	-0.136724	0.497346	-0.274908	0.7844

Log likelihood	-20.2
Obs with Dep=1	31
Obs with Dep=0	32

It can be observed from the regression output in Table 4.3, above, that all the coefficients take on the anticipated signs. It is also apparent that the *price*, *gross margin* and *powercost* variables are not significant in explaining technology choice. As has been mentioned earlier, the coefficients of the *logit* model are interpreted as describing the effect on the logarithm of the odds that either choice (i.e. discrete dependent variables) will be made given a set of independent variables. The coefficients of the regional dummy variable, the per hectare fixed costs and the per hectare irrigation labour requirements are positive and statistically significant. Since the interpretation of the overall goodness-of-fit for qualitative choice procedures uses the likelihood ratio test, the same procedure, as already applied in the crop choice equation, is undertaken here. The log - likelihood estimate with the three restrictions is - 43.9. Substituting this, and the log likelihood statistic in Table 4.3, for the unrestricted model into the log likelihood ratio test formular gives:

$$-2[-20.2 - 43.9] \sim 128.2$$

Since the value computed above is greater than the critical value of *chi* square with six degrees of freedom at 5 per cent significance level (12.59), we may reject the null hypothesis that the coefficients of the explanatory variables are equal to zero i.e. the restrictions do not apply. Thus, we may likewise conclude that the model, as a whole, has explanatory power. Likewise using the likelihood ratio index formular yields:

$$\rho = 1 - \frac{L(\beta)}{L(0)} = 1 - \frac{-20.2}{-43.9} = 0.53$$

The above value is a pseudo R^2 but may not be interpreted in the same manner one does normal R^2 . Never the less, the index of 0.53 gives a 'feel' of the 'performance' of the model.

4.5 The Output equation

The per hectare crop output equation was modelled as a function of the per hectare water application, amount of labour hours and other inputs, applied, the position of the farm with regard to operating capital, the energy costs and the crop price. The model is functionally given below.

$$Loutput_i = \delta_1 + \delta_2 Lwater_i + \delta_3 Loglhrs_i + \delta_4 Lphcost_i - \delta_5 Lenergy_i - \delta_6 Lprice_i + e_i \quad (76)$$

The crop output model, as formulated above, was estimated using OLS estimation procedure. The variables are in log form, implying that they may be interpreted as elasticities. The ordinary least square estimates of the model are given in Table 4.5 below.

Table 4.4 : Regression output : crop output equation

LS // Dependent Variable is LOUTPUT

Date: 08/14/95

Sample: 1 63

included observations: 63

Variabl e	Coefficient	Std. Error	T-Statistic	Probability
C	0.317254	1.592429	0.199026	0.8428
Lwater	0.666731	0.213781	3.118765	0.0028
Loglhrs	0.262894	0.089906	2.924087	0.0049
Lphcost	0.396317	0.127851	3.099836	0.0030
Lenergy	-0.336527	0.133390	-2.522882	0.0145
Lprice	-0.684249	0.107456	-6.367687	0.0000

R-squared	0.541685	Mean dependent var	1.534602
Adjusted R ²	0.501482	S.D. dependent var	0.937466
S.Error	0.661990	Sum squared resid	24.97280
L.likelihood	-60.24468	F-statistic	13.47372

The F-statistic computed for the equation is significant, implying that the variables included in the model are collectively significant in explaining observed crop output per hectare. In other words, the model as a whole has explanatory power. The R-square statistic computed for the output equation is 0.54, which implies that the model explains only 54 per cent of the variation in the per hectare crop output across the 63 observations included in the analysis. All coefficients have the expected signs. The coefficient of *lwater*, the amount of irrigation water applied, is positive as previously anticipated. The coefficient-statistic for *lwater* was estimated as 0.68, and reveals that crop output is quite elastic with respect to irrigation water application, i.e. elasticity of 0.68. This result underscores the significant role that irrigation plays in crop production.

The coefficient of the variable, *Loglhrs*, for amount of labour hours applied per hectare, also takes the anticipated sign. The coefficient, estimated at 0.26, may be interpreted to mean that the elasticity of output with respect to the amount of labour hours applied per hectare is low (0.26). This implies that output is quite inelastic or relatively unresponsive to variations in the amount of labour hours applied per hectare. The t-statistic computed for this variable is statistically significant.

The coefficient of pre-harvest costs, *lphcost*, also has the expected sign. The coefficient estimate of 0.39 implies that the elasticity of output with respect to expenditures on inputs other than water and interest payments (previously defined) is quite low. The t-statistic for the coefficient is significant at 2 per cent level.

The coefficient of the interest variable, *lpropint*, has the expected sign. The coefficient estimate of - 0.16 may be interpreted as implying that the elasticity of output with respect to interest payments is low. The result would have indicated that farms with higher debt obligations are, *ceteris paribus*, more likely to have lower per hectare outputs but the coefficient is, however, statistically insignificant.

The variable for energy use per hectare, *lenergy*, also has the expected sign. It may be interpreted as the elasticity of output with respect to energy, we observe it is a low 0.33, i.e. it is rather inelastic. The t -statistic is significant at 1 per cent level.

The last variable, *lprice*, also has the expected sign. The coefficient of 0.68 may be interpreted that the elasticity of output with respect to crop prices is relatively elastic. This suggests a marked positive response in output to crop prices. Moreover, the t-statistic for the price coefficient is significant. It should be realised, however, that there is a likelihood of a possible dual causation between price and output. This is particularly the case for crops whose prices were not traditionally set by Marketing / Control Boards and which, therefore, were largely determined by market forces. Under such circumstances, use of at least three stage least squares, preferably simultaneous equations procedure would have been recommended. This has, however, been ignored for the reason that most of the crops in the sample had their prices set by the Boards and thus output levels do not influence prices. Thus, there is an unambiguous unidirectional causation from price to output and not vice versa. Secondly, even if the causation could not be determined on the basis of Board controlled prices, our sample size is too small to accommodate simultaneous equation estimation.

4.6 Summary and conclusion

In this chapter, we have presented empirical results of the equations discussed in Chapter Three. This section highlighted the important empirical findings which have policy implications. These are followed up and discussed in Chapter 5. Here we compare and contrast our findings with those reviewed in Chapter 2.

Our particular interest in the crop choice equation was to determine whether the water demand attributes of specific crops determine the probability of farmers choosing to grow a particular crop. In other words, to determine whether crop choice was sensitive to higher water costs. We modelled crop choice as a function of the per unit crop price, water demand, per hectare gross margin, its per hectare labour requirement and the circumstances regarding the farm's working capital and other input requirements. Obviously, the variable of special interest here is water use. Our results indicate that, on the whole, water use and by extension water

prices do not affect farmers' crop choice decisions. The most important variable is the per hectare gross margin associated with a particular line of production. All the other variables in the equation were not significant. This finding is in agreement with Howitt *et al* (1990), whose study notes that the 1,927 farmers in their sample of the Western US, tend to adopt higher valued crops, in response to higher water prices, and that this shift had little to do with water - saving attributes of the crops *per se*. It does, however, contrast the finding of Kim *et al* (1990), who report that in the Ogallala aquifer of the Texas High plains, farmers responded by not only reducing water applied but, also by switching to higher value crops. In our case, the statistical insignificance of the water demand variable in the crop choice equation does indicate that water price has an insignificant influence on crop choice.

For the short - run water demand equation, our results indicate that the proxy for water cost, *lpowerco*, had a negative coefficient, as supported by theory; but this was, nonetheless, statistically insignificant. In other words, farmers' water use / consumption does not respond significantly to water cost. This finding is in agreement with the findings of Carey *et al* (1990), Just *et al* (1990b), Alouze C.M (1990), Antle and Hatchett (1990), Caswell *et al* (1990) and Clayton *et al* (1990). In the same vein, it is in contrast to the findings of Just *et al* (1990a), Burt *et al* (1990) and Kim *et al* (1990).

The technology choice equation was designed to answer the question of whether water prices have a significant role in influencing the adoption of more water - conserving irrigation technologies. Our estimates for the water cost proxy, *powerco*, is statistically insignificant. It is apparent from our results that it is not *water cost* that explains the choice of technology adopted, but the differing labour requirements for use with those technologies in question the capital costs per hectare occasioned by the choice of technology, and the disparities in regional characteristics as captured by the regional (dummy) variable. This important finding contrasts, for example, that of Howitt *et al* (1990) who, in their study of six counties of the San Joaquin Valley of California, found water cost to influence irrigation technology adoption.

The last equation estimated, per hectare crop output, yielded a statistically significant water use coefficient. This confirms the normal expectation of the critical role of water in irrigated agriculture as a determinant of farm output. This is in agreement with several other studies; e.g., Burt *et al* (1990). We turn to the policy implications for irrigated agriculture in the study region in particular and South Africa in general. This is the subject of Chapter Five.

CHAPTER 5

POLICY IMPLICATION AND CONCLUSION

5.1 Policy Implications

The empirical findings of the previous chapter have important policy implications that go beyond the narrow confines of irrigated agriculture. However, for the sake of limiting ourselves to more central issues, we shall here focus exclusively on the implications it does have for irrigation water policy. The conclusion to be drawn from our analysis, and one that most economists involved in the irrigation water research would not have initially expected, is that farmers' consumption of water does not seem to respond to water prices in making their crop water application decisions. This result, however, is not difficult to comprehend. It results from the fact that *water cost* forms a modest proportion of a farmer's total production costs and therefore it need not significantly influence either the amount of irrigation water applied or the choice of crops or of technology. This suggests that changes in water prices, alone, will not be effective in achieving efficient water use in irrigated agriculture. This said, one needs to bear in mind that, in South Africa, the cost of irrigation water has been so low that farmers have had little reason to be significantly influenced by water prices in either irrigation water application, crop or technology choice. Moreover, many farmers received credit for installing irrigation and farm water improvements at preferential and concessionary terms. This made the development of on-farm irrigation infrastructure relatively inexpensive and, indeed, easy. It is clear, therefore, that the efficacy of pricing as a tool for efficient water use has been compromised by its unduly low cost and negligible weight in the farmers' production costs. Thus, it could still be relied upon, if, together with other measures to guide farmers towards efficient and more conservative use of this important input, its price were to approximate its opportunity cost and scarcity value. It is also clear that prices need not be used in isolation to effectively perform their important rationing function. This suggests that other forces, together with prices, must be relied upon to achieve and perform those functions that prices alone seemingly fail to perform. As a starting point, it might be useful for policy makers to note those functions, in addition to rationing, which water prices are expected to perform and then proceed to identify and assign alternate and or price-supporting policy prescriptions.

Specifically, it is anticipated that the pricing of water should give users an incentive to pursue efficiencies in its utilisation. This is in stark contrast to the reality that in South Africa, water has hitherto been 'under-priced' as an economic good. Part of the explanation for this under-pricing, other than the political importance of farmers and the importance of agriculture in achieving security in food production (especially during the era) is the widespread and misbegotten belief and conceptualisation of water as a 'free resource'. This belief, pervasive as it seems to be, necessarily has unfortunate consequences. These include conflicts between user sectors not only regarding the quantity available to the several sectors, but also conflicts regarding externalities which are not internalised into the costs to each user sector. For example, chemical pollution from irrigated agriculture and ground water depletion will affect industrial and domestic users. In short, water prices should encourage efficient utilisation, arbitrate and resolve inter and intra - sectoral allocations while minimising negative externalities.

Secondly, pricing is intended and conceived as a tool for 'screening' and discouraging lower valued uses thereof, e.g. low - value irrigation crops. This would result in both optimal inter - and intra - sectoral allocation. Prices are thus envisaged to lead to a situation where water can thus be freed or transferred to more profitable uses. It is obvious that an effective performance of this role by the price mechanism would, in the long term, be of interest to both farmers and broader interest groups within the nation in so far as it encourages shifts into lines of production (crops) that are profitable, exportable, and income and employment generating. Pricing is, thus, a tool for, amongst other things, increasing economic efficiency, encouraging growth as well as promoting environmental protection.

In short, two issues are obvious: the first is that water must be priced to reflect its true opportunity cost; secondly, non - price policy tools exist that, together with correct pricing, should make those objectives contained in the last two paragraphs attainable. The issue of opportunity cost pricing of water is a contentious one. It should be clear that an attempt to "price water" as an economic resource via the price mechanism is likely to encounter political opposition as well as attract the opposition of various interest groups of water users. It is, thus, clear that even though the adoption of opportunity cost pricing is a desirable tool for proper resource management, the political costs of its implementation are certainly not negligible and need to be addressed.

Moreover, much as opportunity cost pricing is theoretically appealing and consequently favoured by many economists, one should not, however, assume away the difficulties involved in devising such a policy. For example, the total opportunity cost must embody environmental and social costs and is a difficult goal to achieve. Perhaps it is this difficulty that has led to water authorities such as those in Israel to adopt a Cost - Plus pricing policy as opposed to a pure opportunity- cost - based pricing that economists would favour. It could be suggested that, as a starting point towards future opportunity cost based water pricing, cost-plus pricing could be implemented as a gradual free - market for irrigation water is considered.

Leaving these two conceptual difficulties aside, there are yet other complications that an opportunity cost based irrigation water pricing policy cannot ignore. First, opportunity cost pricing cannot exist effectively in a situation where water markets are non - operational. To the extent that water markets are non - operative, true opportunity - cost based pricing will be illusory. Secondly, water markets are, *themselves*, tied to the legal status of water rights. For example, riparian rights presume that one has land entitlements. In South Africa, the skewed distribution of land ownership would mean that black farmers might as well have no, or few, riparian water rights. This importantly implies that land redistribution policies must go hand - in - hand with policies regarding water rights. Thirdly, it is important that irrigation water policy and pricing take due cognisance of the wider objectives of agricultural policy as contained in the 1995 White Paper on Agriculture which sets out the policy objectives for this decade. Notable objectives for which special attention needs to be taken include assuring low and stable prices for basic foods, consumed by, especially, low income earners; supporting the restructuring of the agricultural system and the transfer of ownership of agricultural resources, such as water, to redress the injustices created by apartheid; widening access to agricultural services; encouraging efficiency and sustainable practices in the allocation and use of agricultural resources so as to encourage economic growth, increased productivity and employment, among yet other objectives. (Backeberg *et al*; 1993). In other words, even if true opportunity cost water pricing were tenable, its implementation must take due cognisance of the diverse groups, objectives and functions within the agricultural sector.

It must be noted, however, that while prices are the *conditio sine qua non* for efficient water allocation in the future as competition for this vital, and scarce resource mounts, there are other complimentary, non-price policy tools for enhancing efficient water use and its conservation. For example, Irrigation water use literature is abound with the contention that risk aversion, on the part of the farmer, is one of the causes of excessive water application beyond optimal levels. To the extent that this is true for South Africa, implies that policies that address crop insurance could have an indirect, but nonetheless important role to play in water conservation. Research and extension services are other important non-price alternatives to irrigation water conservation. From the empirical analysis of Chapter 4, it is clear, for example, that the crop growing season length has a major influence on short run irrigation water demand. Over time, scientific research has been able to develop crop varieties that are not only high-yielding but which also mature early. Since crop season length has an important influence on short-run irrigation water demand, research into such varieties and purposeful extension services aimed at their adoption could complement price-based water conservation efforts. Indeed, there is much latitude for propagating and disseminating these ideals among emergent small scale farmers who are likely to benefit from land redistribution and who will obviously face more severe water scarcity problems than do their more established commercial farm counterparts. Additionally, there are other good reasons for stressing the importance of this point especially amongst emerging farmers. It is obvious that such farmers are not likely to enjoy the same advantages in terms of access to fixed and operating capital credit at concessionary terms, as was the case with their commercial counterparts, and thus measures that do not interfere with input prices should be preferred as a means of assisting emerging small scale, black farming enterprises that will engage in irrigated agriculture. Secondly, small farmers are likely to have limited technical and managerial skills that are necessary for conservation-oriented farm management practices. Therefore, these and other issues regarding the adoption of more efficient irrigation technologies are all central to a meaningful discourse regarding irrigation water price policy.

As part of the non-price approach to irrigation water management, the influence of risk management in irrigation agriculture has been advanced in the literature on irrigation water conservation and is not without merit. Risk aversion has been given as a possible reason for intensive irrigation practices i.e. irrigation water

over application. This is a *management*, non - price approach to irrigation water conservation that merits further consideration especially as regards policies pertaining to crop insurance. It could be argued that where crop / agricultural activity risks are appropriately covered, farmers are expected to be largely less risk averse in making decisions and implementing changes in their farm businesses. In the context of this dissertation, such management changes hinge on greater reliance on crop insurance as a means of reducing the riskiness of farming and specifically in discouraging farmers from over-applying irrigation water. The point is that an effective insurance cover may substitute for water over-application as a form of insurance from the farmer's perspective. Crop insurance may, thus, provide a market-friendly support to the exclusive use of water-pricing or cost - based approaches as the sole means of containing water over- use in irrigated agriculture.

A further consideration in terms of irrigation water policy is that increased efficiency in irrigation water use requires a policy shift away from 'supply - oriented' Engineers' approach that considers the development of new dams, canals, and irrigation water system as the sole means of addressing irrigation water shortages and more towards the management of demand, through a combination of price induced reallocation and demand management. It is thus imperative that policy makers think not in terms of what the crop's irrigation water demand is, but more towards, farmer's water demand for irrigation. The two need not be the same by definition and this has important implications for water conservation. Such a shift in policy would go a long way towards achieving sustainable development in irrigated agriculture in South Africa in the face of fierce competition for scarce public funds from other sectors such as health, education, housing and yet others or even between irrigation water supply and household water supply projects. Therefore, conservation will need to be encouraged through those of pricing mechanisms, new technologies, education and optimal management measures and not by supply-oriented new investments in irrigation water supply projects and schemes.

Another approach that has been proposed as a measure to induce efficient water use in irrigated agriculture, and especially in those that are reliant on underground water, are pump taxes. The theoretical justification for such taxes is based on the need to combat common-pool externalities. In South Africa, however, there are

difficulties in this approach that prevent its immediate application. To begin with, the administration of the tax itself would be complicated and relatively expensive to implement. Secondly, complications arise with regard to water rights as presently constituted. Thirdly, and assuming that the tax could be implemented, the observed non responsiveness to water costs on the part of the farmers, as evident from empirical estimates in Chapter Four, indicates that one can only expect or anticipate relatively modest reductions in per hectare water use from such a tax and yet more difficult adjustments as marginal farmers have to stop irrigating or leave farming business altogether.

It is also important that irrigation water policy, especially to extent that the small - scale, black farmer is going to be the focus of it, does not neglect an important dimension, gender. Women are likely to be affected in at least two ways. First, in the rural communities and amongst emergent black farmers, women provide the bulk of the labour force in agriculture and any effects of irrigation water policy that impacts either negatively or positively on the profitability of rural - small farm irrigated agriculture will certainly affect them. Policy makers must therefore at least anticipate some of these effects. It is common knowledge that new agricultural technologies , in particular those that enhance extensive land use via improved productivity and profitability, commonly increase demands on women's labour. Secondly, when discussing water prices, water markets and water rights that go with it, it is important to realise that women's inaccessibility to land would alienate them from effective access and ownership of water rights except, perhaps, only via common property arrangements embedded in the nuptial contracts with their husbands. It is important therefore that changes in the legal framework that are geared towards making water the economic good that it is via, for example, revision of water rights, must not lose sight of its implication to gender issues. Further, it is not just women that are likely to be negatively affected by such changes in water rights, the poor need to be taken into account as well. To the extent that riparian rights are dependent on whether one has property (land), and given the extent of landlessness, and the skewed distribution of land ownership in South Africa, it is imperative that such changes are carefully evaluated to ensure that they do not harm, especially, women and the poor

Finally, a cautionary note is necessary. The results of this study are only as good as the assumptions and the data used in the analysis. While, for comparative

reasons, we have attempted to employ (with modifications) one of the models that have been used in other studies, the data used in the analysis is secondary data and thus the results are perhaps less reliable than desirable. Secondly, the study has focused exclusively on farmers who did their own pumping, as opposed to those who received state subsidised, low - priced water, and therefore any comment made with regard to public irrigation schemes is based not on empirical analysis but the general literature on public irrigation schemes. Thirdly, the data and models estimated pertain to the Orange Free State and Transvaal provinces only. Whereas we believe that, the results may not be dramatically different in other provinces with regard to short - run agricultural water demand, we are reluctant to make policy suggestions for areas outside the study area, or blanket generalisations which may not necessarily be supported by the data. Subsequent research should examine yet more specific, and well defined regions.

5.2 Conclusion

South African agriculture has witnessed phenomenal expansion, both in space and output, over the last decades. Central to this achievement has been irrigated agriculture. However, as population and industrial growth continue, inter - and intra - sectoral competition for water may be expected to intensify. It is not unreasonable to suggest that the scarcity value of water, in whatever use, will of necessity rise and its conservation become increasingly important. Since agriculture accounts for the largest single proportion of water use, it is imperative that conservation and proper pricing policies aimed at its efficient utilisation begin in this sector. One would expect water prices to play a leading role in this regard. One would further expect conservation and efficient utilisation of water in agriculture to be manifested in choice of high value crops and adoption of more efficient water conserving techniques and irrigation water demand that is quite elastic with respect to water price / cost. Our findings are, however, to the contrary. It is clear from our analysis that water prices neither affects the derived demand for irrigation water, nor does it feature prominently in decisions regarding conservation, crop and technology choice. We have indicated that the inefficacy of pricing as a tool in the performance of its functions in irrigation water management, to which we alluded earlier in this Chapter, may be due to the fact that irrigation the cost of irrigation water as a per cent of the farmers total variable cost, in South Africa is too low to solicit any appreciable response from them. Moreover, and much as proper pricing is critical for efficient irrigation water use, we have stressed that conservation and the achievement of other objectives with regard to water conservation need not be the preserve of water price policy alone. We have suggested other ways and means of ensuring the achievement of efficiency in irrigation water use which should enhance water conservation. Such measures included purposeful extension service and education into available and more efficient irrigation technologies, research into, and the adoption of, early maturing crop varieties, as well as the institutionalisation of crop insurance as possible ways of increasing water conservation and more efficient utilisation of water in irrigated agriculture. While these measures can enhance efficiency in water use, one role these alternative measures can not perform well is the allocative function, which, water price alone seem to have done well in other countries regarding the allocation and use of irrigation water and other resources. Our results, until now, could indicate that prices do not serve this allocation

function in South Africa as they appear to have done in other countries. Perhaps, with the passage of time and with reductions in input and output pricing policy distortions, prices will re-assert themselves as important determinant of the demand for this exceedingly important resource in irrigated agriculture.

Appendix 1 : Data Used in the analysis

BUDGET	ENERGY	FCOST	FUEL	GMARGIN	GMONTHS	HVCROP	INPUTS	INTEREST
241	3366	220	869	761	9	0	1013	130
243	2062	62.55	495	355	5	0	1630	170
244	2291	70	543	1528	6	0	1660	146
245	3208	97	760	390	7	0	1966	143
246	2368	71	561	9530	6	1	5300	386
247	2520	76.45	597	1254	6	0	1467	152
248	366	111	869	16126	7	1	2749	224
256	2037	52.1	482	258	5	0	1169	118
258	2040	52.1	483	1720	5	0	1709	124
259	21122	54.07	500	766	6	0	1944	210
261	616	13.82	146	1717	4	1	6196	477
264	1258	28.19	298	1758	10	0	402	91
275	339	34.7	80.37	2324	8	0	1179	107
276	370	37.9	87.7	1598	5	0	801	98
280	1602	41.02	379	1758	6	0	2003	146
281	2395	18.3	396	500	6	0	1969	166
282	1702	43.5	403	143	6	0	1265	163
283	1378	35.29	326	1302	5	0	1561	93.93
284	1637	41	387	617	6	0	907	70
286	2623	35.4	621	1958	7	0	1605	170
287	2244	57	531	3570	6	1	1009	127
288	4687	120	1110	1897	11	0	1927	140
293	2497	255	591	2564	7	0	5147	540
413	1998	89	473	2223	5	0	3817	196
414	1156	91	274	4861	4	1	1570	119
420	2361	145	559	2811	4	0	16627	2307
421	809	36	191	1305	4	0	3521	106
429	1233	55	292	8256	4	1	2481	170
430	1230	55.14	291	5260	4	1	2913	95
441	1850	82.9	438	4519	5	1	4827	338
443	986	44.2	233	3294	7	1	1839	268
444	809	36.28	191	9391	4	1	4021	140
463	6622	200	1569	1878	4	0	22339	126
572	6837	175	1620	128	4	0	1848	195
573	2674	59	633	1020	4	0	2178	144
593	1936	40.6	458	748	4	0	1660	97
594	1233	55	292	936	5	0	1111	92
597	4137	125	980	216	6	0	1332	151
610	847	24	200	15.8	5	0	1717	250
618	1356	60	321	571	5	0	792	77
578	1973	88.4	467	2078	7	0	898	122
579	5500	91	1303	1470	5	0	1422	158
606	1846	41	437	651	6	0	921	119
612	3846	49	911	253	5	0	1899	308
619	1387	31	328	566	5	0	989	78
448	1156	51	274	1874	4	0	1537	117

440	1850	83	438	3903	5	1	4471	178
434	3545	208	840	5556	7	1	4390	344
435	4586	157	1086	2187	6	0	1770	171
452	1942	87	460	1374	6	0	12763	1004
453	5781	259	1370	236	5	0	6982	520
569	3787	114	897	1625	4	0	810	107
584	1310	58.7	310	1244	6	0	3496	407
585	1310	58.7	310	1470	5	0	2586	212
606	4877	102	1156	2137	6	0	2245	150
616	2004	89	474	109	6	0	1615	110
622	2062	86	488	3231	2	1	3566	148.3
623	4675	196	1107	3231	7	1	3699	307
624	3666	111	869	1611	3	0	2268	128
625	2053	92	486	2843	7	0	1462	3072
626	1190	53	282	2849	5	0	5820	722
627	909	40	215	2257	4	0	8719	501
629	1742	78	412	6395	6	1	7948	387

BUDGET INTEREST IRIGMP MHOURS OUTPUT PHCOST POWERCOS PRICE

241	130	0.165	66	17	2128	0.7242	280
243	170	0.0102	37	6	2144	0.7242	330
244	146	0.102	41	5.5	2379	0.7242	750
245	143	0.102	58	2.6	2911	0.7242	1500
246	386	0.0102	43	2.4	6278	0.7242	1500
247	152	0.0102	45.8	1.5	2249	0.7242	1824
248	224	0.0102	66	30	3890	0.7242	986
256	118	0.0072	27	8	1833	0.5925	330
258	124	0.0072	27	6	2368	0.5925	750
259	210	0.0071	28	3	2725	0.5925	1500
261	477	0.0048	16.6	2.5	7222	0.293	1500
264	91	0.0048	34	15	1417	0.293	280
275	107	0.0075	18.3	5.5	1417	0.1462	750
276	98	0.0075	20	7.5	1082	0.1462	330
280	146	0.0071	21.37	6.5	2613	0.5925	750
281	166	0.0019	64.7	10	2177	0.5925	330
282	163	0.0071	22.7	7	1910	0.5925	330
283	93.93	0.0071	18.38	2	1984	0.5925	1857
284	70	0.0071	392	2.7	1438	0.5925	839
286	170	0.0071	34	3.5	2499	0.5925	1500
287	127	0.0071	29	2.45	1759	0.5925	1824
288	140	0.0071	62	20	1458	0.5925	280
293	540	0.0071	135	50	7118	0.7308	986
413	196	0.0071	108	5	4667	0.7308	1541
414	119	0.0202	62	2	2290	0.7308	638
420	2307	0.0208	127	3.3	3893	0.505	3630
421	106	0.0202	43	10	3311	0.7308	1168
429	170	0.0202	66	18	3409	0.7308	990
430	95	0.0202	66	2	2114	0.7308	677
441	338	0.0202	100	26.8	5615	0.7308	367
443	268	0.0202	53.3	2	2443	18.5	3200

444	140	0.0202	43	30	4426	35	1230
463	126	0.0191	120	2.5	3687	1.357	4000
572	195	0.0354	91	1.5	3687	2.962	2600
573	144	0.0227	78	2.5	3001	1.34	970
593	97	0.0233	52	3	2249	1.46	360
594	92	0.0202	66	4	1534	0.7308	746
597	151	0.0202	75	3.8	2566	1.5	746
610	250	0.0122	45	7	2194	0.7308	350
618	77	0.0202	73	2.4	1258	0.7308	839
578	122	0.0202	106	1.35	1586	0.7308	1825
579	158	0.024	100	2	3049	2.17	889
606	119	0.0202	99.8	7	1573	0.7308	330
612	308	0.0397	207	4.15	3251	1.3919	1000
619	78	0.0202	75	2	1396	0.7308	427
448	117	0.0202	62	18	2255	0.7308	486
440	178	0.0202	100	30	5157	0.7308	367
434	344	0.0207	191	3	5753	0.7308	4300
435	171	0.0182	83	2.2	3154	1.4293	3200
452	1004	0.0202	103	4.5	15079	0.7308	1080
453	520	0.0202	312	40	9134	0.7308	240
569	107	0.0202	68	3.1	1910	1.508	674
584	407	0.0202	70	2.5	4335	0.7308	1550
585	212	0.0202	70.8	2.2	3126	0.7308	885
606	150	0.0233	131	8	3641	10461	235
616	110	0.0233	108	4	2223	0.7308	600
622	148.3	0.0233	37	3	37650	2.17	3200
623	307	0.0305	85	3	5174	2.172	3200
624	128	0.0305	66	1.19	3282	2.172	170
625	3072	0.0202	111	2.189	50000	0.7308	7610
626	722	0.0202	64	2.189	59486	0.7308	7610
627	501	0.0202	49	2	9688	0.7308	4840
629	387	0.0202	94	1.7	8758	0.7308	7610

BUDGET	PROFIT	PROPINT	REGION	TECH	WATER
241	-1.0283	0.06109	1	1	1200
243	-1.79831	0.079291	1	2	675
244	-0.44272	0.06137	1	2	750
245	-2.01011	0.049124	1	2	1050
246	0.417393	0.061485	1	2	775
247	-0.58415	0.067586	1	2	825
248	1.422024	0.057584	1	2	1200
256	-1.96075	0.064375	1	2	815
258	-0.31972	0.052365	1	2	816
259	-1.26904	0.077064	1	2	845
261	0.897393	0.066048	1	2	500
264	0.215635	0.06422	1	2	1020
275	0.494748	0.075512	1	2	549
276	0.389942	0.090573	1	2	600
280	-0.39632	0.055874	1	2	641

281	-1.4711	0.076252	1	2	1010
282	-2.59201	0.08534	1	2	680
283	-0.42121	0.047344	1	2	551
284	-0.84614	0.048679	1	2	654
286	-0.24397	0.068027	1	2	1049
287	0.70782	0.0722	1	2	897
288	0.263208	0.096022	1	2	1875
293	1.282462	0.075864	1	1	810
413	-0.74166	0.041997	2	1	648
414	0.752692	0.051965	2	1	375
420	-0.32564	0.592602	2	1	1118
421	-0.93105	0.032014	2	1	262
429	0.884521	0.049868	2	1	400
430	0.911549	0.044939	2	1	399
441	-0.21715	0.060196	2	1	600
443	0.298876	0.109701	2	1	320
444	0.752256	0.031631	2	1	262
463	-0.67461	0.034174	2	1	1156
572	-3.36054	0.052889	2	2	546
573	-1.07914	0.047984	2	2	472
593	-1.10084	0.04313	2	2	314
594	-0.49402	0.059974	2	2	400
597	-2.47483	0.058846	2	2	650
610	-4.93347	0.113947	2	2	275
618	-0.78989	0.061208	2	1	440
578	0.270191	0.076923	2	1	640
579	-0.72955	0.05182	2	1	600
606	-0.88223	0.075652	2	1	599
612	-2.55333	0.09474	2	1	655
619	-0.90277	0.055874	2	1	450
448	-0.18508	0.051885	2	1	375
440	-0.27861	0.034516	2	1	600
434	-0.03484	0.059795	2	1	1150
435	-0.36614	0.054217	2	1	760
452	-0.09263	0.066583	2	1	630
453	-3.65593	0.05693	2	1	1875
569	-0.1616	0.056021	2	1	595
584	-1.24839	0.093887	2	1	425
585	-0.75449	0.067818	2	2	425
606	-0.53286	0.041197	2	2	791
616	-3.01527	0.049483	2	2	650
622	-2.45554	0.003939	2	1	225
623	-0.47085	0.059335	2	1	510
624	-0.7116	0.039001	2	1	400
625	-0.56426	0.06144	2	1	666
626	-0.73798	0.012137	2	1	386
627	-1.45685	0.051713	2	2	295
629	-0.31445	0.044188	2	2	565

Source: Combud, Directorate of Agricultural Economics, 1994

Note: Variable Definitions

Budget = Farm Budget Serial number

Energy = Total energy used

Fcost = Irrigation Investment Fixed Costs

Fuel = Fuel budget

Gmargin = Per hectare Gross margin

Gmonths = Length of crop growing season (months)

Hvcrop = Value based classification of crops (1= above mean, 0 = otherwise)

Inputs = Expenditure on other inputs (e.g. chemicals and fertilisers) other than water.

Interest = Interest rate payment on operating capital credit

Irigmp = Expenditure on irrigation machinery and parts

Mhours = Machine hours

Output = Output per hectare

Phcost = Total preharvest cost per hectare

Powercos = Unit power cost

Price = Unit output price

Profit = Per hectare profit

Propint = Operating credit interest as a proportion of preharvest cost

Region = Region identification dummy (1 = Transvaal, 0= Orange Free State)

Tech = Irrigation technology type (1 = sprinkler, 0 = centre pivot)

water = Irrigation water applied per hectare

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