WATER USE EFFICIENCY AND INFLUENCE OF MANAGEMENT POLICIES, ANALYSIS FOR THE SMALL-SCALE IRRIGATION SECTOR IN SOUTH AFRICA

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Water use efficiency and influence of management policies, analysis for the small-scale irrigation sector in South Africa

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WATER USE EFFICIENCY AND INFLUENCE OF MANAGEMENT POLICIES, ANALYSIS FOR THE SMALL-SCALE IRRIGATION SECTOR IN SOUTH AFRICA

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List of abbreviations

ANOVA	Analysis of Variance
ARDC	Agriculture and Rural Development Corporation
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
CR	Contingent Ranking
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
GLM	General Linear Model
GM	Gross Margin
IMT	Irrigation Management Transfer
NWA	National Water Act
NWRS	National Water Resource Strategy
RIM	Residual Imputation Method
VRS	Variable Returns to Scale
WTP	Willingness To Pay
WMA	Water Management Area
WUA	Water Users' Association

CHAPTER 1

Scope, objectives and outline of the thesis

1. General introduction and problem statement

Water availability and water quality affect the level of output and hence economic growth. It is critical to all production chains of the economy and directly or indirectly it is a primary input to every economic good (Bouhia, 2001; Rosegrant et al., 2002; Birol et al., 2006). Moreover, water availability is also linked with poverty, with poor people spending a high proportion of their time, income and other resources securing water to meet there basic needs (Hope, 2006; Ward, 2007). Internationally there is a growing tendency to consider access to water as a human right (WHO, 2003). This is also translated in the Millennium Development Goals, where one of the targets is to halve population without access to clean water by 2015 (UNDP, 2005).

Currently however, this essential resource is under threat. Over the last 50 years water withdrawals have tripled. (World Water Assessment Programme, 2009). As human population grows, and as the level of economic development increases, the demand for water is growing, posing severe challenges on national governments in many countries. It is predicted that by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under conditions of water stress (UNWATER, 2007). The growing national, regional and seasonal water scarcities caused by the increased demand furthermore put severe pressure on international development and on the environment (Gleick, 1993; Bouhia, 2001; Rosegrant et al., 2002; Cook et al., 2006). As water becomes scarce, competition between different uses (agriculture, industry, households, energy, environment) has also increased. In developing countries this growing scarcity and competition for water threatens advances in poverty eradication, public health and food production (Ward, 2007). In addition, as these economies develop, environmental and other in-stream demands are becoming more important. It is in this context that the need for efficient allocation and use of water emerges and that the search for sustainable water policies is high on international and national agendas (Gleick, 2000; Bazzani, 2005; Kassam et al., 2007; Ward, 2007).

Currently the largest consumer of water in most developing countries is irrigation, with water demands often above 80% of total consumption. This illustrates the relevance of the irrigation sector as water user (Rosegrant et al., 2002; Bazzani, 2005). It has therefore been suggested that the most readily available path to meet future demands is achieving water savings in agriculture (Ringler, 2001; Rosegrant et al., 2002; Cai and Rosegrant, 2004). As a consequence irrigated agriculture is increasingly put under pressure to both demonstrate and improve upon its performance (Wichelns, 2002; Malano et al., 2004). It is likely that water will have to be diverted more and more to meet the needs of urban areas and industry, but this has to happen without compromising agricultural growth because food production has to meet rising population levels. Therefore improvements in the irrigation sector to increase water use efficiency are needed at the technical, managerial and institutional levels (Inocensio et al., 2002; Rosegrant et al., 2000; Wichelns, 2004). According to several authors (Wallace, 2000; Gleick, 2001; Cai et al., 2003; Molden and Bos, 2005; Kassam et al., 2007) scope for improving the efficiency and productivity of water use in agriculture is still considerable.

Because South Africa is a country that faces the above mentioned problems, it is selected as a case to study the efficiency of water use and the impact of water management policies. South Africa is a water scarce country. The temporal and spatial variations in runoffs and the unevenness of surface and groundwater distribution resulting from the climate and geography, considerably constrain the availability of water in terms of adequate, reliable and timely supplies at the required places for various users (Farolfi and Perret, 2002; DWAF, 2004; Prasad et al., 2005). Besides these limitations, the competition for water within a sector and across sectors in South Africa is still expected to increase due to growing water demands resulting from increasing economic activities and due to the national commitments to fulfil basic human needs and to preserve ecosystem integrity. An overview of the source-wise water supply and sector-wise water allocation in South Africa is given in Table 1.1 and 1.2. Irrigation clearly is the largest water consumer (Table 1.2). These tables also illustrate that the gap between total water supply and total water requirements has nearly closed. In several regions, water demand even already exceeded the available supply and progressively larger volumes of water are transferred from those catchments where water is still available (Ashton and Haasbroek, 2002). In 2005 already 11 out of the 19 Water Management Areas had deficit water supplies (Prasad et al., 2005).

Table 1.1. Source-wise water supply, South Africa, 2000

Sources	**Supply (Million m³/yr)**	**%**
Surface water	10240	77.4
Groundwater	1088	8.2
Usable return flow:	1899	14.4
From irrigation	*675*	*35.5*
From urban sector	*970*	*51*
From mining sector	*254*	*13.5*
Total	13227	100

Source: DWAF, 2004

Table 1.2. Sector-wise water requirements, South Africa 2000

Sectors	**Demand (Million m³/yr)**	**%**
Irrigation	7920	62.0
Urban	2897	25.1
Rural	574	4.3
Mining and bulk industrial	755	5.7
Thermal power generation	297	2.2
Afforestation	428	3.7
Total requirements	12871	100

Source: DWAF, 2004

Moreover, the expanding South African agriculture, mining, industry and urban sectors tended to develop in those areas poorly supplied by surface water resources. The previous political imperatives to build and maintain water supply schemes to support the predominantly white farming community also contributed to the uneven spread of demand for and access to water (Ashton and Haasbroek, 2002). However because water is now regarded as one of the key ingredients for sustainable development (Mkhandi, 2003; Pienaar and van der Schyff, 2007) it receives a lot of attention in South African legislation. In the new water legislation, introduced after the end of Apartheid, equity in access to water resources, benefits and services is emphasized, particularly for those who historically have not benefited from the country's endowment in water resources (Prasad et al., 2006). Moreover, it is clear that with the growing water scarcity, the increasing competition across water-using sectors and the increased concern about environmental sustainability, the need for water savings and more efficient water use has increased in importance in water resources management in South Africa.

The National Water Act of South Africa (Republic of South Africa, 1998) therefore created a new framework and a new institutional environment for integrated and decentralized water resource management. At regional and at local levels new management entities, catchment management agencies (CMA's) and Water Users' Associations (WUAs), are established (Hassan and Farolfi, 2005). There is also a need for improved water management strategies. Because water is used for diverse purposes and objectives the development of such strategies is quite complex. In general water resources management has become a field where computer-aided analytical techniques are expected to facilitate the complex process of decision making which involves several stakeholders with varied interests and various socio-economic objectives of the natural resource development and management strategies (Bazzani, 2005; Prasad et al., 2005; Hippel et al., 2008). Decision support tools help to facilitate the design and implementation of water management strategies (Haasbroek et al., 2003; Prasad et al., 2005; Juana et al., 2008).

Although there have been variations in interpreting what a Decision Support System (DSS) means, there seems to be some consensus as to its purpose i.e. to support decision making in more or less complex situations (Prasad et al., 2005). When evaluating policy goals and instruments regarding water allocation issues and improvements in water management it is important to consider economic criteria (Wichelns, 2002). Economic concepts and tools therefore constitute one type of DSS. They can be used to support policy formulation, implementation and evaluation. Economic analysis has the potential to inform the choice among numerous potential methods of improving the quantity and reliability of water supply as well as the choices for eliminating water resource deficits (Ward, 2007). The need for economic analysis for the design and implementation of efficient water resources management policies is well documented in the economics literature (Birol et al., 2006, Hellegers, 2006). Two functions can be distinguished: ex-post analysis and ex-ante analysis. In ex-post analysis an existing water use situation or existing mechanisms influencing the allocation of water are evaluated. In the case of agricultural water use this is helpful in identifying opportunities to increase the net values generated with limited water resources. Ex-ante analysis on the other hand is conducted to design future management policies that encourage farmers and water agency personnel to improve water management practices in ways that enhance social net benefits (Wichelns, 2002; Ward, 2007). Despite the numerous DSS developed for water resource management, the need to further develop decision support tools in this field and to provide information to policy makers is widely recognized (Bazzani, 2005; Mysiak et al., 2005; Prasad et al., 2007).

The small-scale irrigation sector was chosen as area of analysis. The importance of this sector in South Africa arises primarily from the number of participants involved. Backeberg (2006) estimates the number of South African smallholder irrigators to range between 200,000 and 250,000. However, in terms of surface they account only for about 100,000 ha of the 1.3 million ha which is under irrigation (Van Averbeke and Mohamed, 2007). Most of the smallholder irrigation schemes are located in the former homelands[1], where poverty is very high and in these poor socio-economic environments smallholder irrigation schemes present an attractive opportunity for the development of local livelihoods. Today, with increasing demand for water from alternative users and prevailing poverty and unemployment in the former homelands and by extension rural areas of South Africa, there is a strong need to increase the efficiency of resource utilisation and productivity in smallholder irrigation farming (Hedden-Dunkhorst and Mphahlele, 2000; Backeberg, 2006). This is a first objective of water policy towards smallholder irrigators in South Africa. Given the role attributed to small-scale irrigation in South Africa, the efficient use and allocation of water as a production input can actually be seen as an intermediate objective, moving towards the main objective of improving the livelihoods of people dependent on agriculture (Backeberg and Sanewe, 2006). A second important objective for small-scale irrigation schemes in South Africa is increased cost recovery. Government has been and still is investing substantial amounts of public

[1] A homeland or Bantustan, was territory set aside for black inhabitants of South Africa as part of the policy of apartheid. Ten Bantustans were established in South Africa to enforce a rigid system of racial classification and segregation (D'Haese, 2003; King, 2007).

money in smallholder irrigation (Perret and Geyser, 2007). Following the National Water Resource Strategy (DWAF, 2004) it now is governments' objective to recover water supply costs and the investment costs of these schemes (Backeberg, 2006).

2. Conceptual framework

This section will discuss the conceptual framework that is proposed in this study to inform water management for the small-scale irrigation sector in South Africa. The framework is presented in figure 1.1. As indicated above, in South Africa two main objectives for the small scale irrigation sector were identified by water management policy: using water more efficiently and allowing the recovering of water supply and infrastructure investment costs.

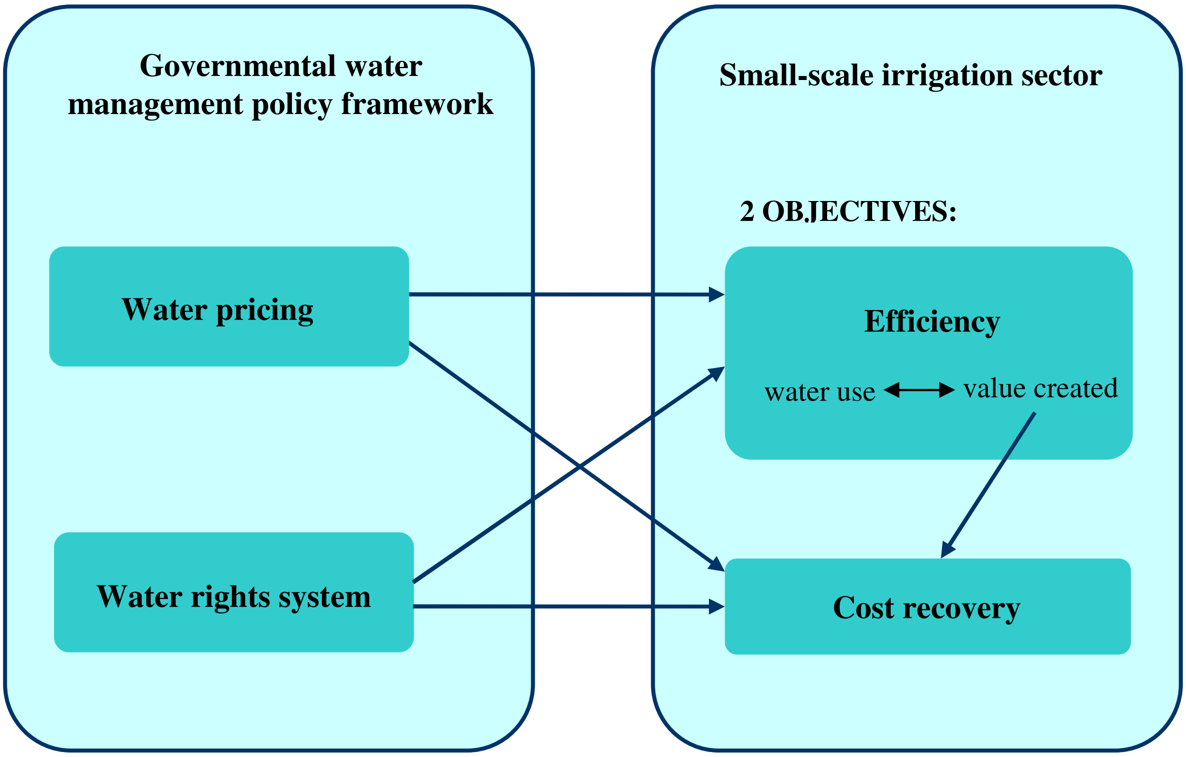

Figure 1.1 Conceptual framework to inform water management for the small-scale irrigation sector in South Africa

A first logical step to inform decision-making is to evaluate the current situation with regard to the two major objectives for the small-scale irrigation sector in South Africa. Such ex post analysis is crucial in understanding the challenges and opportunities for improved water management. As indicated in the conceptual framework, the efficiency of water use is understood as the relation between the value generated by the water use and the amount of water used. The more value generated with a certain volume of water, the more efficient a producer is; or alternatively a producer can also be more efficient by using less water to generate a certain value. This link with efficiency shows the importance of knowing the economic value of water. Thus, capturing the economic value of water use is an integral part in the design of economic incentives and institutional arrangements that can ensure sustainable, efficient and equitable allocation (Birol et al., 2006). Indeed, reliable estimates of water value help to make informed choices and can provide an important input in guiding rational decision making (Hermans et al., 2006; Hussain et al., 2007). The value generated by water use is also related with the cost recovery objective because it determines the capacity of farmers to pay for water. Knowledge of the value of water provides insight into the viability of cost recovery and its impact on the profitability of irrigation. Furthermore insight into the profitability of irrigation is especially useful to support decisions with respect to the rehabilitation of the irrigation system. Besides it helps policy makers to understand to what extent charging for water is helpful in practice, and what purposes it can serve (like cost-recovery and/or demand management) (Hellegers and Perry, 2004).

Under conditions of increasing scarcity of resources including water, performance measures play an important role in identifying opportunities to improve performance of small-scale irrigation schemes as production systems. An important pre-condition for identifying these opportunities is the understanding of the production function. Benchmarking individual producers against the production frontier of the best performing farmers gives information concerning the scope for improving efficiency and productivity (Malano et al., 2004; Malana and Malano, 2006). Increases in productivity can be achieved by two approaches: by increasing technical efficiency through more efficient utilization of production inputs; or by increasing allocative efficiency through production of outputs with higher returns (Cook et al., 2006). It is therefore essential to measure efficiency. The levels of technical and allocative efficiency are determined by decisions made by agricultural producers and managers of water systems. These decisions on their turn are influenced by the policy and regulatory instruments and by the level of complementary interventions such as infrastructural development (Cook et al., 2006).

Because of this potential to influence decisions, the governmental water management policy framework aims to encourage farmers to improve water management practices in ways that enhance achievement of the key objectives of improved efficiency and cost-recovery. While there are a number of different types of regulatory policies that can be considered, the ex-ante analysis in this study will be limited to an economic instrument (water pricing) and to an institutional instrument (water rights improvements).

Economic instruments are often promoted as policy instruments for water demand management (Tardieu and Préfol, 2002; Hellegers and Perry, 2006; Russel et al., 2007; Molle et al., 2008). Economic instruments can be used to provide financial resources to cover the costs of providing water, but they can also foster economically efficient water allocation, moving water from lower to higher value uses. They are also said to foster conservation and innovation, and provide signals to induce behavioural changes (Abu-Zeid, 2001; Bazzani, 2005; PRI, 2005). In this way they could be used to attain the two objectives identified for the smallholder irrigation sector in South Africa: improved efficiency and cost recovery.

The study of the effect of economic instruments can be done in a neoclassical framework. Because economic theory suggests that demand for water should behave like that for any other good, other things being equal, water use should decline with rising prices (Gómez-Limón and Riesgo, 2004; PRI, 2005). Therefore, pricing water has often been suggested as a way of providing incentives for water use reduction and/or efficiency improvement through a price signal (Perry, 2001; Oster and Wichelns, 2003; Tsur, 2004; Wichelns, 2004; PRI, 2005, Scheierling et al., 2006; Easter and Liu, 2007; Liao et al., 2007; Singh, 2007; Molle et al., 2008). Besides this, pricing water is also promoted to internalize the environmental and social costs of water use, and serves to raise revenues for public water supply infrastructure and operations (Perry, 2001; Massarutto, 2003; PRI, 2005; Easter and Liu, 2007; Molle et al., 2008). However, farmers' reactions to water price changes have been shown to differ a lot (Gómez-Limón and Riesgo, 2004; Riesgo and Gómez-Limón, 2006) and various authors also found that demand for irrigation water can be quite inelastic (Yang et al., 2003; Gómez-Limón and Riesgo, 2004; Easter and Liu, 2007). Moreover, several authors (Tardieu and Préfol, 2002; Gómez-Limón and Riesgo, 2004; Perret and Geyser, 2008) have warned for the collateral effects of water pricing, such as decreases in agricultural income or reduction in agricultural labour. For these reasons, before implementing water pricing, apart from having an insight into the water saving potential of this economic instrument, it is necessary to consider the social and regional development effects on the irrigated agriculture sector (Riesgo and Gómez-Limón, 2006).

Another issue recently receiving quite some attention (Matthews, 2004; Bruns et al., 2005a; PRI, 2005) is the definition of the water rights framework. This can be evaluated in a New Institutional Economics framework. The way the rights of an entitlement are defined will influence the values that market participants put on it. If water rights are ill-defined, this creates high transaction costs (information search, negotiation, monitoring) for making decisions over water use (Challen, 2000). Thereby the value people assign to water is limited, which seriously impairs the efficient use of water (Randall, 1978; Ostrom, 2000; Heltberg, 2002; Wichelns, 2004; PRI, 2005; Linde-Rahr, 2008). Farmers for instance may be motivated to apply more water than necessary when property rights are not secure and when availability of water is inflexible or uncertain (Wichelns, 2002; Oster and Wichelns, 2003). If property rights were well designed, this would add to economically efficient water use (Meinzen-Dick and Nkonya, 2005; PRI, 2005). In addition, an increased willingness to pay for water linked to better defined property rights can also help to ensure cost recovery. Improvement of the water rights system is thus a policy option, which stimulates smallholders to use water more productively, encouraging cooperation and investment (Bruns et al., 2005a). At the other hand it can also be used to allow governments to charge higher water prices and thus improve cost recovery. Because of the compatibility of these possible outcomes with the water policy objectives in South Africa the issue of the water rights system is highly relevant for South Africa. Especially since there is already quite some criticism on the new water rights framework introduced by the National Water Act. For governments it is then important to decide which dimensions of the water rights system to adjust. Transferability of rights through markets for instance is often advocated because in theory, in a free and competitive ideal setting, markets are self-regulated and result in the maximum resource-use efficiency by moving water to its highest value use (PRI, 2005; Chong and Sunding, 2006; Brooks and Harris, 2008). However in reality without restrictions on water transfers the market could result in the concentration of rights in the hands of a group of holders, excess withdrawals or other undesirable outcomes (Bruns, 2003; PRI, 2005).

3. Research objective and hypotheses

The overall objective of this research is to inform decision making in water management at small-scale irrigation schemes in South Africa with respect to the two key objectives for the sector, namely improved efficiency and cost recovery. The study focuses on the impact of economic instruments and institutional changes to achieve these objectives and provides tools and analyses techniques to evaluate this impact.

More specifically, this research will try to meet this purpose by focusing on five sub-objectives of the overall research objective: (1) on determining the economic value of water in production on small-scale irrigation schemes in rural areas in South Africa; (2) on evaluating the efficiency of water use at these schemes using a systems approach; (3) on explaining the efficiency of water use in terms of various farm and farmer characteristics; (4) on testing the effect of a water pricing policy on water use, farm profit and input use and (5) on assessing the efficiency of the current water rights system and the scope for improvements in the definition of this system. More specific research objectives are included in the following thesis chapters.

In addition seven research hypotheses are advanced in this research. Verification of the research hypotheses will yield valuable insights for improved decision making for water management at small-scale irrigation schemes in South Africa.

H1. Water values at the small-scale irrigation schemes are low and this can jeopardize the objective of cost recovery (Chapter 3)

H2. Economic water values are highly variable (Chapter 3)

H3. There is considerable scope to improve water use efficiency on the small-scale irrigation schemes (Chapter 4)

H4. Farm (a) and farmers' attributes (b) determine the level of water use efficiency (Chapter 4)

H5. Introduction of water pricing leads to a decrease in water use (Chapter 5)

H6. Water pricing can have a negative effect on the viability of the production of smallholders irrigators (Chapter 4, 5)

H7. There are considerable economic benefits attached to making improvements in the water rights framework in South Africa (Chapter 6)

4. Research design and data sources

4.1 Research methodology

To be able to meet the research objectives and to test the hypotheses advanced above, appropriate research methodologies were developed. Each empirical chapter (Chapter 3 to Chapter 6) contains a methodology section in which the methodology is explained and situated in economic theory.

4.2 Data collection

Information required in the research methodology is gathered in two primary data collection phases. The first phase in 2005 used a questionnaire to compile detailed farm budgets for 60 farmers spread over 13 small-scale irrigation schemes situated in Zeerust Municipality, North-West Province. The questionnaires furthermore gathered information on the irrigation schemes and on household characteristics, farm activities, quantity of water consumed and on irrigation practices. This dataset is used for the analyses in Chapter 3, Chapter 4 and Chapter 5. More detailed information regarding the sampling procedure and the kind of data collected is provided in Chapter 3.

The second primary data collection phase took place in 2008. Two regions in Limpopo Province, where clusters of smallholder irrigation schemes are located, were selected. Within these regions seven irrigation schemes were identified from the national database of small-scale irrigation schemes (Denison, 2006). The questionnaires used in this phase included a contingent ranking experiment, but also detailed information regarding farming activities, alternative income sources and institutional aspects of water management. In total 134 questionnaires were completed. This dataset is used for the analyses in Chapter 6. More information regarding the sampling procedure and the content of this questionnaire can be found in Chapter 6.

Figure 1.2 Situation of the study areas (adapted from DWAF, 1999)

Both data collection phases took place in regions where improved water management is important. Zeerust Municipality is situated in the Crocodile West- Marico water management area (see figure 1.2 and figure 4.2 for more detail). In this area development and utilisation of surface water has already reached its full potential. However mining developments and population and economic growth, mainly around Johannesburg and Pretoria, are expected to continue strongly (DWAF, 2004). This enhances the need for improved water management in the Crocodile West- Marico area and puts the agricultural water use under pressure. The regions where data was collected in the second phase are located in the Olifants water management area (see figure 1.2 and figure 6.3 for more detail). With one of the main rivers of this water management area, the Olifants river, flowing through the Kruger National Park, which is located at the downstream extremity of the water management area, the provision of water to meet ecological requirements is one of the controlling factors in the management of water resources throughout this water management area. It is estimated that savings in water use of approximately 20% will be required to provide for the ecological water requirements

(DWAF, 2004; Prasad et al., 2006). Water demand management tools are therefore also of crucial importance for the Olifants water management area.

4.3 Delimitation of the study

Although there is a need for improved water management in all water using sectors, the analysis in the study is limited to one sector, namely the small-scale irrigation sector.

There are different policy domains influencing the small-scale irrigation sector. These include rural development policy, agricultural policy and water management policy (Backeberg et al., 1996). This work looks at the small-scale irrigation sector from the water management perspective. However the policy domains are interlinked. For instance an objective like recovery of the costs of water supply is clearly linked with improved viability, which is on its own more an objective of rural development policy.

When considering improved water management there are many different policy options. These include amongst others laws, regulations, economic instruments and institutional reforms like irrigation management transfer. The analysis of policy options in this study is limited to the effect of water pricing and the benefits of improvements in the water rights system.

4.4 Assumptions of the study

An underlying assumption for this doctoral research is that farmers' decision making can be influenced by policy and regulatory instruments. The simulation of the effects of water price introduction for instance assumes that profit maximization is an objective of the smallholder irrigators and thus farmers will respond to higher water prices. Although contested by some, price responsiveness of small-scale farmers in traditional agricultural settings is generally accepted by economists (Sauer and Mendoza-Escalante, 2007; Abler and Sukhatme, 2006).

5. Thesis outline

The empirical part of this thesis consists of a compilation of papers that have been published in, accepted by or submitted to international peer-reviewed journals or that were published in the proceedings of international conferences covering the scientific disciplines of water resources management, agricultural economics and policy, and agronomy. Each empirical chapter can be read as a stand-alone paper, but repetitions between papers were kept to a minimum. In total the thesis includes seven chapters. Figure 1.3 presents the positioning of the chapters in relation to the conceptual framework. Each chapter discusses relevant literature and focuses on analyzing specific parts of the framework following the rationale presented below.

Chapter 2 draws the context for this study. An overview of the existing water policy framework in South Africa is provided and the role, history and relevance of the small-scale irrigation sector are discussed based on a review of existing literature. This helps to put the policy interventions analysed in the following chapters in the perspective of the existing framework. It furthermore also adds to the understanding of the challenges the small-scale irrigation sector in South Africa is facing.

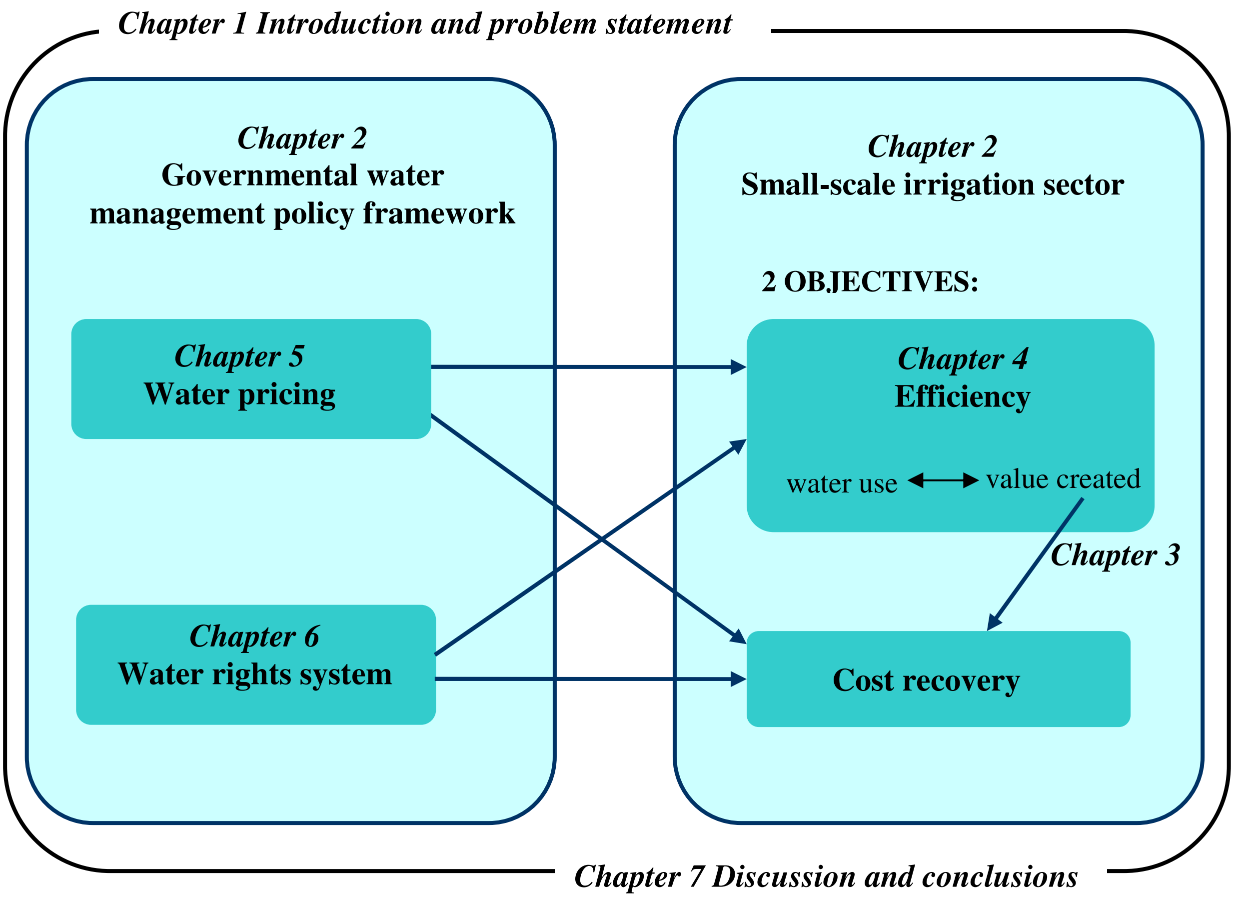

Figure 1.3 Thesis structure related to the conceptual framework

Chapter 3 and Chapter 4 constitute the ex-post analysis part of the thesis. In these chapters the existing water use situation and its impact on the efficiency and cost recovery objectives are evaluated

Chapter 3 focuses on the economic value of irrigation water in smallholder production. Based on detailed farm budgets, economic water values are calculated at crop, farm and scheme level and the variability of the values is investigated. This sheds light on profitability of small-scale irrigation farming and consequently on the capacity of the sector to ensure cost-recovery. For the calculation of the water values the residual imputation method (Lange, 2007; Agudelo and Hoekstra, 2001; McGregor et al., 2000) is used. As a second step, comparisons of mean scores through independent sample t-tests and analysis of variance F-tests are used to detect differences in water values at crop, farm or scheme level.

Chapter 4 develops and applies a systems approach to evaluate efficiency performance of smallholder irrigators in terms of water use. Data Envelopment Analysis (DEA) is used to calculate different efficiency measures for smallholder irrigators. Both the Constant Returns to Scale (CRS) and the Variable Returns to Scale (VRS) DEA models for overall technical efficiency are estimated using the program DEAP (Coelli, 1996). Sub-vector efficiencies for water use are modelled in GAMS using the methodology proposed by Färe et al. (1994). Then, the relationship between overall technical efficiency and water use efficiency is examined using correlation statistics. Finally a Tobit model is run in LIMDEP version 8 (Green, 2002) to identify the determinants of efficiency.

Chapter 5 and Chapter 6 constitute the ex-ante analysis part of the thesis. In these chapters the impacts of possible policy interventions aiming to improve water management practices are predicted.

Chapter 5 analyses the impact of the introduction of water pricing on irrigation water use and on the farmers' production system. A mathematical programming model in GAMS is used to estimate the impact of changes in the water price. The model consists of a two steps approach: first technical and economic efficiency levels are determined, then these are used as a representation of the production technology in a profit maximization model. In addition to offering insight in the water saving effect of the introduction of water charges, the method also enables to evaluate the environmental effects (use of fertilizers and pesticides) and the socio-economic effects (labour use, effect on farm profit and total agricultural output).

Chapter 6 identifies the efficiency of the current water rights system for smallholder irrigators in South Africa. This is done by economically valuing possible improvements in the definition of the water rights. Using the data of a contingent ranking experiment, a ranked-ordered logit model is estimated in STATA to determine willingness to pay for such improvements. Besides giving an indication concerning the efficiency gains that could be achieved by water rights improvements, these willingness to pay values also generate information concerning the preferences of the target group for specific improvements.

Chapter 7 provides the general discussion and conclusions. The most important findings of this doctoral research are discussed and conclusions, implications and recommendations from the different research parts are tied together. Finally, a list of all references cited in the thesis is presented.

CHAPTER 2
Water policy and the small-scale irrigation sector

Abstract

After the end of the Apartheid regime, South African water policy went through a thorough reform process. This formed part of a broader effort in South Africa to restructure the constitution, the legal system, policies and institutions. Three major principles to guide water management in the future were constitutionalised: equity, sustainability and efficient and beneficial use for the society. Crucial reforms include the introduction of economic tools to manage water and the focus on decentralisation and users' participation. These policy changes will also have an impact on the irrigation sector. This sector is one of the focus areas of the South African water management because irrigation has been an essential factor in raising the productivity of agriculture. The irrigation sector does not only significantly contribute to the economy, but also is important in terms of income generation, food security and poverty alleviation. Although smallholder irrigation constitutes only a minor part of the sector in terms of area or water use, it is relevant due to the large number of smallholder irrigators. Moreover, because of the perceived role in rural development major government investments were made in the sector and are currently still made. The performance and economic success of the small-scale irrigation sector in South Africa have however been very poor and the sector suffers low efficiency of water use and fails to ensure cost recovery.

KEY WORDS: Water policy reform, small-scale irrigation, South Africa, historical overview

1. Introduction

This chapter draws the background for this dissertation. First the Water Policy framework in South Africa is reviewed. The major stages of the policy development are discussed and the most relevant outcomes are highlighted. The following section examines the smallholder irrigation sector. Because the importance of the small-scale irrigation sector in South Africa must be understood in the context of its role in rural livelihoods and poverty reduction, this role is theoretically explored. Then the origin and history of the smallholder schemes is discussed. Knowledge of the origin of the schemes can help to understand their current status. Finally the current conditions and typical characteristics of this type of schemes are looked at in detail and the challenges for the sector are identified.

2. Water policy in South Africa

To overcome the legacy of the apartheid system, since 1994, the new democratic government of South Africa has devoted enormous effort to restructure the constitution, the legal system, policies and institutions. The water policy reforms in South Africa can also be seen in this context (Wester et al., 2003). Eliminating the disparities between various sectors of South African society with respect to access to water was one of the driving forces behind the policy changes (Mukheibir and Sparks, 2003; Karodia and Weston, 2000). A second driver for the significant transformations in water resources management policy in South Africa was the growing awareness that the increased exploitation of water resources due to the rising water demands in South African catchments, as well as the intensification of associated impacts on water quality needed to be addressed (Mukheibir and Sparks, 2003). A shift from the previous philosophy that water is a free good that can be used regardless of its scarcity value to one where water is considered an economic good was necessary. Moreover the old centralised bureaucratic water allocation procedures should be replaced by decentralised procedures introducing user participation and a role for a market mechanism (Conningarth Economists, 2004).

Following major (macro) stages of water policy development in South Africa can be identified (de Coning and Sherwill, 2004; de Coning, 2006; Jonker, 2007): (1) the development of the Water Law Principles (DWAF, 1996), (2) the White Paper on a National Water Policy for South Africa (DWAF, 1997), (3) the National Water Act (Republic of South

Africa, 1998) and (4) implementation initiatives such as the establishment of the National Water Resource Strategy (DWAF, 2004). An graphical overview of the key stages in the transformation process is given in figure 2.1.

The most significant principles of the 28 Water Law Principles were (de Coning and Sherwill, 2004):

• Principles 3 and 4, which led to the abolition of riparian water rights and private ownership of water;

• Principle 7, which establishes environmental sustainability and social and economic benefit as key criteria for water resources management and allocation decisions;

• Principle 16, which provides for the use of economic instruments in the water management and control of pollution; and

• Principle 24, which states that "beneficiaries of the water management system should contribute to the cost of its establishment and maintenance".

Also three fundamental objectives for managing South Africa's water resources arise from the Principles. The first one is to achieve equitable access to water. This includes equity of access to water services, to the use of water resources, and to the benefits from the use of water resources. The second objective is to attain sustainable use of water by making progressive adjustments to water use creating a balance between water availability and legitimate water requirements, and by implementing measures to protect water resources. The third fundamental objective is to achieve efficient and effective water use in order to optimize social and economic benefit (DWAF, 2004).

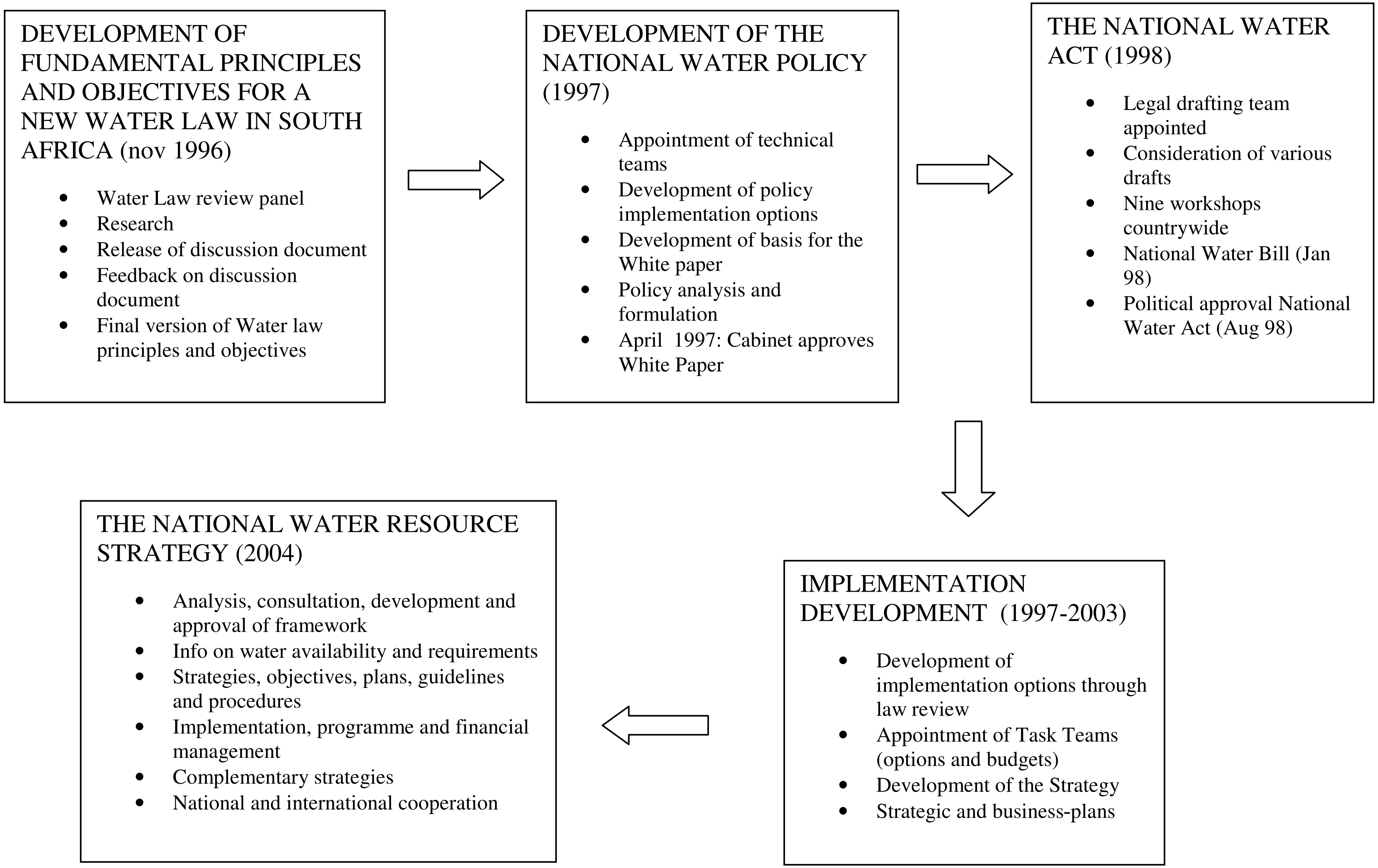

Figure 2.1 Key stages in the water policy transformation process in South Africa *(adapted from de Coning, 2006)*

The second step in water policy development in South Africa was the creation of the White Paper on National Water Policy. The White Paper sets out new integrated policy positions for protection, use, development, conservation, management and control of South Africa's water resources (Karodia and Weston, 2000). The Water Law principles formed the basis for the White Paper, but the formulation of the White Paper was also based on a thorough review of existing water law (DWAF, 2004; de Coning 2006).

The third stage of water policy transformation in South Africa consisted of the elaboration of the National Water Act (NWA). The NWA of 1998 is the principal legal instrument related to water resources management in South Africa (DWAF, 2004). Under the auspices of the Department of Water Affairs and Forestry (DWAF), it was drafted based on a thorough review process, including research of water management in other countries and inputs from public participation forums (Waalewijn et al., 2005). It changed and modernized the legal and institutional framework for water management in South Africa by replacing the 1956 Water Act. In line with the general objectives of water policy reform in South Africa, the Act also seeked to redress imbalances of the past. The three major principles for water management are underscored in the National Water Act: equity, sustainability and efficient and beneficial use for the society. Because these principles sometimes demand contrasting policy interventions they form a kind of triangle of constraints for decision-making (Levite and Sally, 2002).

Following specific key elements of the National Water Act, which will guide water management in South Africa in the coming years, are identified. First, the status of the nation's water resources as an indivisible national asset was confirmed and formalized: all water resources belong to the nation and the national government is entrusted to act as the custodian of the nation's water resources (Oosthuizen, 2002; Mukheibir and Sparks, 2003; Waalewijn et al., 2005). A second important innovation in the NWA was that environmental water demands and demands for basic human needs are guaranteed as a right. They should be protected within an allocated volume known as the Reserve (Oosthuizen, 2002; Levite and Sally, 2002; Waalewijn et al., 2005). Thirdly a new system of allocation was conceived. The system will use water pricing, limited term allocations and other administrative mechanisms to bring supply and demand into balance in a manner which is beneficial to the public interest (Oosthuizen, 2002). In this context, the riparian system of allocation, in which the right to use water was tied to the ownership of land along rivers, was abolished and replaced by a system of limited-period and conditional authorizations to use water (Nieuwoudt, 2002). The Act furthermore contains provisions to enable the transfer or trade of these water use rights between users. To promote the efficient use of water and to achieve cost recovery, users will be charged the full financial costs of providing access to water, including infrastructure development and catchment management activities (Oosthuizen, 2002; Perret and Geyser, 2007).

The new legislation has also changed the institutional context of water management. The aim of establishing new institutions was to delegate water resources management to regional and localised levels, to involve stakeholders in water resources management and thereby give effect to integrated water resources management (Karodia and Weston, 2000). These objectives are in line with two cornerstones in South African constitution: first the principle that people should be able to participate in the decision-making process as and when it affects them and second the subsidiary principle, whereby functions that can be more efficiently and effectively carried out by lower levels of government should be delegated to the lowest appropriate level (Mac Kay, 2003). For this purpose South Africa has been divided into 19 Water Management Areas (WMA), coinciding with the major catchment areas (figure 2.2). New participatory corporate bodies, termed Catchment Management Agencies (CMAs) were established by the Act. Once operational each CMA will possess management authority in its specific water management area. For this area they are expected to progressively develop a Catchment Management Strategy (CMS) to secure the protection, use, development, conservation, management and control of water resources. These strategies have to be in alignment with the National Water Resource Strategy. The CMAs, which are placed directly under the Minister of Water Affairs and Forestry, will be governed by a Board and have the role of seeking agreement on water related matters among various stakeholders (Thompson et al., 2001; Oosthuizen, 2002; Levite and Sally, 2002; Waalewijn et al., 2005; Funke et al., 2007).

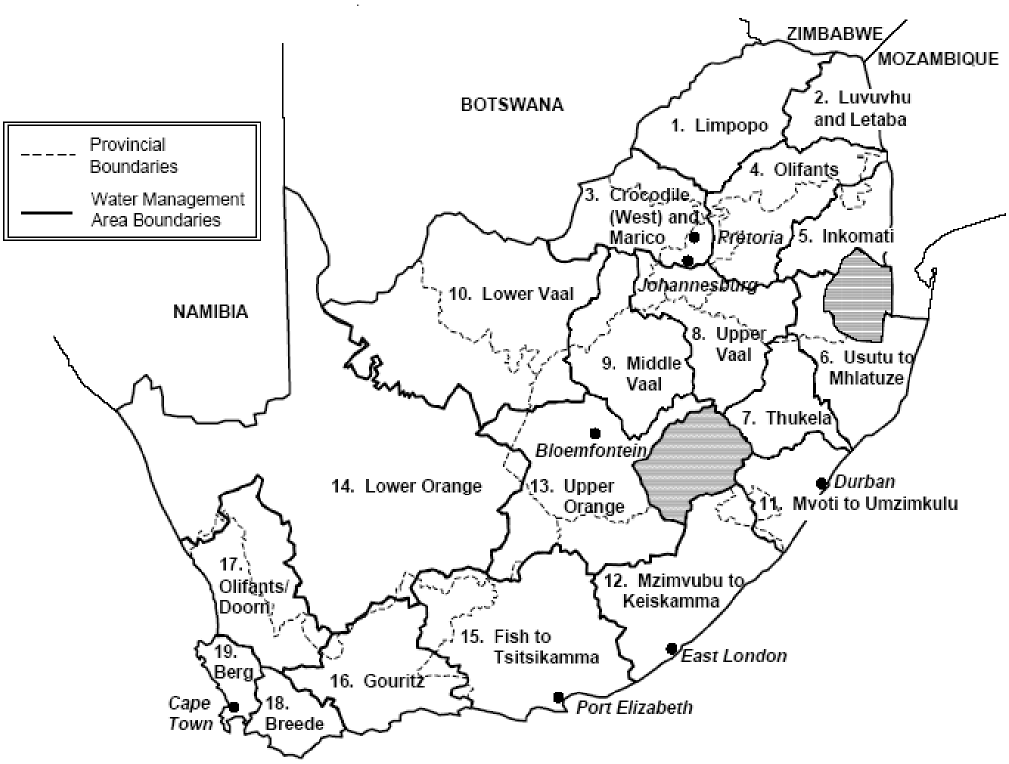

Figure 2.2 Water management areas in South Africa *(source DWAF, 1999)*

A third tier of water management organizations is placed under the CMA: the Water Users Association (WUA). WUAs are statutory bodies, operating at a local level and replacing the previously existing irrigation boards and any other local water management institutions. WUAs can however also be newly established for specific water management tasks or sectors. WUAs are in effect cooperative associations of individual water users who wish to undertake water-related activities for their mutual benefit. They will address local needs and priorities. Unlike the irrigation boards, the WUAs are supposed to control all water resources and have representatives of all stakeholders, giving them a voice in the allocation process (Waalewijn et al., 2005). They are expected to help communities to find the financial and human resources needed to more effectively carry out water-related activities (Levite and Sally, 2002; Oosthuizen, 2002).

Because of insufficient financial, administrative and technical capacity, it was decided that not all the provisions of the Act would come into force from the day of enactment, but that they would be implemented in a phased and progressive manner, in separate components over time, according to geographical need and as soon as was deemed reasonable and practical (de Coning, 2006; de Coning and Sherwill, 2004; Mac Kay, 2003). For instance before CMAs have been formally established in a WMA, the regional offices of DWAF will continue to manage the water resources of their respective areas (Funke et al., 2007). Another example is the use of general authorisations to allow limited, but conditional water use without a licence (Anderson et al., 2007). This is primarily used to reduce the administrative effort of authorising every use in the country individually. Compulsory licensing will only be introduced in areas which are, or are soon likely to be, under "water stress" or where it is necessary to review prevailing water use to achieve equity of access to water (Republic of South Africa, 1998; DWAF, 2004).

Finally between 1997 and 2003 the National Water Resource Strategy (NWRS) was prepared. The National Water Resource Strategy (NWRS) provides the practical implementation framework within which water resources will be managed throughout the country (DWAF, 2004; Backeberg, 2005). In accordance with the requirements of the White Paper and the NWA, the NWRS sets out the objectives, plans, guidelines, procedures and the institutional arrangements relating to the protection, use, development, conservation, management and control of water resources (Karodia and Weston, 2000). The strategy also sets out broad time scales and priorities for implementation at national level, providing at least some guidance on which changes to introduce first (Mac Kay et al., 2003).

Implementation of the reform aspects of the NWA have been slow to date (Seetal, 2005). Currently, the Reserve (basic human needs and ecological demands) has been determined at a desk-top level for the entire country and studies are being undertaken to determine these reserves at a comprehensive level in several catchments. Also currently, only four CMAs have been established and proposals for the establishment of a number of others are under consideration (DWAF, 2008a). Up to now, the compulsory licensing process was only successfully introduced in one area (Van Niekerk, 2008). For water use in the other geographical areas the general authorisations have been prolonged (DWAF, 2008a). Water pricing for subsistence and emerging farmers, which was originally planned to be introduced gradually in a time span of five years, is still not fully introduced. In practice, notwithstanding the fact that the five-year moratorium has already long expired, smallholders are still hardly charged whatsoever (Perret and Geyser, 2008).

3. Smallholder irrigation in South Africa

3.1 The role of irrigation in rural livelihoods and poverty reduction

Agriculture remains the most likely route out of poverty for the vast majority of rural livelihoods in developing countries. It is emphasized in the World Development Report 2008 “Agriculture for Development” that growth in agricultural productivity in sub-Saharan Africa is vital to poverty reduction and to achievement of the Millennium Development Goals (World Bank, 2007). Several authors have demonstrated a strong positive relationship between increases in agricultural productivity and poverty reduction (Irz et al., 2001; IFPRI, 2002; Dorosh and Haggblade, 2003; Hartmann, 2004; World Bank, 2005; IEG, 2007). Also in rural areas of South Africa, farming is an important activity for rural households, sustaining their livelihoods and providing food security (Dovie et al., 2003). At least 35% of the economically active population of approximately 14 million people in these areas is directly or indirectly dependent on agriculture. This consists primarily of small-, medium- and large-scale enterprises, which provide employment opportunities for formal and casual labour (Department of Agriculture, 2001). Furthermore, 42.7% of the population are rural survivalists with traditional agrarian lifestyles (Backeberg and Sanewe, 2006). The share of agriculture in the gross domestic product (GDP) is relatively low ranging between 4.2 and 5.3%. But, because of its backward linkages with input supplies and service provision and its forward linkages to processing and marketing, the total impact of agricultural economy rises to more than 30%. Water and its managed use have been an essential factor in raising the productivity of agriculture (NEPAD, 2003). Because of the macro economic considerations mentioned above and the direct role of agriculture in contributing to income generation, food security and poverty alleviation, the orientation of the South African water sector is towards the irrigation sector (Backeberg, 2005).

In this context irrigation therefore has been argued to be a ‘privileged solution’ for rural development in Africa (Hope, 2004). There are different mechanisms through which irrigated agriculture can contribute to rural development (Hasnip et al., 2001; Massarutto, 2003; Hope, 2004; Smith, 2004; Hussain and Hanjra, 2004). First, irrigation ensures improvements in the levels and security of productivity, allowing higher production, higher yields and lowering the risk of crop failure. Secondly, it creates year-round employment and incomes for irrigating farm households and farm labour. Thirdly, irrigation enables smallholders to adopt more diversified cropping patterns, and to switch from low-value subsistence production to high-value market-oriented production. This transition to the market economy integrates the poor into land, labour, commodity, and information markets, which empowers them. Finally, there are significant linkage and multiplier effects of agricultural intensification of which irrigation is one aspect, for the wider economy. The increased production generated by irrigation for instance, lowers food prices, increasing the real incomes for consumers (net food purchasers) and allowing an expansion in the demand for other goods and services.

These envisaged positive effects of irrigation have led to promoting irrigation interventions amongst policy makers and donors. At a certain moment irrigation was seen as “self-evidently suited” to the problem of rural development, becoming an uncritical “blue–print approach” (Hope et al., 2008). In Africa, however, large scale public interventions in irrigation have been characterized by poor planning and limited understanding of extreme natural variations in agro-climatic conditions, which have resulted in disappointing economic returns, negative impacts on indigenous irrigation systems and environmental damage (Lankford, 2002, Hope, 2004). Also because of institutional failing, expectations of the contribution of irrigation to poverty reduction seem to have been unrealistic. Moreover increasing water scarcity has caused agricultural water allocations to be questioned more and more (Hope et al., 2008).

Notwithstanding these points of criticism evidence from numerous countries shows that smallholder irrigation can contribute significantly to household food supply, as well as to income and employment generation (Lipton, 1996; Merrey, 1997; Hasnip et al., 2001; Hussain and Hanjra, 2004; Brabben et al., 2004; Manyatsi and Mwendera, 2007). According to Hedden-Dunkhorst and Mphahlele (2000) the new South African government recognized this potential and committed itself to support smallholder irrigation. This is apparent from government initiatives such as the Revitalisation of Smallholder Irrigation Schemes Programme in Limpopo province or similar initiatives in other provinces and from the role attributed to smallholder irrigation in the Internal Strategic Perspectives of most WMAs. As mentioned in the previous section, the South African government considered ensuring more equitable access to irrigation to be a way in which water policy can contribute to poverty reduction within the political imperative to revise water policy to favour previously disadvantaged communities (Hope et al., 2008). Increased commercialisation by resource-poor black irrigation farmers, who are mostly located in the poorest rural areas, is believed to be a viable strategy towards reducing rural poverty, inequality, food insecurity and unemployment. In this context, any investment and financial support by the public sector to smallholder irrigation schemes undoubtedly falls under the ‘equity’ objective of the National Water Act (Perret and Geyser, 2007). The government therefore has embarked on a nationwide drive to ‘revitalise’ government-owned small-scale irrigation schemes (Tapela, 2008).

3.2. History of small scale irrigation in South Africa

In order to analyse the current agricultural sector and the resource use in South Africa, the way in which resources were allocated under the Apartheid system should be considered. Under Apartheid, economic activities were heavily regulated and the allocation of resources, subsidies and state funds were politicised and based on racial classifications (Tren and Schur 2000a; Van Averbeke and Mohamed, 2007). While white farmers were favoured politically, black farmers and their communities were actively discriminated against.

The Land Act of 1913 and the Land and Trust Act of 1936 created the so-called “homelands” or “Bantustans”. By these acts, land ownership by black people in South Africa was largely restricted to these areas, ensuring that the majority of the population was confined to approximately 13% of the total land area of South Africa. Moreover the areas where the black communities were settled largely consisted of marginal lands with few resources and frequently little or no access to water (Tren and Schur 2000a; Van Averbeke and Mohamed, 2007).

Most of smallholder schemes were constructed in the homelands after the Second World War. During the Apartheid period, the establishment of irrigation schemes with funding from South Africa formed part of the economic development strategy of the homelands. Agriculture was regarded as the main internal development opportunity for the homelands, because the resource base of these territories had remained essentially rural (Van Averbeke and

Mohamed, 2007). The schemes were primarily aimed at providing African families residing in the homelands with a full livelihood. The development of the irrigation schemes through public investment followed the recommendations of the Tomlinson Commission (1955) on the development of homeland areas (Veldwisch, 2004; Perret and Geyser, 2007). According to the Tomlinson Commission, irrigated holdings of 1.3 to 1.7 ha were adequate to provide a family with a living that would satisfy their needs, whereby the whole family would work on the holding. The Commission also proposed that all schemes should be placed under proper control and supervision, with uniform regulations as regards to water rates, credit facilities and conditions of settlement (Perret, 2002a). Parastatal structures like the Agriculture and Rural Development Corporation (ARDC) were created to manage the smallholder irrigation schemes through an elaborate top-down command and support system (Van Rooyen, 1995).

Under parastatal management, farmers were working almost as labourers. In a version of contract farming, irrigation to smallholders was fully subsidized, and the parastatals organized mechanized cultivation, planting and fertilizer application in the schemes. Plot holders did not have to make any decisions about farm management, which was pretty much centralized. The farmers' responsibilities were to weed, harvest and to move the irrigation pipes around. The parastatals furthermore provided them production loans and were responsible for the marketing of the pooled produce (Hedden-Dunkhorst and Mphahlele, 2000; Shah et al., 2002; Perret, 2002a; Seshoka et al. 2004; Veldwisch, 2004). The recurrent costs for this type of schemes were very high and consequently the schemes placed a large financial burden on the State (Perret, 2002a, Perret, 2002b).

With the advent of democracy in 1994 policies, including those for agriculture, were reformed and the homelands were reincorporated in the State. At that time, the provincial governments decided to dismantle the agricultural homeland parastatals they had inherited (Tren and Schur 2000a; Van Averbeke and Mohamed, 2007). Because no transition plan was in place, farmers were left stranded, both technically and financially, and schemes were often left behind with large debts. The effect of the parastatals' abrupt withdrawal on smallholders was telling, with an almost immediate partial or total collapse of production. Cropped areas in many South African smallholder schemes fell sharply, simply because plot holders were unable to organize by themselves the working capital needed to hire tractors, buy seeds and fertilizers, and obtain services (Kamara et al, 2002; Shah et al., 2002, Van Averbeke and Mohamed, 2007). Moreover, because of the poor management and lack of skills and funds for maintenance, irrigation infrastructure deteriorated fast (Seshoka et al., 2004). The situation of under-producing and collapsed smallholder irrigation schemes is both a prominent political concern at the national level and a major budget item on many Departmental and District Municipality financial plans (Denison and Manona, 2006a).

Because of the above-mentioned widespread perception that these schemes have potential for substantial "economic growth, employment and poverty alleviation", revitalization programmes are currently carried out on the schemes (Tapela, 2008; Denison and Manona, 2006a; Veldwisch, 2004). Such revitalization processes involve infrastructure rehabilitation, technical and managerial training, institutional and organizational facilitation. The revitalization is linked to Irrigation Management Transfer (IMT). It is foreseen that after revitalization farmers will be put in charge of their schemes in institutional and financial terms. The IMT is part of the broader decentralization process of water resource management in South Africa discussed in section 2 of this chapter (Perret and Geyser, 2007). Following the institutional changes in water policy, each scheme will be managed by a water users' association (WUA), which will take charge of both water management and cost recovery for water services. In other words, the WUA should achieve financial sustainability by selling water and water services to farmers. Through increased participation IMT is believed to improve scheme management performance and to increase the profitability of irrigated agriculture. Apart from increased participation, an underlying objective of this IMT is also to free central and provincial governments from the financial burden of the maintenance and operation costs of the small-scale irrigation schemes (Hedden-Dunkhorst et al., 2001; Perret et al., 2003). Another important objective of the revitalization is to improve water use efficiency. Therefore modern irrigation technology, such as micro-irrigation and floppy sprinkler systems, are currently introduced in the schemes under revitalization (Van Averbeke and Mohamed, 2007).

Beside the state owned small-scale irrigation schemes, during the 1990s, NGOs and various other donor organisations also initiated community schemes or garden schemes with the objective of poverty alleviation and improved food security. There are many schemes of this type in South Africa and they are usually very small in size (Perret, 2002a). Subsistence clearly is the major objective underlying such schemes. Short-term results of these initiatives are often good, but not all schemes remain successful in the long term. At some sites, maintenance and management problems caused schemes to collapse because communities did not have the capacities to take over management, following the withdrawal of support services (IPTRID, 2000). At other sites maintenance shifted from the donors to the community users or their representatives after a couple of years without any problem.

3.3. Current conditions and characteristics of small-scale irrigation in South Africa

South Africa has about 1.3 million ha under irrigation, of which 0.1 million ha is held by smallholders (Backeberg, 2006). Smallholder irrigators have been categorised into four groups, namely, (i) farmers on irrigation schemes; (ii) independent irrigation farmers; (iii) community gardeners; and (iv) home gardeners (Van Averbeke and Mohamed, 2007). There are about 320 small-scale irrigation schemes in South Africa, covering approximately 46,000 to 47,500 ha. Most of them are located in Limpopo Province. The garden schemes and food plots are numerous and it is estimated that they account for an additional 50,000 ha (Perret, 2002a, Denison and Manona, 2006a; Van Averbeke and Mohamed, 2007). The total number of smallholder irrigators in South Africa is estimated at between 200,000 and 250,000, most of these farming very small plots, primarily to provide food for home consumption (Van Averbeke and Mohamed, 2007; Perret, 2002a). Key features of the small-scale irrigation schemes include the gravity-based supply system, the limited average farm size (about 1 to 2 ha per beneficiary), the subsistence orientation (maize being the major crop), and the significant area that is virtually never cropped (Perret and Geyser, 2007).

Other common characteristics of the state-founded type of schemes are the old age of beneficiaries, the large proportion of female farmers, the large average family size and the large proportion of non-farming beneficiaries. The large proportion of female farmers and the old age of the beneficiaries reflect the fact that over time irrigation smallholders have diversified their activities and that the livelihood system has changed through massive out-migration of male labour to the industrial and mining sector, thus leaving women and pensioners' headed households behind at the irrigation schemes (Perret, 2002a). It appears that often the plots are kept more as a form of security or insurance than that they are worked to their full productivity potential (Shah et al., 2002).

Overall, the performance and economic success of the small scale irrigation schemes in South Africa have been very poor and fall far short of the expectations of planners, politicians, development agencies and the participants themselves, and that despite huge investments (Perret, 2002a, Wester et al., 2003; Van Averbeke and Mohamed, 2007; Perret and Geyser, 2007). The schemes have not been financially viable nor self-sustaining since capital or operation costs were never covered by operation outputs and profit. Under-pricing and government subsidisation of water infrastructure and services, and the management by the parastatal agencies generated dependency and ignorance on the farmers' side. In addition the costs of infrastructure and the actual value of water as an input to production were mostly ignored (Perret and Geyser, 2007).

Nowadays, subsistence farming prevails in these schemes, with low productivity and virtually no commercialisation. This is the result of the decades of central management, the lack of initiative or decision-making by the beneficiaries, the limited knowledge of crop production among smallholders, the lack of input, credit and produce markets, the ineffective extension and mechanisation services, the low land productivity, the infrastructure degradation and the unsuccessful financial management (Perret, 2002b; Backeberg, 2006; Perret and Geyser, 2007; Van Averbeke and Mohamed, 2007). Nevertheless, it needs pointing out that in the past economic success through market-oriented production was not the prime objective of these projects. In this light, the measurement of the success of smallholder schemes should never ignore the importance of food security through own production. As Perret (2002a) remarks, food security remains the major objective for many smallholders and subsistence-oriented crop production patterns have never changed. Figure 2.3 depicts the typical existing situation at small-scale irrigation schemes.

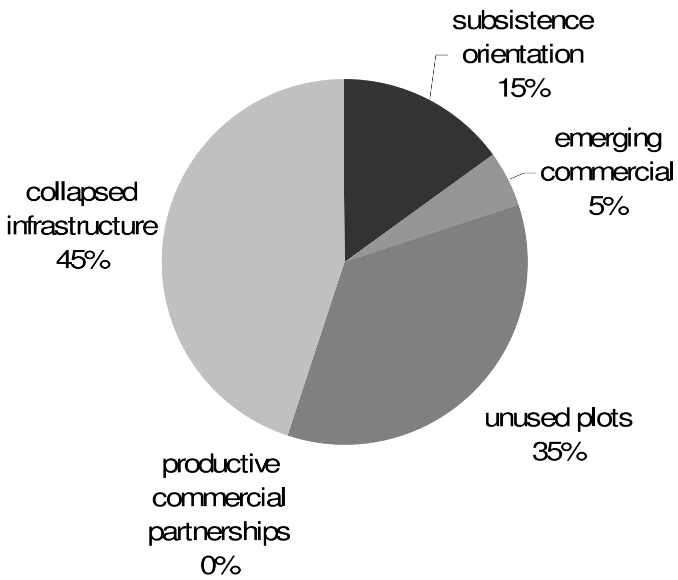

Figure 2.3 Typical existing situation on small-scale irrigation schemes[2] *(source Denison and Manona, 2006b)*

However, with the new agricultural and water policy, increased commercialisation becomes important. According to Van Averbeke and Mohamed (2006) a successful smallholder is now defined as a highly productive farmer who actively participates in markets and earns sufficient cash income, primarily from agriculture, to enjoy a life style that is free of poverty. This is important, because following the IMT process, in the future, water users are supposed to cover the financial costs (O&M costs) of irrigation water and irrigation services internally and capital cost recovery will also be phased in gradually, in the form of a depreciation charge to farmers (Perret, 2002a; Veldwisch, 2004). To ensure that farmers will have the necessary financial capacity, government has been and still is investing substantial amounts of public money in the revitalization of smallholder irrigation schemes (Perret and Geyser, 2007). These investments should create the conditions necessary to motivate and enable smallholders to progress from subsistence to commercial producers, a process called smallholder empowerment (Van Averbeke and Mohamed, 2007). Another issue is that water resources should be utilised more productively. Although currently not a constraint for economic

[2] This figure with illustrative percentages gives a picture of the typical situation on small-scale irrigation schemes. It is not linked to a specific scheme.

development, the quantity and quality of water resources available for irrigation are clearly limited (Backeberg and Sanewe, 2006).

Up to now, it appears that the interventions to revitalize smallholder irrigation schemes in most instances have failed to achieve the target outcomes. Apparently unlocking the potential of smallholder irrigation through revitalization initiatives is far more difficult, time-consuming and costly than many professionals and politicians had expected (Denison and Manona, 2006a). Moreover on the typical small-scale irrigation schemes with a large number of beneficiaries, collective self-management like it is introduced now will involve large invisible transaction costs. For instance the costs of fee collection, responding to complaints, delivering water to each user, monitoring farmers' behaviour and extracting consensus on key decisions vary directly with the number of irrigators (Shah et al., 2002). In addition when considering the time, effort and resources a typical smallholder irrigator is willing and able to make on the irrigated plot it appears that irrigation farming might not be the preferred livelihood option for many smallholders. Kamara et al. (2002) therefore stress the need to substantiate whether or not the people are truly interested in irrigation farming as a reliable source of income and livelihood. Finally, even if water allocation to smallholder irrigation provides expected income and food benefits to the beneficiaries, it is debatable if it is the most optimal option viewed within the wider development challenges of the rural areas in South Africa (Hope et al., 2008). Because of these issues, the soundness of the government investments in the small-scale irrigation sector is questioned by several authors (Hope et al, 2008; Perret and Geyser, 2008; Tapela, 2008; Perret and Geyser, 2007).

Notwithstanding these considerations, for South African government small-scale irrigation remains a key sector for rural development and to pursue the objective of equity, which is very important in the South African context (Prasad et al., 2006). There is clear and committed political intent to finance irrigation revitalisation initiatives and expansion at national, provincial and municipal levels. Thus the funding of these schemes is likely to continue and even increase (WRC, 2007). From a water management perspective the major challenges for this sector therefore are to improve efficiency of water use and cost recovery.

CHAPTER 3

Irrigation water value at smallholder irrigation schemes

Abstract

Insight into the value of water is essential to support policy decision-making about investments in the water sector, efficient allocation of water and water pricing. However, information on irrigation water values at small-scale schemes is scarce and in general little attention is paid to the determinants of these values. In this chapter values are calculated for small-scale irrigation schemes in the North West Province of South Africa using the residual imputation method. An average water value of 0.188US$/m³, in line with expectations for vegetable crops, was found. Furthermore the crop choice and the irrigation scheme design and institutional setting were shown to significantly influence the water value, whilst individual characteristics of farmers proved to be less important.

KEY WORDS: Water valuation, small-scale irrigation, water management, South Africa, residual imputation method

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1. Introduction

Rational decision-making about water management issues requires reliable estimates of the economic value of water (Ward and Michelsen, 2002; Hellegers, 2005; Hellegers and Perry, 2006; Hussain et al., 2007). Knowledge of this value is for instance necessary when making investment decisions in water resources development, policy decisions on sustainable water use and water allocations, or when the socio-economic impacts of water management decisions must be determined (Hussain et al., 2007). Specifically for the agricultural sector, this knowledge is important to design fair, informed and rational pricing systems, providing incentives to irrigators to use water sparingly and efficiently and allowing recovering operation and maintenance costs (Perret and Geyser, 2007; Lange, 2007).

In South Africa, small-scale irrigation is seen as an important rural development factor, creating employment opportunities, generating income and enhancing food security. Huge investments are therefore made in the sector, rehabilitating existing schemes (Perret and Geyser, 2007). On the other hand, the growing water scarcity causes increasing pressure on farmers to allocate water more efficiently. Moreover, following the new water policy, water subsidies currently received by farmers will gradually decrease and become negative, i.e. in the near future farmers will have to pay for the water they use (DWAF, 2004). In this context, knowledge about water values can contribute to the objective of improving efficiency through better water allocation at farm level, but is also crucial when water pricing policies that do not undermine the role of small-scale irrigation are to be designed. In addition, knowledge about irrigation water values can provide indications on the soundness of the large government investments in the sector. In an attempt to contribute significantly to this knowledge, this chapter applies the residual imputation approach to provide estimates of the water values at crop, farm and scheme level, in small-scale irrigation schemes of the North West Province of South Africa. Analysis of variance (ANOVA) is used to reveal significant differences in water values between crops, farms and schemes and the contribution of the factors responsible for the variability in the water values is quantified in a general linear model (GLM). In the following, first the methodology for calculating water values is described. The results section starts with a short historical overview of the development of small-scale irrigation in South

Africa and proceeds with the presentation and discussion of the calculated water values. The main conclusions and policy implications of this study are then presented.

2. Methodology

2.1 The concept of the economic value of water

Water resources are natural assets, the value of which resides in their ability to create flows of goods and services that are valued by society (Agudelo, 2001; Turner et al., 2004). Although not all authors use exactly the same classification, two broad categories of economic values derived from water can be distinguished: use values and non-use values (Agudelo, 2001; Turner et al., 2004; Comprehensive Assessment of Water Management in Agriculture, 2007).

Use values are also known as extrinsic values or direct use values. They arise from direct interaction with water resources. As use has a number of dimensions (quantity, quality, timing and location), the values can be classified along these dimensions, specifying the water use under several different categories. In figure 3.1 three options are considered: by subtractability, by location, and by economic role (Agudelo, 2001).

First, according to their subtractability water use values can be subdivided into consumptive and non-consumptive values. After consumptive use, water or some of its characteristics are not available anymore for use by others. Because every water use has both quality requirements and quality effects, it is not just the reduction in the amount of water, which determines whether a use is consumptive or not. A reduction in any quality characteristics of that water, which otherwise could be beneficially used elsewhere, also makes a particular use consumptive. Non-consumptive use values include the benefits received by those who leave the water and its properties essentially intact for others to use. Examples of consumptive uses of water are: municipal and industrial use, agricultural use, wastewater transport and assimilation. Non-consumptive uses include: hydropower, fishing, most water based recreation, navigation, etc.

Another breakdown of uses is by location. The water uses that are occurring in a watercourse and that are dependent on its flow characteristics are called instream uses (e.g. navigation, hydroelectric power generation, recreation and waste dilution). Uses where the water is removed from the watercourse are called offstream uses (e.g. municipal, agricultural and industrial water demand).

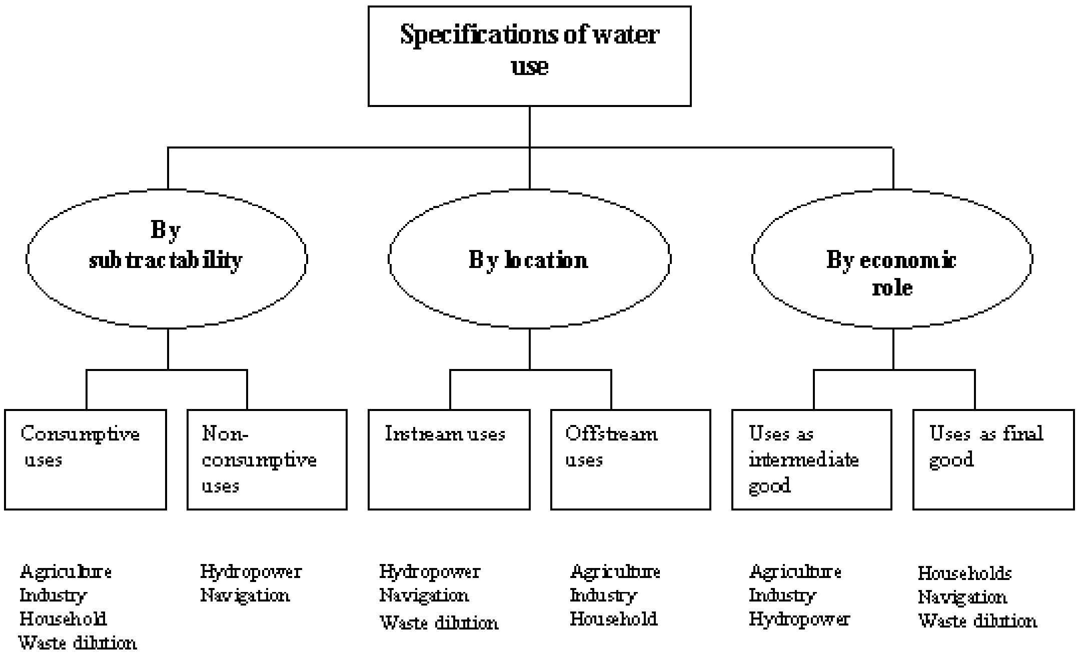

Figure 3.1 Specification of water use (*source Agudelo, 2001*)

Third, in economic terms, according to its role in the production chain, water can be classified or defined as either an intermediate or a final good. An example of water as an intermediate good is the water use in the production of other goods or services, such as irrigation of crops or driving of turbines to make electricity. Alternatively, water can also be used as a final good by the final consumer in households or for recreational activities like swimming. The value of water used as an intermediate good depends on the ultimate value of the resultant goods or services, while the consumer’s uses of water provide direct utility and value.

Non-use values constitute the second main category of water values. They are sometimes called intrinsic values, passive use values, or existence values. Non-use values are values placed on the existence of a resource and its physical, biological or cultural characteristics. They are not associated with any specific use. Non-use values include benefits received from knowing that a good exists, even though an individual may not even directly experience it. Some authors like Turner et al. (2004) also include the bequest value and the option value within the non-use values. The bequest value is derived from the knowledge that a feature of a water resource will be passed on to future generations so that they will have the opportunity to enjoy it. The option value is the satisfaction that an individual derives from the ensuring that a resource is available for the future given that the future availability of the resource is uncertain. It can be regarded as insurance for possible future demand for the resource (Turner et al., 2004).

In this chapter only the direct use value of water is considered. The focus will be on the use of water as intermediate good in agricultural production. In the next section methodologies to assess this value will be discussed.

2.2 Estimation of water value

Neoclassical economic theory predicts that, in a competitive market, the economic value of a good corresponds to its market price, which reflects individuals' willingness to pay for that good. For water however, due to the limited role played by markets, valuation techniques must be used (Young, 1996; Agudelo, 2001).

Several methods for estimating the value of water have been developed. They can be grouped according to whether they rely on observed market behaviour and data to infer economic value (indirect techniques), or alternatively use survey methods to obtain valuation information directly from water users (direct techniques) (Agudelo, 2001). Examples of indirect techniques used for valuing irrigation water can be found in following studies: Kulshreshtha and Tewari (1991) used derived demand functions, Faux and Perry (1999) and later Latinopoulos et al. (2004) used an hedonic pricing approach and several authors, among whom Lange (2007), Agudelo and Hoekstra (2001) and McGregor et al. (2000), used residual imputation approaches to estimate water values. Other indirect techniques such as the averting behaviour method, travel cost method, income multiplier approach and replacement cost/cost savings methods are less relevant for irrigation water valuing. Direct valuation techniques seek to elicit preferences of individuals through questioning them on their willingness to pay for a good or a service. These techniques include the contingent valuation method, contingent ranking and conjoint analysis (Turner et al., 2004). Hassan and Farolfi (2005) for example used the contingent valuation method to estimate water demand functions of different users in the Steelpoort sub-basin, South Africa and Salman and Al-Karablieh (2004) determined farmers' willingness to pay for groundwater in the highland areas of Jordan. A detailed discussion of water valuation methods can be found in Young (1996) and more recently in Lange and Hassan (2007).

In general, the most scientifically accepted methods are those based on actual market behaviour and information (Hussain et al., 2007). In the case of South Africa, there are currently no water markets from which values for irrigation water can be derived. Furthermore since subsistence farmers in the study area are not paying for water, it is impossible to establish a relationship between price and demand from actual behaviour to generate demand functions. Moreover, because water is still provided by the government for free, strategic biases or simply the belief among smallholders that water is a free gift (Abu-Zeid, 2001), could probably lead to erroneous estimations of water values when using direct methods such as contingent valuation (Wasike and Hanley, 1998). Therefore, following Lange (2007), the Residual Imputation Method (RIM) was used in this study. Although this method clearly has its shortcomings, which are discussed in a next section, it was considered the most suitable technique to estimate water values for the studied small irrigation schemes.

2.3 Residual imputation method (RIM)

The RIM determines the incremental contribution of each input in a production process. If appropriate prices can be assigned to all inputs but one, the remainder of total value of product is attributed to the remaining or residual input, which in this specific case is water (Young, 1996; Agudelo, 2001; Lange and Hassan, 2007).

The technique is based on two principal axioms (Young, 1996):

1) The prices of all resources should equal returns at the margin. This is a well-known condition for competitive equilibrium, i.e. as would occur if perfectly competitive markets were to exist for all agricultural inputs;

2) The total value of production can be divided into shares, in such a way that each resource is paid according to its marginal productivity and the total product is completely exhausted. This

is satisfied when the total value function is a linear homogeneous production function. Euler's theorem shows that this is the case when a production function involves constant returns to scale.

Residual valuation thus assumes that if all markets are competitive, except the one for water, the total value of production (TVP) equals exactly the opportunity costs of all the inputs (Agudelo, 2001):

$$TVP = \sum_i VMP_i Q_i + VMP_w Q_w \qquad (3.1)$$

Where:

TVP= total value of the commodity produced;

VMP_i= value of marginal product of input i;

Q_i= quantity of input i used in production, w for water.

It is assumed that the opportunity costs of non-water inputs are given by their market prices (or their estimated shadow prices). Therefore the shadow price of water can be calculated as the difference (the residual) between the total value of production (TVP) and the costs of all non water inputs to production. The residual, obtained by subtracting the non-water input costs from total annual crop revenue equals the gross margin (GM) and can be interpreted as the maximum amount the farmer could pay for water and still cover costs of production. It represents the at-site value of water:

$$GM = TVP - \sum_i P_i Q_i \qquad (3.2)$$

Where:

GM= gross margin;

P_i= price of input i.

This monetary amount, divided by the total quantity of water used on the crop, determines the marginal value for water (VMP_w), corresponding to the irrigator's maximum willingness to pay per unit of water for that crop (Agudelo, 2001). Average values were used in this study as a proxy of the marginal ones[3].

$$VMP_w = \frac{TVP - \sum_i P_i Q_i}{Q_w} \qquad (3.3)$$

The assumptions of the RIM are not overly restrictive, but care is required to assure that conditions of production under study are reasonable approximations of the conceptual model. The main issues can be divided into two types (Young, 1996; Lange and Hassan, 2007): 1) those relating to the specification of the production function and 2) those relating to the market and policy environment (i.e. the pricing of outputs and non-residual inputs). If inputs to production are omitted or underestimated (incorrect production function) or if there are inputs that are unpriced or not competitively priced, then the RIM will generate inaccurate estimates. To overcome the first problem, all relevant inputs should be included in the model. The second problem can be solved by determining shadow prices for the inputs that are not correctly priced. Because of this sensitivity to the specification of the production function and the assumptions about market and policy environment, the residual imputation method is only suitable when the residual input contributes a large fraction of the output value. This is the case for irrigated agriculture in water scarce regions.

2.4 Data collection and variables

Data was collected from small-scale irrigation schemes situated in Zeerust Municipality (North-West Province, South Africa) from July to September 2005 (figure 4.2). The surface area of this municipality is 7192 km² with a population of 136000 (AGIS, 2005; Zeerust Local Municipality, 2004). This municipality was chosen because promotion of small scale irrigation has been explicitly identified as a development policy for the region while at the

[3] Whether average values can be used instead of marginal water values depends on the purpose. Average estimates, which are easy to compute and interpret, can be used when the objective is comparing values of water use across the same sector or when a good indicator of overall performance is needed (Hussain et al., 2007).

other hand it is part of one of the South African water catchments (Crocodile West–Marico) that is expected to suffer most from water scarcity in the future (DWAF, 2004).

Questionnaires were used to collect data for the period 2004-2005. In total 60 farmers were interviewed, spread over 13 small-scale irrigation schemes. The number of farmers active on the schemes studied ranged from 1 to 45, with a total of 189. The sample covers about 15% of the estimated smallholder population in the study area. The total irrigated area of the schemes comprises 191ha. Extension staff of the North West Province Agricultural Department acted as interpreters. Schemes and individual farmers were selected randomly from a list provided by the Department. At each scheme the number of respondents was adapted to the number of resident farmers. The objective was to interview at least 15%-20% of the farmers at each scheme.

The interviews gathered information on irrigation schemes and household characteristics, farm activities, quantities and costs of inputs used in production, quantities and value of output[4], quantity of water consumed and irrigation practices. Estimation of water use was based on the reported duration and frequency of irrigation events together with irrigation infrastructure characteristics. In this estimation expert knowledge of the extension staff was used as a supplement to farmers' answers. In the absence of water metering this was considered a good way to estimate individual water use. The expert knowledge was also helpful to determine market prices of inputs and outputs. Table 3.1 provides an overview of the use of the different inputs.

[4] Total output value consists of both the value of cash sales and the value of subsistence consumption. Farmers were asked how much it would cost them to buy the self consumed part on the market. In this way subsistence consumption is valued using consumer prices.

Table 3.1 Descriptive statistics on output produced and inputs used in irrigated production per farm (n=60)

	Unit	Average	St. dev.	Minimum	Maximum
Output	US$	423.52	1706.74	22.56	13114.88
Inputs:					
Labour expenditures	US$	43.62	114.3	7.42	900.9
Expenditure on pesticides	US$	10.83	12.33	0	54.14
Expenditure on fertilizers	US$	9.63	13.69	0	72.24
Expenditure on fuel	US$	23.16	139.27	0	1082.9
Water use	m^3	1287	3299	82.9	22150
Land use	ha	0.16	0.4	0.01	2.8

2.5 Data analysis

A first step in the analysis consisted of relating the observed reality to the history and characteristics of the South African irrigation schemes and farming practices. To facilitate the reader's appreciation of the calculated figures, some elements of the national context are briefly repeated in the first part of the results section. The second step was to determine water value at crop level using the RIM. The revenue earned by the farmers for each crop was calculated multiplying their production by market prices. By doing so, the self-consumed part of production was valued. At the input side, costs of fertilizers, pesticides, herbicides, fuel and labour were taken into account. These were considered the relevant inputs in the production process. For fertilizers, pesticides and herbicides, the competitive market prices were used to determine costs, even when extension services provided these inputs to farmers for free. For these inputs and the output, market prices are thus considered to equal shadow price. On the other hand, for the costs of family labour a shadow price was calculated based on discussions with farmers and extension personnel and on the scarce data on wage labour in the dataset. A value of 1.5 US$ per day was used[5]. Given the high unemployment in the study area, up to 40% according to PROVIDE (2005), the minimum wage of 5.3 US$ per day would not be a correct reflection of the cost of family labour. This kind of price corrections, as proposed by Lange and Hassan (2007), is necessary to fulfil the assumptions of the RIM. Next, the

[5] The average ZAR/US$ exchange rate for the period July-September 2005 was used for conversion: 1 ZAR= 0.1504US$ (source: IMF, 2006).

estimated water values were compared over crops using one-way ANOVA tests. The third part of the analysis was to estimate the value of water at farm and scheme level and to test if significant differences could be observed among the analysed farms and schemes. Finally, a General Linear Model (GLM) was used to assess the importance of both quantitative and categorical factors influencing the variability in water value. The Variance Components procedure option estimates the contribution of the different factors included in the GLM (crops, irrigation technologies, irrigation schemes, educational background, farmer's age, gender and plot area) to the variance of the dependent variable (value of water).

3. Results and discussion

3.1 Small-scale irrigation in South Africa

The importance of the institutional context as a factor influencing water values is stressed by Hermans et al. (2006). Therefore, this section briefly repeats the most important characteristics of the small-scale irrigation sector, which were identified in Chapter 2. The sector roughly contains two types of irrigation schemes: larger government funded schemes and community schemes or garden schemes.

Historically at the government schemes, management and operations were centralized and administered by government agencies. This system led to a high level of dependency upon government interventions, imposed a large financial burden on the state and resulted in poorly performing schemes (Shah et al., 2002). By the end of the 90's, when the government agencies withdrew, income of the farmers was already very poor, but without access to inputs and organizational structure to obtain credit and other services, the situation got even worse. Many production units proved not to be financially viable and farmers left production, making the burden of carrying management of the scheme on remaining farmers even heavier (Kamara et al., 2002). Recently rehabilitation programmes for these schemes were put in place, aiming to revitalise their role in rural development,. Perret and Geyser (2007) report that in Limpopo for instance 1.08 billion rand will be spent for rehabilitation or refurbishment of schemes between 2006 and 2010 and in Eastern Cape 100 million rand was spend in 2006. A key aspect of these programmes mostly also is the transfer of ownership to local communities. They furthermore include education and training and promotion of affordable technologies (IPTRID, 2000; Perret, 2002a).

The community schemes or garden schemes on the other hand were usually established by NGOs or development projects in the framework of poverty alleviation and food security. Generally the beneficiaries of these schemes were already more involved in the scheme management from the outset, increasing the possibility of a successful management transfer. Nevertheless results of these initiatives are also mixed (IPTRID, 2000).

The current situation of the small-scale irrigation schemes still reflects the origins and evolution as described above. For both types food security remains a major objective and crops and production patterns remain largely the same, along with the weak market opportunities and the poor agribusiness environment. Even so, following the changing institutional context in South Africa, farmers are now more encouraged to make some cash profit in order to be able to pay back production costs and services (Perret, 2002a).

3.2 Descriptive overview of irrigation in the study area

The average rainfall in the study area is 590 mm. Most of this rainfall occurs between October and April. Reference evapotranspiration is 1700 mm (SAPWAT, 2003). Three different institutional settings for irrigation could be identified in the sample: 1) Schemes modelled after the former Bantustan schemes: These are the largest schemes in the sample with an average area per farmer of about 1.6 ha; 2) Typical food gardens: These assemble more farmers on smaller areas and consequently the area per farmer is smaller, mostly well below 1 ha. Farmers are more involved in the management of the schemes, although most of them work only part-time at these schemes. Usually, they offer paid labour on commercial farms during labour peak months and work in the food gardens the rest of the year; 3) Individual irrigators: Encouraged by the institutional context, some farmers started irrigating on private plots of land on an individual basis. The fact that these smallholders started up their business after 2002 reveals the recent character of this phenomenon. Three farmers belonging to this category were included in the sample.

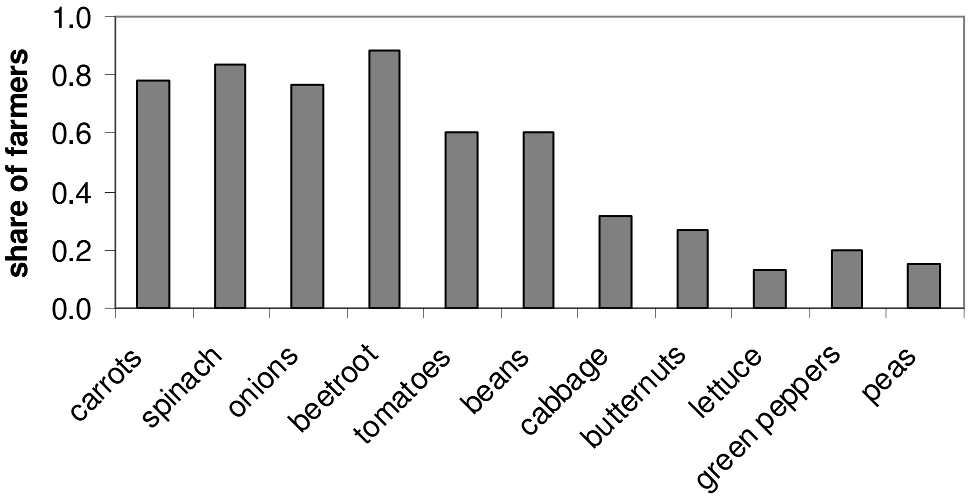

Figure 3.2 Distribution of crops among farms (n=60)

The irrigation schemes in this study are nearly entirely used for vegetable crops. Figure 3.2 depicts the share of farmers planting different vegetables. Beetroot, spinach, onions and carrots are widely planted, being produced by 70-90% of the farmers. A different picture emerges in terms of planted area (figure 3.3). Butternuts, cabbages and tomatoes appear to be the most important crops. Both figures also indicate a high degree of fragmentation, with most farmers dividing their field into several plots. It is furthermore important to know that not all schemes are cultivated throughout the year. At some of the schemes the farmers cultivate their fields for one growing period and work as labourers during the rest of the year. At other schemes both winter crops and summer crops are grown. Often the summer crop (rainy season) is rainfed maize.

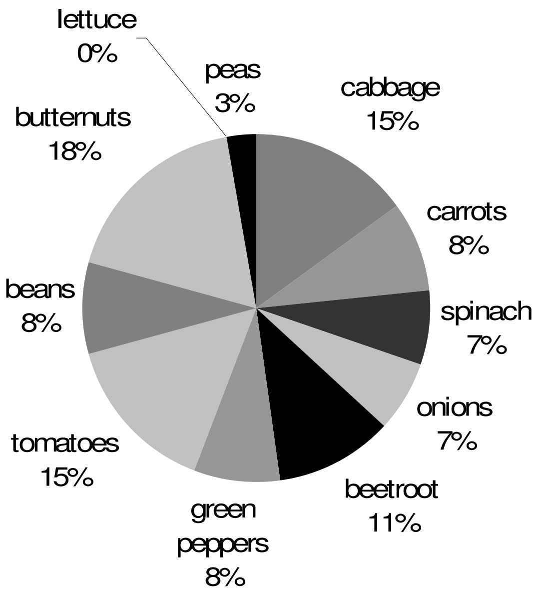

Figure 3.3 Importance of crops in terms of planted area (% of total irrigated area occupied by each crop)

The irrigation technology used by the farmers is usually uniform within a scheme. Furrow irrigation is the most frequently used method, as 40% of the studied farmers adopt it. The use of hosepipes and bucket irrigation accounts for 20% and 33% respectively. These low-cost irrigation methods are typical for the small-scale irrigation schemes. Sprinkler irrigation is not very common (only four farmers in the sample). A plausible explanation formulated by Brabben (2001) for the limited adoption of sprinkler irrigation is that farmers will only make the investment in modern equipment when the financial return is clear and relatively assured. Moreover, research has shown that for smallholders in South Africa, furrow irrigation is often more sustainable than equivalent irrigation using sprinklers (IPTRID, 2000). It is worthwhile noticing that in this study the three farmers who own their land have all invested in sprinkler irrigation. Irrigation practices differ a lot between and within schemes. While some farmers for example adapt the wetting frequency to the growth stage of the irrigated crop, other continue to irrigate with the same frequency the entire season.

Variation in input use and output produced is considerably large. The range in plot sizes, from less than 100 m² to 2.8 ha, is obviously a reason for this. Generally farmers seem to use a low input strategy. Statistics of the inputs and outputs used in the calculation of the gross margins are presented in table 3.1.

3.3 Discussion of estimated water values at crop, farm and scheme levels

Irrigation water values (VMP_w) are calculated per crop, scheme, scheme type and farm. Results of the RIM calculations of water value per crop are presented in table 3.2. In more than a quarter (27%) of the 320 observed plots, negative gross margins (GM) where obtained, leaving no residual value to attribute to water. Surprisingly, negative GM are also frequently found for crops that are widely planted like beetroot, onions and spinach. Tomatoes and cabbages on the other hand seldom yield negative GM.

The meaning of these negative GM must be put into perspective. Negative margins do not necessary mean that farmers' profit was negative. GM are theoretical, as in their calculation market prices were used, while on the farm, inputs are often not fully charged or even provided for free by extension services. The positive willingness to pay for irrigation water in spite of calculated negative GM, found in another study by Perret et al. (2003), supports this explanation. However, the negative GM found in this study do confirm poor overall performance of small-scale irrigation. It implies that at this moment without government support on inputs, production would not be economically viable. In the light of the investments made in the sector and the stated objective of cost recovery, this is a worrying situation. The study clearly supports the finding of Perret and Geyser (2007) that capacity of farmers to pay for water is low and insufficient for cost recovery of irrigation services. The occurrence of negative GM was also reported by Ntsonto (2005) studying smallholder schemes in South Africa and by Lange (2007) in Namibia.

Table 3.2 Computed water values ($/m³) per plot arranged per crop (n=320)

Crop	# cases	# (%) cases with negative GM	Water value[a] (St. dev.)	Adjusted water value[b]	Range	Water values from literature for comparison
Beans	32	5 (15)	0.991 (0.941)	0.836	0.00-3.081	2.03[c]
Beetroot	52	21 (40)	0.124 (0.246)	0.074	0.00-1.26	0.99[c] /0.01-0.40[d]
Butternuts	16	7 (44)	0.042 (0.06)	0.024	0.00-0.183	0.02-0.27[d]
Cabbage	17	0 (0)	0.368 (0.417)	0.368	0.003-1.663	0.78[c]/0.07-0.44[d]
Carrots	47	13 (27)	0.111 (0.161)	0.080	0.00-0.678	0.003-0.21[d]
Green peppers	11	6 (55)	0.222 (0.504)	0.101	0.00-1.677	n.a
Lettuce	7	0 (0)	1.532 (1.075)	1.532	0.109-3.008	n.a
Onions	46	17 (37)	0.154 (0.276)	0.097	0.00-1.494	n.a
Peas	8	1 (13)	0.118 (0.140)	0.103	0.00-0.417	n.a
Spinach	48	16 (33)	0.060 (0.082)	0.040	0.00-0.293	n.a
Tomatoes	36	1 (3)	0.238 (0.273)	0.231	0.00-1.281	0.27-1.22[e]
TOTAL	320	87 (27)	0.259 (0.515)	0.188	0.00-3.081	

[a] For the calculation of this value, only cases with positive gross margins were taken into account
[b] Average was calculated assuming a value of 0 for the cases with a negative gross margin
[c] Values derived from Combud crop budgets[6] (Combud, 2002)
[d] Water values found by Ntsonto (2005), the range indicating different management styles
[e] Water values found by Bader (2004), the range indicating different locations
n.a.: no values found to compare

[6] These are detailed enterprise budgets for each province in South Africa, published on a regular basis by the Provincial Departments of Agriculture. The budgets do not contain water use, but crop irrigation requirements for the budgeted crops could be calculated with the irrigation scheduling tool SAPWAT (SAPWAT, 2003).

In literature, only few studies calculate water values for specific vegetable crops. Generally aggregate values are presented at farm or even at scheme level. Table 3.2 shows that, for the crops for which comparison is possible, average water values calculated in this study are of the same order of magnitude as those given in other literature sources. Another observation is that although the study only looks at vegetable crops, computed values prove to be highly variable. This was also the case in similar studies. For instance, the range of values in table 3.2 reported by Ntsonto (2005) is equally large. Conradie and Hoag (2004) and Frederick et al. (1997) both give an overview of different studies calculating water values and find that reported values vary widely within and between the studies.

The aggregate average water value for the vegetable crops in this research is 0.259 US\$/m³ when the cases with negative GM are not taken into account, and 0.188 US\$/m³ if a value of zero is attributed to these cases. These values are comparable to results of other recent studies. In a review paper on water values, Hussain et al. (2007) report values up to 0.37 US\$/m³ for high value crops in some African countries, concluding that for vegetable production, water values are usually higher than 0.2 US\$/m³. Schiffler (1998) in Jordan and Bouhia (2001) in Morocco even found a value for vegetables respectively of 0.665 US\$/m³ and 0.686 US\$/m³.

In this study, water values were shown to differ significantly between crops using one-way ANOVA (table 3.3). Knowing that values differ significantly between crops, a post hoc test (Tamhane's T2)[7] was used to point out where exactly the significant differences in water values are situated. This analysis showed that significant differences in mean water values (at $P<0.05$) exist between beans on one side and carrots, spinach, onions, beetroot, tomatoes, butternuts and peas on the other side. Furthermore, the VMP_w of tomatoes also differed significantly from that of butternuts and spinach. From the perspective of improving water allocation, farmers should prefer crops with higher water values.

In order to explore the inter-schemes water value variability, VMP_w per irrigation scheme and scheme type were calculated and compared. The importance of recognizing different types of schemes was stated by Tren and Schur (2000b). They concluded that for schemes in a same

[7] Tamhane's T2 was used since a significant Levene statistic ($P<0.001$) indicated that equal variances could not be assumed. Tamhane's T2 is a post-hoc test specially designed for situations in which population variances differ and is conservative in relation to type 1 errors (Tamhane, 1979).

region and producing the same crops, the total output and efficiency could vary tremendously due to differences in scheme design and management structure. Similarly, Hussain et al. (2007) pointed out the influence of water management factors on water values. The ANOVA analysis revealed that using ‘irrigation scheme’ as factor, the plot level VMP_w differ significantly at the 0.05% level (table 3.3). To explain the differences, it is necessary to test whether they could be attributed to the various institutional settings and design principles of the schemes.

Table 3.3 One-way ANOVA tests showing differences between irrigation water values

Factors	**Degrees of freedom (between; within groups)**	**F-value**	**Significance**
Plot level			
Crops	(10;309)	20.841	0.000
Irrigation schemes	(13;306)	2.029	0.018
Scheme types[a]	(2;317)	6.185	0.002
Farm level			
Gender	(1;57)	0.356	0.553
Educational level [b]	(3;55)	1.555	0.211
Fragmentation (number of crops)	(8;50)	1.259	0.286

[a] The three different scheme types discussed in the first section of the results were introduced as factors
[b] Educational level was split into four categories: no education, primary education, secondary education and tertiary or vocational education

Table 3.4 reports the average and range of VMP_w for the three types of schemes discussed above. The values found are of the same size as those reported by Hussain et al. (2007) for schemes producing vegetables in some other African countries. The highest VMP_w was found for food gardens (0.321 US$/m³). However, including the cases with negative GM, the VMP_w becomes 0.251 US$/m³, which nearly equals the water value for farmers irrigating on private land. An F-value of 6.19 confirms the significance of differences between scheme types (see table 3.3). A Tamhane’s T2 post hoc test showed that for the schemes modelled after the former Bantustan schemes, the VMP_w were lower than those for the food gardens and those for the irrigators on private land at the 99% and 90% significance level respectively.

The higher values for the food gardens can be attributed to a more intensive production on the smaller plots. Other reasons for the higher values in the food gardens are a higher involvement and a lower degree of dependency on public support, leading to better management. These factors could also explain the higher water values for farmers irrigating on private land. The weak performance of the former Bantustan schemes highlights the necessity to improve their management.

Table 3.4 Computed water values per plot arranged per type of irrigation scheme (n=320)

Scheme Types	# plots	# plots with negative gross margins (% of total)	Value water US$/m³ (st. dev)	Range
Former Bantustan-like schemes	79	17 (21.5)	0.088 (0.149)	0.00-0.874
Food garden schemes	225	70 (31)	0.321 (0.593)	0.00-3.081
Individual irrigators	16	0 (0)	0.246 (0.238)	0.004-0.824

Finally, irrigation water values were assessed at farm level. The cumulative distribution of these values is presented in figure 3.4. VMP_w range between 0 and 1.11 US$/m³, with an average of 0.186 US$/m³. 85% of the farmers encounters a water value below 0.4 US$/m³ and for eight farmers (13%) negative gross margins at farm level were obtained, indicating that at market prices these farmers would not make profit out of their farm activities. In her study on Namibia, Lange (2007) also reports that some farms appear to be operating with losses.

No significant differences related to gender, number of crops or the educational level[8] of the family head could be found between the water values at farm level (table 3.3). Also farmer's age and farm size had no significant effect on the water value. To test if differences in cropping pattern could perhaps mask the relationship between farmers' characteristics and

[8] For the educational background, four categories were created: no schooling, elementary education, secondary education, tertiary or vocational education.

water values, the influence of these characteristics was also explored per crop. Again no significant results were found, indicating that individual characteristics of farmers appear to have limited effects on the water values. Farmers' performance seemed to be related principally to scheme design, output prices and the institutional settings.

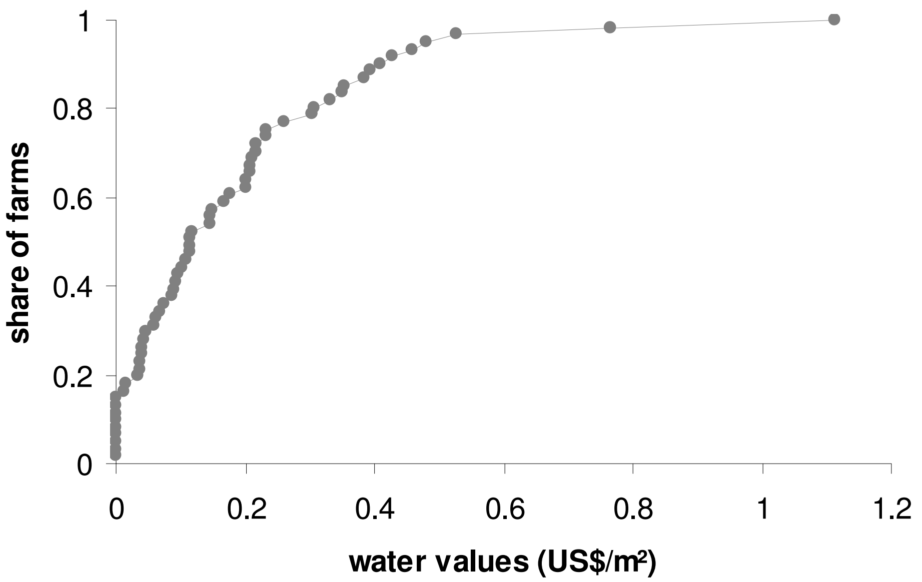

Figure 3.4 Cumulative distribution function of irrigation water values at farm level

3.4 Explaining variance in computed values

The last part of the analysis aimed at checking the results of the partial analysis and at estimating the contribution of different factors (crops, irrigation technologies, irrigation schemes, educational background, farmer's age, gender and plot area) to the variance of the value of water. For this purpose, the Variance Components Procedure option of GLM was used. Approximately 60% of the variability in water values can be explained by the variables included in the GLM and the model is highly significant (table 3.5).

The partial Eta squared statistic in the table describes the proportion of total variance attributable to a factor. The crop choice clearly has the largest effect, accounting for nearly 40% of the variability in the values. Variability can also be attributed for about 10% to the effect of the irrigation schemes. This effect can be explained by physical differences such as soil characteristics or differences in terms of scheme management. In line with the analyses above, farmer's characteristics like educational background , farmer's age or gender appear to be less important; the first two factors accounting for 1.9% each and the last for only 0.5%. Moreover educational background and gender were not significant at 95% level. This confirms that personal characteristics of the farmers have only a marginal influence on variability in water values. Surprisingly, the effect of irrigation technology is even smaller. A possible explanation is that nearly all farmers in the sample use low efficiency technologies like furrow irrigation, bucket irrigation or hosepipes and thus variability in water values cannot be attributed to this factor.

Table 3.5 GLM model decomposing water value variance into factors

Factors	**df**	**F**	**Partial Eta Squared[a]**
Crops	10	13.63***	0.394
Irrigation technology	1	0.41	0.002
Irrigation schemes	11	1.88**	0.090
Educational background (four categories)	3	1.33	0.019
Farmer's age (years)	1	4.09**	0.019
Gender (0=male)	1	0.96	0.005
Plot area (m²)	1	0.03	0.000
Error	210		
Total	241		
Model	31	9.90***	0.594

*** indicates a 99% significance level ** a 95% significance level and * a 90% significance level
[a] Partial Eta squared calculated here is based on the marginal sums of squares (type III). These are preferred since they correspond to the variation attributable to an effect after correcting for any other effects in the model. A normal outcome of this is that the partial Eta squared of the factors do not sum to that of the model.

4. Conclusions and policy implications

Insight into the value of water is essential to support policy-making about water pricing and the efficient allocation of water among different water users and uses in a river basin. In this chapter the Residual Imputation Method was used to calculate water values in small-scale irrigation schemes in the North West Province of South Africa. The observed values of water were in the range of those found in other studies for irrigated vegetables in semi-arid areas throughout Sub-Saharan Africa (Hussain et al., 2007).

The analysis revealed a high level of variability in irrigation water values. It was shown that the differences in water values can be mainly attributed to two factors, which can be relevant for policy makers and extension services: 1) the characteristics of irrigation schemes, and 2) the type of crop grown. As for the first factor, food gardens and individual irrigators proved to perform better in terms of water values than schemes derived from former Bantustans organisations. One reason for this can be the higher intensity in terms of labour and inputs, which generally leads to higher gross margins and consequently higher irrigation water values. Another reason can be identified in the lower degree of dependency upon state interventions in these schemes, which leads to a more dynamic and flexible management. Some findings of this study therefore support the argument that more participatory scheme management leads to efficiency improvements. They indicate moreover that transfer of ownership to farmers should remain a key aspect of rehabilitation plans.

However, the most important factor influencing the value of irrigation water is the crop being produced. Thus even in a case study involving only high value crops, crop choice remains the most important factor explaining differences in water value. Extension services can use this knowledge to promote more efficient allocation by creating incentives that encourage farmers to grow crops with higher water values. Other factors like farmers' characteristics, irrigation technology, or plot size proved to be less important in this case study. A possible explanation for the low importance of the latter factors might reside in the fact that the dataset was relatively homogenous for these variables. Additional research with a more heterogeneous population in terms of these factors can shed some light on this.

A high percentage of negative gross margins at plot level was found. This reveals that the sector would still have problems to be viable without government support, an issue which should be taken into account when designing water pricing and allocation policies. The fact that irrigated crop yields in small scale irrigation schemes are often weak and erratic is also problematic given the current huge public investments in smallholder irrigation in South

Africa. These investments prove to be inconsistent with the liberal discourse on cost recovery and expected small scale irrigation performance. The government officially assigns an internal rate of return of 4% to those rehabilitated schemes (Denison and Manona, 2006a), and expects farmers to gradually pay water charges, which will include capital and replacement fees through a phasing-in process (Perret, 2002a; Backeberg, 2006). The finding of Perret and Geyser (2007) that this is probably out of reach in current production conditions is thus confirmed in this study.

CHAPTER 4

The efficiency of irrigation water use and its determinants

Abstract

This chapter analyses the efficiency with which water is used in small-scale irrigation schemes in North-West Province in South Africa and studies its determinants. In the study area, small-scale irrigation schemes play an important role in rural development, but the increasing pressure on water resources and the approaching introduction of water charges raise the concern for more efficient water use. With the Data Envelopment Analysis (DEA) techniques used to compute farm-level technical efficiency measures and sub-vector efficiencies for water use, it was shown that under Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) specification, substantial technical inefficiencies, of 49% and 16% respectively, exist among farmers. The sub-vector efficiencies for water proved to be even lower, indicating that if farmers became more efficient using the technology currently available, it would be possible to reallocate a fraction of the irrigation water to other water demands without threatening the role of small-scale irrigation. In a second step, Tobit regression techniques were used to examine the relationship between sub-vector efficiency for water and various farm or farmer characteristics. Farm size, landownership, fragmentation, the type of irrigation scheme, crop choice and the irrigation methods applied showed a significant impact on the sub-vector efficiency for water. Such information is valuable for extension services and policy makers since it can help to guide policies towards increased efficiency.

KEY WORDS: data envelopment analysis; technical efficiency; water use efficiency; South Africa; small-scale irrigation

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1. Introduction

The growing water scarcity in many countries puts pressure on irrigation systems, as main consumptive user, to release water for other uses and to improve performance (Malano et al., 2004). The North West province in South Africa is such a water-stressed region. Moreover, because rainfall is low (<500mm per year) and extremely variable in space and time, irrigation is a key factor indispensable for agricultural production (Ashton and Haasbroek, 2002). As in many areas in South Africa, economic development among the previously disadvantaged communities is low in Zeerust Municipality, and, given the high levels of unemployment, small-scale irrigation schemes are of great importance for the livelihood of many families there. Apart from the employment opportunities, these schemes are furthermore believed to play an important role in rural development because of their potential to provide food security and additional income opportunities (Perret and Touchain, 2002). On the other hand, performance and economic success of these schemes have been poor, which raises questions on their level of efficiency (Perret, 2002a). Moreover, the new water policy in South Africa regards water as an economic good and thus charges will be levied on its use. Currently water use of farmers at small-scale irrigation schemes is subsidized. However, these subsidies will gradually decrease and in the future farmers will have to pay to ensure cost recovery (DWAF, 2004), hence small-scale irrigators will face two new problems in the future: firstly, less water will be allocated to the agricultural sector, due to the increasing water scarcity, and secondly, they will have to pay for the water they use. In other words, they will have to deal with a reality where water becomes a limited input for which they have to pay. The impact of this new reality is unclear, but it will definitely have an impact on the production system and stress the importance of using water in a more efficient way.

This chapter analyses the efficiency with which water is used in small-scale irrigation schemes and studies its determinants, using data of a sample of 60 farmers in Zeerust Municipality. Although the sample is relatively small, the case study will provide insights that reflect the typical situation of many rural areas in South Africa. It is however difficult to ascertain whether the use of water is efficient or not, since irrigated agriculture is a multiple input-multiple output process. In that respect, it is important not to consider water as a resource in an isolated manner (Malana and Malano, 2006; Rodríguez Díaz et al., 2004b).

Studies on efficiency differentials among farms often use simple measures, such as yield per ha or output per m³, which are easy to calculate and understand. However, such measures tell very little about the reasons for any observed differences among farms. Output per m³, for example, does not take into account the differences in non-water inputs among farms such as labour or fertilizers (Coelli et al., 2002).

In the first step of the analysis in this chapter, Data Envelopment Analysis (DEA) is used to calculate more consistent measures of efficiency (Fraser and Cordina, 1999). DEA is a systems approach widely used in management science and economics, in which the relationships between all inputs and outputs are taken into account simultaneously (Raju and Kumar, 2006). The method enables to determine the relative efficiency of a farm and to examine its position in relation to the optimal situation. Moreover, this methodology allows not only technical, but also sub-vector efficiencies to be calculated; a measure that can be used to specifically monitor the efficiency of water use[9].

A second step of the study consists of analysing the determinants of the efficiency measures (Reig-Martinez and Picazo-Tadeo, 2004). Separate Tobit models are estimated as a function of various attributes of the farmers or farms within the sample, allowing to deduce which aspects of the farms' human and physical resources might be targeted by public investment to improve efficiency (Chavas et al., 2005; Binam et al., 2003).

Although there have been several studies that have analysed the efficiency of agricultural production in developing countries (Haji, 2006; Malana and Malano, 2006; Chavas et al., 2005; Abay et al., 2004; Binam et al., 2004; Dhungana et al., 2004; Binam et al., 2003; Coelli et al., 2002, Wadud and White, 2000), most of them have focused on mono-cropping of major food crops like rice, maize or wheat or on cash crops like coffee and tobacco. Besides, these studies have not specifically focused on the use of water. The novelty of the analysis in this chapter is that it has a clear focus on water, for which the sub-vector efficiencies are

[9] In this chapter the sub-vector efficiencies for water use will be used as an indicator of water use efficiency. "Water use efficiency" is a widely used term. It is used for various performance indicators that relate water use and crop production. Irrigation engineers often define it as "mass of product per volume of water used", while economists look at "gross production ($) divided by volume of irrigation water applied". The sub-vector efficiencies are an alternative for the last type of measure, also taking into account the differences in non-water inputs.

calculated and analysed. This is highly relevant given the growing water scarcity and the future introduction of water pricing. It is of significant importance for policy makers, because it not only creates awareness concerning inefficiencies in water use, but also provides insight into possible improvements by exploring the determinants of these inefficiencies.
The remainder of the chapter is organised as follows. The next section elaborates on the efficiency concepts and their measurement and discusses the theoretical background for DEA and in section 3, data collection is described. Obtained efficiency scores are presented with the determinants of inefficiency in section 4 and discussed in section 5. Section 6 provides some conclusions.

2. Methodology

2.1 Efficiency measures

Efficiency refers to the global relationship between all outputs and inputs in a production process (Rodríguez Díaz et al., 2004b). The performance of a farm can be evaluated based on different efficiency measures, namely technical, allocative and economic efficiency. This study is limited to the calculation of technical efficiencies. More specifically, the measures that originate from the seminal work on technical efficiency by Farell (1957) are used. There technical efficiency is defined as the ability of a farm to produce the maximum feasible output from a given bundle of inputs, or to use minimum feasible amounts of inputs to produce a given level of output. These two definitions of technical efficiency lead to what is respectively known as the 'output-oriented' and the 'input-oriented' efficiency measures (Coelli et al., 1998; Coelli et al., 2002; Dhungana et al., 2004; Rodríguez Diaz et al., 2004a; Rodríguez Díaz et al., 2004b; Coelli et al., 2007). Input-oriented models were chosen in this study to reflect the reality where the main aim is to use resources more efficiently and not to increase production (Rodríguez Diaz et al., 2004a).

Technical efficiency itself can be further decomposed into two components: scale efficiency and pure technical efficiency. The former relates to the most efficient scale of operation in the sense of maximising average productivity. Pure technical efficiency however, is obtained when separating the scale effect from the technical efficiency.

For calculating the efficiency of an individual input, sub-vector efficiency measures are introduced in order to generate technical efficiency measures for a subset of inputs rather than for the entire vector of inputs. The concept looks at the possible reduction in a subset of inputs, holding all other inputs and output constant (Oude Lansink and Silva, 2004; Oude Lansink and Silva, 2003; Oude Lansink et al., 2002; Färe et al., 1994).

2.2 The Use of DEA to measure efficiencies

Two major approaches to measure efficiency have evolved, namely parametric and non-parametric approaches, with the stochastic frontier production function approach and the DEA methodology respectively as most popular techniques.

The DEA methodology has some important advantages over the econometric approach to efficiency measurement. Firstly, because it is nonparametric there is no need to make assumptions concerning the functional form for the frontier technology or the distribution of the inefficiency term. Secondly, the approach permits the construction of a surface over the data, which allows the comparison of one production method with the others in terms of a performance index. In this way DEA provides a straightforward approach to calculating the efficiency gap that separates each producer's behaviour from best productive practices, which can be assessed from actual observations of the inputs and outputs of efficient firms (Haji, 2006; Reig-Martinez and Picazo-Tadeo, 2004, Malano et al., 2004; Wadud and White, 2000). Furthermore, when using DEA, efficiency measures are not significantly affected by a small sample size, as long as the number of inputs is not too high in comparison to the sample size (Thiam et al 2001; Chambers, 1998). Oude Lansink et al. (2002) finally argue that calculating sub-vector technical efficiencies using a stochastic frontier approach would be highly problematic.

The disadvantages of DEA, however, are that it is deterministic and sensitive to measurement errors and other noise in the data, although several studies comparing both methodologies have shown that results from both methods are highly correlated (Alene and Zeller, 2005; Thiam et al., 2001; Wadud and White, 2000). In this study a DEA approach is preferred because of its flexibility and the possibilities of calculating sub-vector efficiencies. DEA is based on the notion that a production unit employing less input than another to produce the same amount of output can be considered as more efficient. Simultaneously a production frontier is constructed and efficiency measures are obtained. The frontier surface is assembled piecewise by solving a sequence of linear programming problems, one for each farm and relating each farm to this frontier. The frontier created envelops the observed input and output data of each farm.

The model is presented here for a case where there is data on *K* inputs and *M* outputs for each of the *N* farms. For the i-th farm, input and output data are represented by the column vectors $\mathrm{x_i}$ and $\mathrm{y_i}$, respectively. The *K* by *N* input matrix, X, and the *M* by *N* output matrix, Y, represent the data for all *N* farms in the sample.

The DEA model to calculate the technical efficiency (TE) is found in Eq. 4.1:

$$Min_{\theta\lambda}\theta, \tag{4.1}$$

subject to
$$\begin{aligned} &-y_i + Y\lambda \geq 0, \\ &\theta x_i - X\lambda \geq 0, \\ &N1'\lambda = 1, \\ &\lambda \geq 0 \end{aligned}$$

where θ is a scalar, *N1* is a vector of ones, and λ is an vector of constants. Using the variables λ and θ, the model is solved once for each farm, looking for the largest radial contraction of the input vector $\mathrm{x_i}$ within the technology set. The value of θ corresponding with this contraction is the technical efficiency score for the i-th farm. This score will always lie between zero and one, one indicating that the farm lies on the frontier and is efficient. The first constraint ensures that output produced by the i-th farm is smaller than that on the frontier. The second constraint limits the proportional decrease in input use, when θ is minimized, to the input use achieved with the best observed technology. Constraint three is a convexity constraint that creates a variable returns to scale (VRS) specification of the model. Without that convextity constraint, Eq. 4.1 makes up the constant returns to scale (CRS) specification. Using that specification it is assumed that farms are operating at their optimal scale (Fraser and Cordina, 1999). In the case of agriculture, increased amounts of inputs do not proportionally increase the amount of outputs. For instance, when the amount of water to crops is increased, a linearly proportional increase in crop volume is not necessarily obtained. This is one reason why the variable returns to scale option might be more suitable for our problem (Rodriguez-Diaz et al., 2004b). Coelli et al. (2002) and Haji (2006) on the other hand found that for small farms like the ones considered in this study, economies of scale were absent; hence both specifications will be modelled. In addition, a comparison of both scores is interesting because it provides information on scale efficiency (SE). Coelli et al. (2002) showed that the relation is as follows:

$$SE = TE_{crs}/TE_{vrs} \quad (4.2)$$

where SE is the scale efficiency, TE_{crs} the constant returns to scale technical efficiency and TE_{vrs} the variable returns to scale technical efficiency.

Using the notion of sub-vector efficiency proposed by Färe et al. (1994), the technical sub-vector efficiency for the variable input k is determined for each farm i by solving following programming problem (equation 4.3):

$$Min_{\theta\lambda}\theta^k, \quad (4.3)$$

subject to
$$\begin{aligned} & -y_i + Y\lambda \geq 0, \\ & \theta^k x_i^k - X^k\lambda \geq 0, \\ & x_i^{n-k} - X^{n-k}\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0 \end{aligned}$$

where θ^k is the input *k* sub-vector technical efficiency score for farm *i*. The terms x_i^{n-k} and X^{n-k} in the third constraint refer to x_i and X with the *k*th input (column) excluded, whereas, in the second constraint, the terms x_i^k and X^k include only the *k*th input. Other variables are defined identically as in equation 1. While constraints 1, 4 and 5 are the same as in model 1, constraint 2 and 3 now ascertain that a value of θ^k is found which represents a maximum reduction of the variable input *k* remaining within the technology set and holding outputs and all other inputs constant.

A graphical representation of the measurement of technical efficiency and sub-vector efficiency using DEA shows the intuitive interpretation of the method (figure 4.1). The problem takes the i-th farm A and then seeks to radially contract the input vector, x_i, as much as possible, while remaining within the feasible input set. The inner-boundary of this set is a piecewise linear isoquant determined by the frontier data points (the efficient farms in the sample are F1 and F2). The radial contraction of the input vector x_i produces a projected point on the frontier surface (A^0). This projected point is a linear combination of the observed data points, with the constraints in equation 1 ensuring that the projected point cannot lie outside the feasible set. The overall technical efficiency measure of farm A relative to the frontier is given by the ratio $\theta = 0A^0/0A$. The sub-vector efficiency for input X_1 is also presented in figure 4.1, in which X_1 is reduced while holding X_2 and output constant. In the graph A is projected to A' and sub-vector efficiency is given by the ratio $\theta^1 = 0'A'/0'A$.

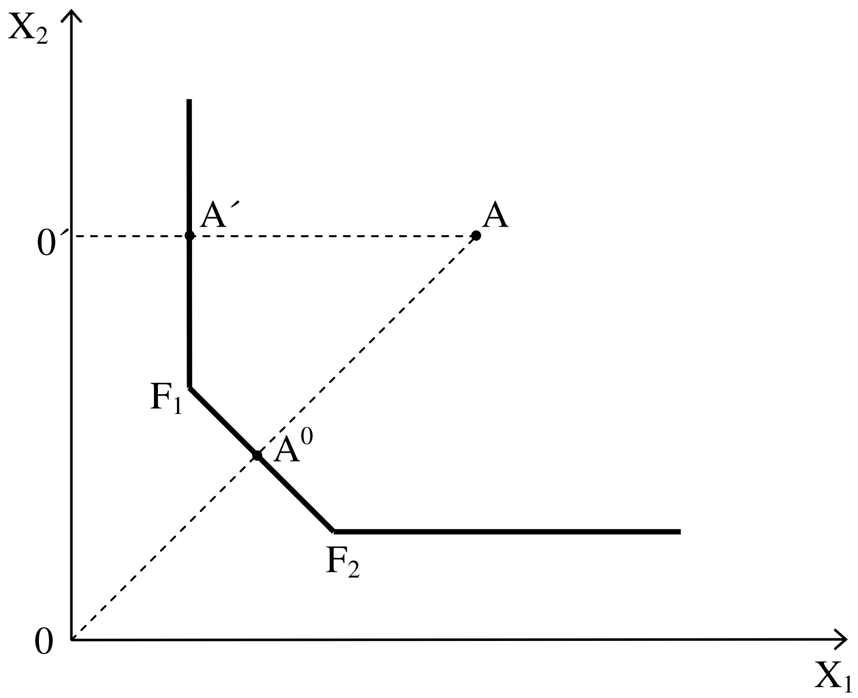

Figure 4.1 Graphical representation of the measurement of technical efficiency and sub-vector efficiency using DEA for an example with two inputs and one output *(adapted from Oude Lansink et al., 2002)*

In this study both the CRS and the VRS DEA models for overall technical efficiency (equation 1) are estimated using the program DEAP (Coelli, 1996). Sub-vector efficiencies were modelled in GAMS using the methodology proposed by Färe et al. (1994) and the modelling suggestions of Kalvelagen (2004). To get better insight in the differences between the measures obtained, following statistical tests are used. First, the correlation between the calculated efficiency measures is assessed using Pearson correlation statistics. Second, the hypothesis that sub-vector and overall technical efficiency measures differ is statistically tested using a paired sample t-test. For comparison, net profit per m³ of water, which is another often used measure of water use efficiency, is also calculated. Correlation between this measure and the obtained sub-vector efficiencies is assessed using the Spearman correlation coefficient.

2.3 Identifying determinants of efficiency using Tobit analysis

After calculating the efficiency measures, the next step is to identify the determinants of inefficiency. This is commonly done by estimating a second-stage relationship between the efficiency measures and suspected correlates of efficiency (Barnes, 2006; Chavas et al., 2005; Binam et al., 2003; Iráizoz et al., 2003). Since the efficiency parameters vary between zero and one, they are censored variables and thus a Tobit model needs to be used (equation 4.4):

$$\begin{aligned}\theta^{k*} &= \beta_0 + \beta_1 z_1 + \beta_2 z_2 + \ldots \beta_j z_j + e \\ &= Z\beta + e \qquad (4.4)\end{aligned}$$

$$\theta^k = \begin{cases} \theta^{k*} \text{ if } 0<\theta^{k*}<1 \\ 0 \text{ if } \theta^{k*}<0 \\ 1 \text{ if } \theta^{k*}>1 \end{cases}$$

where θ^k is the DEA sub-vector efficiency index for water used as a dependent variable and Z is a vector of independent variables related to attributes of the farmers or farms within the sample. The variables included in the Tobit model are discussed in the following section. The estimation of the Tobit model is based on maximum likelihood procedures (Verbeek, 2000). Two separate Tobit regressions for CRS and VRS specifications are estimated using LIMDEP version 8 (Greene, 2002). For Tobit estimates to be consistent it is necessary that residuals are normally distributed (Holden, 2004). Therefore, a normality test is necessary. In this study the conditional moment test for normality in censored data is used to test normality. To determine fit of the regressions two measures are calculated: an “ANOVA based” fit measure R^2_{ANOVA} and a “decomposition based” fit measure R^2_{DECOMP}. In the case of Tobit models these fit measures are best suited to be used as a substitute for the Ordinary Least Squares R^2, because both mimic R^2 and converge to it as censoring probability goes to zero. They are composed as follows: The R^2_{ANOVA} takes the variance of the estimated conditional mean divided by the variance of the observed variable. The R^2_{DECOMP} takes the variance of the conditional mean function around the overall mean of the data in the numerator (Greene, 2002). Finally the joint significance of all variables within the model is assessed using three test statistics, namely the Lagrange multiplier statistic (LMstat), the likelihood ratio statistic (LR) and the Wald statistic.

2.4 Data collection

The data collected from July to September 2005 from small-scale irrigation schemes situated in Zeerust Municipality (North-West Province, South Africa) were used in this chapter. More details on the sampling procedure were provided in Chapter 3. Zeerust Municipality is located in the Central District Council of North West Province and shares a border with Botswana (figure 4.2). The most important economic activity in this municipality, characterised by high unemployment, is agriculture.

During the interviews information was gathered on the irrigation schemes, household characteristics, farm activities, quantities and costs of inputs used in production (capital, variable and overhead), quantities and value of output, the quantity of water consumed and irrigation practices. In general in South Africa this type of farmers does not keep records concerning their farming activities, so data gathered during interviews was based on recollections of farmers. The expert knowledge of the extension staff was used as a supplement to the recollections of the farmers, something that was particularly helpful for the estimation of the water use and the prices of their produce.

For the different outputs both quantities and corresponding prices were obtained. Total output was then converted into monetary terms, the inputs considered in the efficiency analysis including land (hectares), irrigation (m³), labour (man days), fertilizers (expenses) and pesticides (expenses). An descriptive overview of these inputs in the sample was provided in table 3.1.

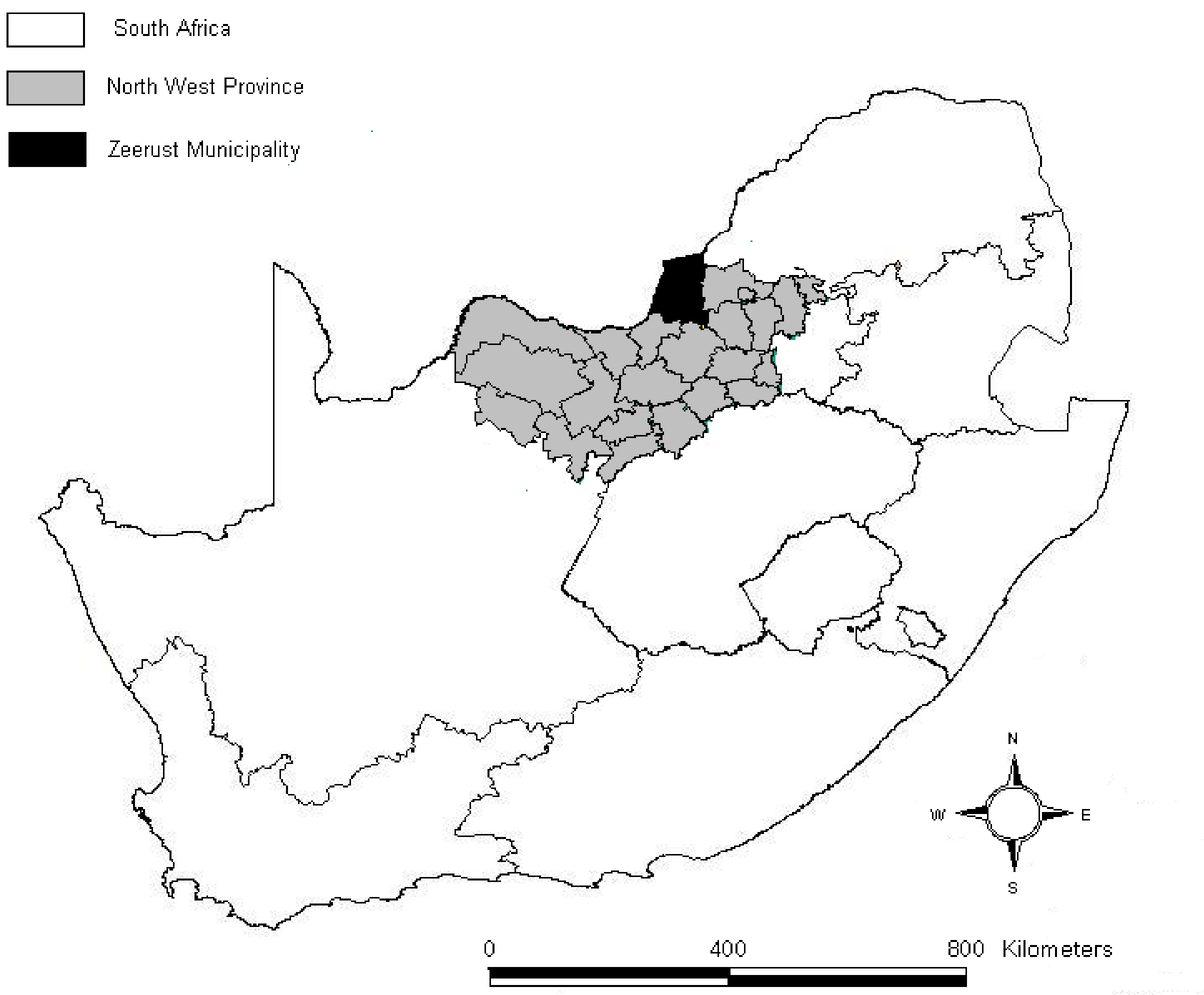

Figure 4.2 Situation of the study area (source: adapted from AGIS, 2005)

Table 4.1 Summary statistics for variables included in the Tobit regressions

	Continuous variables				Dummy variables	
	Mean	St dev	Min	Max	Number of farmers with dummy=1	Number of farmers with dummy=0
Farmers' age (years)	58	13	27	86		
Household size	6	3	1	19		
Cultivated area (ha)	1.018	1.210	0.011	6.6		
Simpson fragmentation index	0.700	0.260	0.000	0.889		
Crop choice (R/m³)[a]	1.236	1.352	0.000	7.405		
Gender (1= female)					27	32
Education (1= primary or more)					30	29
Landownership (1= owner of land)					3	56
Irrigation technique (1= surface)					35	24
Irrigation technique (1=buckets)					21	38
Type of irrigation scheme (1=typical small-scale)					19	40
Type of irrigation scheme (1= food garden [b])					37	22

[a] As a quantitative proxy for the compilation of crops selected by the farmers the overall profit per m³ of water was used.
[b] Parallel to typical small-scale irrigation schemes founded by government, a second type of schemes originating from civil society (communities, NGO's) has evolved. The plots at these schemes are usually very small and the main objective is to provide some additional food or income to the persons working there.

In the Tobit analyses various farmer or farm specific factors were regressed on the sub-vector efficiencies for water. Regression includes factors of a demographic nature, such as age of the farmer (in years), gender (dummy variable taking 1 if farmer was female and 0 otherwise) and household size (number of members in the household), as well as socio-economic characteristics like education (dummy variable taking 1 if farmer minimally attended primary education and 0 otherwise), cultivated area (total area in ha), landownership (dummy taking 1 if land is privately owned and 0 if it consisted communal land), crop choice (farmers profit per m³ of water used) and a land fragmentation index (Simpson index, defined as the sum of the squares of the plot sizes, divided by the square of the farm size, with higher values of this index indicating more fragmentation). Since three irrigation techniques were identified within the sample (sprinkler, surface, and bucket irrigation), two dummies for irrigation methods were also included. Furthermore three types of institutional contexts for irrigation schemes were recognised (food gardens, typical small-scale schemes and individual farmers irrigating), therefore two dummies for these arrangements were also included. The descriptive statistics for the variables included in the Tobit model are presented in table 4.1.

3. Results

The farmers at the irrigation schemes studied mainly grow vegetable crops using simple irrigation techniques (see table 4.1). Beetroot, spinach, onions and carrots are widely planted, being produced by 70-90% of the farmers. In terms of surface butternuts, cabbages and tomatoes appear to be the most important crops in the sample. The degree of fragmentation is quite high because most farmers divide their field into many plots, growing about 6 different crops on average. Furthermore, the variation in input use and output produced is considerably large. The range in land sizes, from less than 100 m² to 2.8 ha, explains this partially (see table 3.1). But even evaluated per ha, water use for instance varies between 3872 m³ and 10030 m³.

Figure 4.3 gives the frequency distribution of the efficiency estimates obtained by the DEA methods. The average overall technical efficiencies for the CRS and the VRS DEA approaches are 0.51 and 0.84 respectively, indicating that substantial inefficiencies occurred in farming operations of the sample farm households. Under the observed conditions, about 14% and 39% of farms were identified as fully technical efficient under the CRS and VRS specification respectively. The large differences between the CRS and VRS measures further indicated that many farmers did not operate at an efficient scale and that adjusting the scale of operation could improve the efficiency.

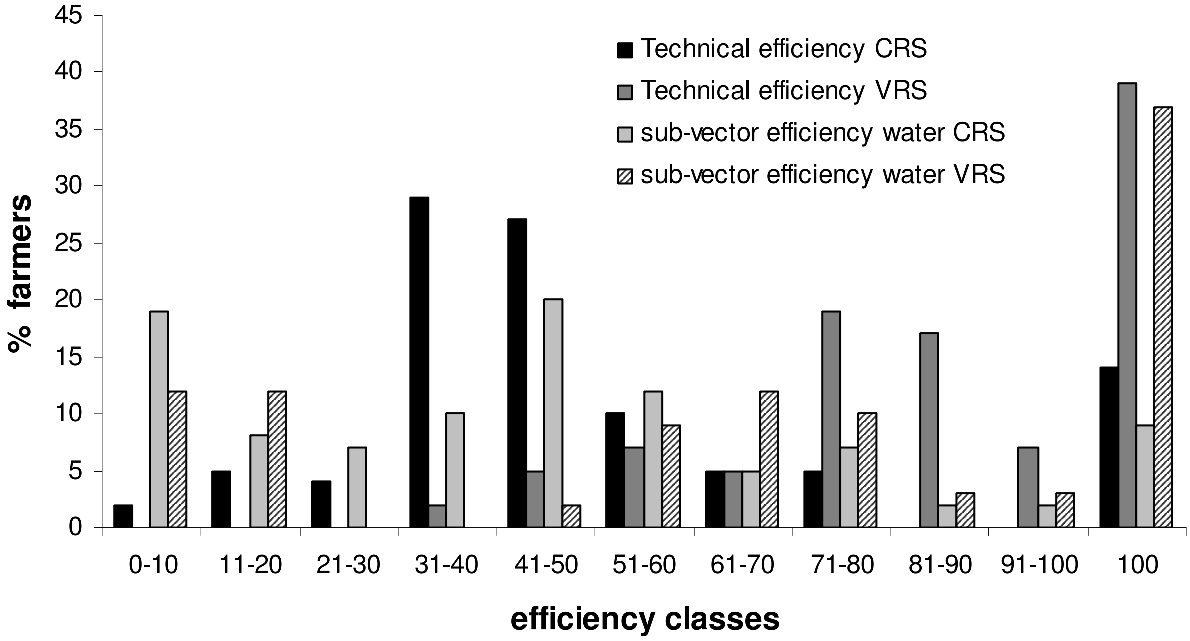

Figure 4.3 Distribution of overall technical and water sub-vector efficiencies under constant and variable returns to scale specifications

The sub-vector efficiencies for water demonstrated even larger inefficiencies. Average water efficiency was only 0.43 under CRS and 0.67 under VRS. Figure 4.4 gives a graphical representation of the cumulative efficiency distributions for the different measures. Again it is clear that under both returns to scale specifications more farms were highly inefficient in the use of water compared to overall technical efficiency.

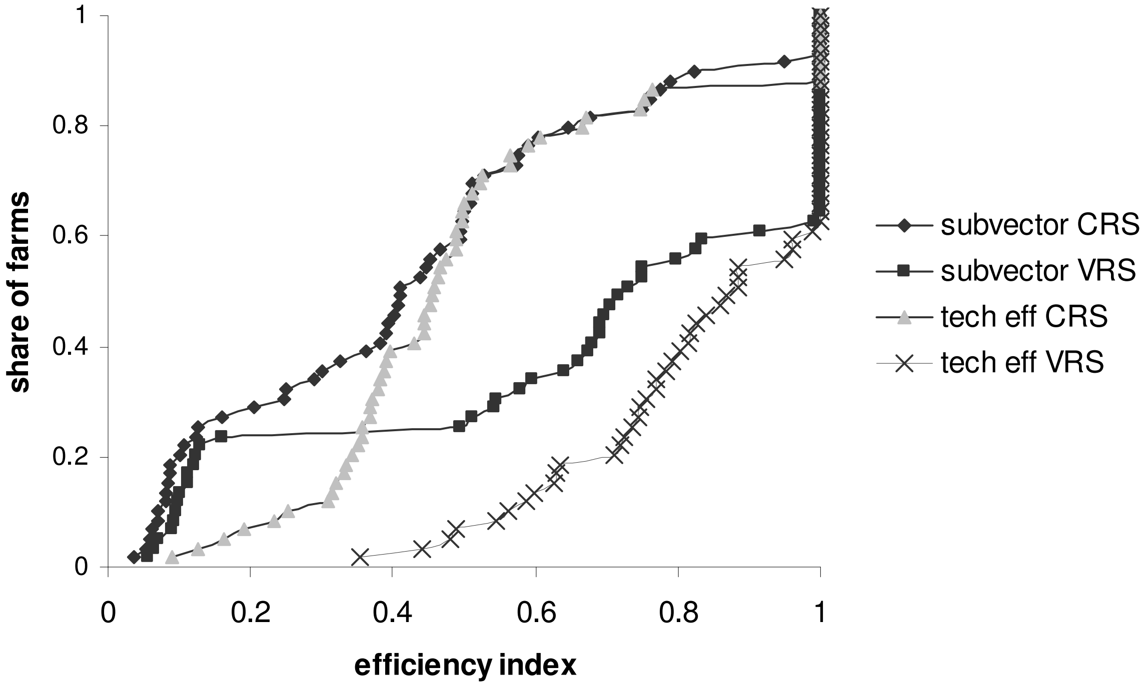

Figure 4.4 Cumulative distribution of technical and sub-vector efficiency for water under VRS and CRS specification

Table 4.2 gives the correlation statistics between sub-vector efficiency for water and the overall technical efficiency, which enables to determine the relationship between the two efficiency measures. Under CRS, technical efficiency and sub-vector efficiency were highly positively correlated. However, under VRS, correlation was still positive but less strong. This shows that sub-vector and overall efficiencies clearly capture different aspects of inefficiency. A paired sample t-test further analysed the equality between sub-vector efficiencies and overall efficiencies. The test revealed that sub-vector efficiencies for water were significantly lower then overall technical efficiency measures, both under CRS and VRS specification (table 4.3). This implies that in terms of water use farmers fail to reach their overall efficiency level. Net profit per m³ is 0.18 \$/m³ on average with a standard deviation of 0.2 \$/m³. Looking at the correlation between the sub-vector efficiency measures and the net profit per m³, Spearman correlation coefficients are 0.685 and 0.413 respectively for the CRS and VRS specification. This confirms that net profit per m³ is not that well suited as indicator of efficiency.

Table 4.2 Pearson correlations between efficiency measures

	Tech CRS	**Tech VRS**	**Sub-vector CRS**	**Sub-vector VRS**
Tech CRS	1			
Tech VRS	0.506 ***	1		
Sub-vector CRS	0.703***	0.140	1	
Sub-vector VRS	0.448***	0.349***	0.731***	1

Note: *** indicates a 99% significance level

Table 4.3 Paired samples t-tests demonstrating the difference between overall technical efficiency and sub-vector efficiency

	Mean difference	**Std dev.**	**t-statistic**
CRS: sub-vector- overall technical efficiency	-0.08	0.21	-2.849***
VRS: sub-vector- overall technical efficiency	-0.17	0.34	-3.912***

Note: *** indicates a 99% significance level

The results of the two Tobit regressions identifying the characteristics that determine the sub-vector efficiencies for water are presented in table 4.4.

The conditional moment test for normality in censored data indicated that the normality hypothesis could not be rejected (p-values for the CRS and VRS model were 0.435 and 0.782 respectively). Furthermore, the two fit measures R^2_{ANOVA} and R^2_{DECOMP} reveal that the fit of both models was more than satisfactory. The three test statistics for joint significance of all variables within the model (LMstat, LR and Wald statistic) all confirmed that both Tobit models were significant.

Concerning the individual variables, the results of the models with CRS and VRS specification showed consistency. Farmers characteristics (gender, age, education, household size) were not significant, whereas cultivated area, landownership, the scheme type dummy for food gardens and the crop choice were significant in both models. The cultivated area negatively influenced water efficiency, while the other significant variables had a positive effect on the efficiency measures. Under the VRS specification fragmentation was also highly significant, with a p-value of 0.0003 and had a negative effect on the sub-vector efficiency for water. The dummies for the irrigation methods, on the other hand, had a negative effect under both specifications, but were only significant under the CRS specification.

Table 4.4 Tobit estimates of determinants of sub-vector CRS and VRS efficiency

Dependent variable	**Sub-vector CRS efficiency**		**Sub-vector VRS efficiency**	
	Coefficient	**St dev**	**Coefficient**	**St dev**
Constant	0.0778	0.1529	0.4898*	0.2589
Gender (1=female)	-0.0204	0.0379	0.0655	0.0708
Age of farmer (years)	-0.0006	0.0014	0.0033	0.0027
Education dummy (1=primary or more)	-0.0240	0.0414	0.0492	0.0780
Household size (number)	-0.0072	0.0061	-0.0125	0.0113
Cultivated area (ha)	-0.0577***	0.0173	-0.1066***	0.0325
Landownership (1= owner of land)	0.6614***	0.1845	0.6605***	0.2114
Dummy irrigation method (1= surface)	-0.2688***	0.0798	-0.0705	0.1444
Dummy irrigation method (1= buckets)	-0.3267***	0.0859	-0.2259	0.1557
Fragmentation index (index)	0.1147	0.0862	-0.5907***	0.1629
Dummy scheme (1=typical small-scale)	0.4208***	0.1477	0.2923	0.2150
Dummy scheme (1= food garden)	0.4981***	0.1504	0.5668***	0.2060
Crop choice (R/m³)	0.1679***	0.0137	0.1333***	0.0261
R^2ANOVA	0.789		0.512	
R^2DECOMP[a]	0.816		0.575	
LMstat	80.12		53.28	
LR	99.51 ***		57.43 ***	
Wald	269.62 ***		97.17 ***	
Test value CM Normality test (p value)	1.665		0.491	

Note: *** indicates a 99% significance level and * indicates a 90% significance level

4. Discussion

The results of the DEA show that substantial inefficiencies occur among smallholder irrigators within the study area, which is consistent with a recent meta-analysis by Bravo-Ureta et al. (2007). They showed that in less developed countries, mean values of technical efficiency per study averaged about 0.74. Moreover, given the poor performance of the type of irrigation schemes in the area mentioned in several studies (IPTRID, 2000; Shah et al., 2002, Perret, 2002a), substantial inefficiencies were expected.

Secondly, results show that scale inefficiencies are significant (0.6 on average) with nearly all farms operating at increasing returns to scale, which implies that most farms should be larger than they presently are to produce efficiently under the present factor mix. Large scale inefficiencies were also reported by Binam et al. (2003) for coffee farmers in Ivory Coast, by Abay et al. (2004) for tobacco farmers in Turkey and by Shafiq and Rehman (2000) for cotton farmers in Pakistan. Haji (2006), on the other hand found that in the more traditional farming systems of smallholder farmers in Eastern Ethiopia, scale inefficiencies were nearly absent. A similar conclusion was drawn by Alene et al. (2006) for intercropping systems in Southern Ethiopia.

Thirdly, when looking specifically at their water use efficiency the results indicate that farmers fail to reach their overall technical efficiency levels. As indicated by Nsanzugwanko et al. (1996), this might be explained by the absence of pricing mechanisms for water. Farmers at this moment have no financial incentive to limit their water use or to invest in water saving technologies. The gradual introduction of water charges for this type of farmers, which is planned for the coming years, can probably be a trigger for more efficient use. Another interesting implication of these results is that there appears to be a considerable scope for reducing the water use, even with the technology currently available. This means that if efficiency improves, it should be possible to reallocate a fraction of the water to other water demands without really endangering production or the role small-scale irrigation might play for rural development. Besides, correlation tests showed that poor performance regarding water use efficiency and overall technical efficiency are linked. This can be explained by the vital role irrigation water plays in the production systems under study. However, this finding also implies that the introduction of water prices can be a threat to the viability of the poorer performers, because they will be most affected by this additional cost. If those farmers fail to improve their water use efficiency, their farming activities might become financially unviable.

Fourthly, the results of the Tobit models show that cultivated area, landownership, the scheme type dummy for food gardens and the crop choice have a significant impact on the sub-vector efficiency for water, under both specifications. Owner-operators seem to be more efficient in their water use, but one has to be careful with this conclusion, given their small number in the sample. Nevertheless, if this finding could be confirmed, it indicates the importance of land rights and can be an additional argument for land reforms, which make people owner of the land they work on. The cultivated area had a negative impact on the sub-vector efficiency for water. Haji (2006) also reported such a negative impact on overall technical efficiency, attributing it to the labour intensive character of the type of vegetable production he studied. However, in this study this finding seems inconsistent with the increasing returns to scale for overall technical efficiency found in the DEA outcomes, but it should be reminded that the Tobit models only consider the sub-vector efficiency. Apparently, the relationship between cultivated area and the totality of farming activities is different from that between cultivated area and the use of water. This was also confirmed in a Tobit model, which is not reported, where cultivated area had a significant positive impact on overall technical efficiency. Yet, further investigation on this matter is needed.

Finally, the institutional context of the schemes seems to be of relevance. Efficiency of water use is higher for farms in food garden schemes, which is in accordance with a study in South Africa by IPTRID (2000) that discussed the large potential of such food garden schemes in vegetable production. The highly significant and positive effect of crop choice on sub-vector efficiency for water supports the call for selecting crops with high higher profits per m^3 of water used or for water saving irrigation technology (see also Chapter 3). Fragmentation has a negative effect under the variable returns to scale specification, indicating that, for a certain size of operation, the sub-vector inefficiency for water is lower if the farm is less fragmented. This is due to the fact that irrigation can be managed more efficiently on larger plots (Wadud and White, 2000). However, under constant returns to scale specification, where farms operating at different scales are compared, the effect of fragmentation is not significant. This can partly be explained by the efficiency differences between the different types of schemes occurring in the area, which apparently neutralizes the effect of fragmentation. Earlier it was shown that the food garden schemes were more efficient compared to the other two types and typically these smaller schemes have a higher degree of fragmentation.

Other variables are not significant; education, for example, has no significant impact on the sub-vector efficiency for water. This is consistent with studies such as those of Haji (2006), Coelli et al. (2002) and Wadud and White (2000). The explanation of Coelli et al. (2002) that this could be due to the low average education level in the sample is also acceptable for this study. Dhungana et al. (2004) and Binam et al. (2004) in contrast reported a significant positive effect of education on efficiency for some of the regressions they performed, possibly pointing to a slightly higher average education level in their samples. Farmer's age does not contribute significantly to a higher level of efficiency either. A possible explanation is that two effects neutralize each other: older more experienced farmers have more knowledge on their land and traditional practices, but are less willing to adopt new ideas. Sometimes one of the two effects dominates, accounting for the mixed results in literature for the effect of age: negative in the study of Wadud and White (2000) and Binam et al. (2003), but positive in the study of Dhungana et al. (2004). In this study experience was not measured, so an age-experience interaction term could not be included to test the hypothesis above. A non-linear relationship for the effect of age was also checked without significant result. Consistent with Haji (2006) and Dhungana et al. (2004) the effect of family size is negative, but, as in Coelli et al. (2002), this effect is not significant. Finally, looking at gender no significant effect can be shown. This is in line with Chavas et al. (2005) and Dhungana et al. (2004).

5. Conclusions

This study showed that the smallholder irrigation farmers in the study area fail to reach their overall technical efficiency levels when it concerns water use. It appears that farmers have little incentives to use water in an efficient manner in the absence of a water price. In this sense, the gradual introduction of water charges for this type of farmers, which is planned for the coming years, could be a trigger for more efficient use. There are however also indications that the effect of introducing a water price might not be entirely positive. The high correlation between sub-vector efficiencies for water and the overall technical efficiency give cause to worries about the viability of the poor performers under the introduction of a water price. Further research on the economic efficiency of the farmers may shed some light on this.

On the other hand, the low efficiency estimates, suggest that substantial decreases in water use can be attained given existing technology, without compromising the key role in rural development played by small-scale irrigation. In this way there is room for lifting part of the increasing pressure on water resources by reallocating a fraction of the irrigation water elsewhere.

The relationship between the sub-vector efficiency for water and farm and farmers' attributes in addition gives information to policy makers and extension services on how to better aim efforts to improve water use efficiency. If for instance the significant positive effect of landownership on the sub-vector efficiency could be confirmed for a larger sample, this would emphasize the importance of land rights, supporting land reforms where people are made owner of the land they work. Another practical example is the positive and significant effect of crop choice on the sub-vector efficiency, which should incite extension services to encourage farmers to select crops with higher profit per m^3 of water. These results are in accordance with findings in Chapter 3. In conclusion, it should be noted that this chapter focused on technical efficiency measures. Additional research on allocative and economic efficiency can further determine the scope for production improvements and can add to our understanding of the effect on efficiency of the introduction of a water price. The effect of the introduction of water prices will be subject of the next chapter.

CHAPTER 5

Estimating the impacts of water pricing

Abstract

Worldwide growing water scarcity has increased the call for economic instruments to stimulate rational water use in agriculture. Furthermore, cost-recovery is now widely accepted as a cornerstone of sustainable water management. In many developing countries, where agricultural water use is often still subsidised, water-pricing policies are thus developed for achieving sustainability of water systems and an efficient allocation of water resources. The exact impact of water pricing policies on irrigation water use and by extension on the farmers' production system is however mostly unknown. This study introduces an innovative two-stage methodology that allows estimating these effects at farm level. Applying the method to small-scale irrigators in South Africa, it is shown that water demand of farmers is quite responsive even to small changes in the water price. In addition, the introduction of a water price is shown to significantly decrease farm profit. This appears to be mainly a problem for the poorer farmers.

KEY WORDS: water pricing; water savings; irrigation; data envelopment analysis; simulation; South Africa

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Speelman, S., Buysse, J., Farolfi, S., Frija, A., D'Haese, M., D'Haese, L. (2008). Estimating impacts of water pricing on smallholder irrigators: study in North West Province South Africa. Submitted to *Agricultural Water Management*

1. Introduction

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

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

As mentioned in the preceding chapters of this thesis, South Africa is one of the countries currently in the process of introducing water charges, imposing a new challenge on the small-scale irrigation sector. Apart from increasing the cost-recovery rate for water supply, an expected benefit of this policy change is that water use efficiency will rise. However, the exact impact on the irrigation water use or on the farmers' production system remains unclear. Ex-ante assessment of these effects is important in South Africa, since small-scale irrigation is identified as a key sector for rural development. This study proposes a novel two-step method, which is applied to a sample of 60 small-scale irrigators in North West Province, South Africa. First technical and economic efficiency levels are calculated, then these are used as a representation of the production technology in a mathematical programming model to estimate the impact of changes in the price of water. This method allows estimating the effect of water pricing at farm level and offers insight in the water saving effect of the introduction of water charges. In addition, the environmental effects (use of fertilizers and pesticides) and socio-economic effects (labour use, effect on farm profit and total agricultural output) can be assessed.

2. Methodology

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

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

2.1. Measuring efficiency with Data Envelopment Analysis (DEA)

The first step in this study consists of determining the current technical and allocative efficiency levels of the farms in the sample using the non-parametric DEA approach. Technical efficiency (TE) is defined as 'the ability of a farm to use minimum feasible amounts of inputs to produce a given level of output' (Coelli et al., 2002)[10]. Allocative efficiency (AE) on the other hand refers to the degree to which inputs are used in optimal proportions, given the observed input prices and the value of the outputs produced. Economic efficiency (EE) is the product of allocative and technical efficiency and captures performance in both measures.

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

A characteristic of DEA is that the relationship between all inputs and outputs is taken into account. A production frontier is constructed and efficiency measures are obtained simultaneously by solving a linear programming (LP) problem. The frontier obtained is formed by actual observations and envelops the observed input and output data of all farms. The model (eq. 4.1 without the convexity constraint) was discussed in detail in Chapter 4.

A second characteristic to capture is the farms' success in choosing the optimal set of inputs given the input prices. This is done by calculating the allocative efficiency. Using the technical and economic efficiency, the allocative efficiency can be determined residually as AE=EE/TE. Economic efficiency itself can be calculated with only minor adjustments to the basic model for calculation of technical efficiency. The calculation involves two steps. First, given the input prices, a cost-minimizing vector of input quantities is determined using the model from eq. 5.1:

$$Min_{x_i^* \lambda} w' x_i^*, \qquad (5.1)$$

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

where w_i is a vector of input prices for the i-th farm and x_i* (which is calculated by LP) is the cost-minimizing vector of input quantities for the i-th farm, given the input prices w_i and the output levels y_i. The other symbols are defined as in eq 4.1.

In the second step economic efficiency (EE) of the i-th farm is calculated as the ratio of the minimum cost to the observed cost (eq. 5.2)

$$EE = w'_i x_i^* / w'_i x_i \qquad (5.2)$$

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

2.2. Simulating impact of different water prices

The frontier and efficiency measures will now be used as a representation of the production technology. An underlying assumption for this second step is that farmers will adjust their water use and input mix in response to the introduction of water charges, because relative prices have changed. Although contested by some, price responsiveness of small-scale farmers in traditional agricultural settings is generally accepted by economists (Sauer and Mendoza-Escalante, 2007; Abler and Sukhatme, 2006). By accounting for economic inefficiency in farmers' behaviour, this study furthermore does not assume the criticized perfect rationality (Abrar and Morrissey, 2006). A second assumption is that in the short run the price responses will not have a direct effect on the overall levels of efficiency of farmers as they were defined above. A study by Maniadakis and Thanassoulis (2004) supports this assumption. When they decomposed productivity changes in Greek hospitals between two time periods, they were able to clearly distinguish the effects of changes in allocative and technical efficiency, changes in the technology of production and changes caused by shifts in input prices. Thereby they showed that shifts in input prices caused changes in input use without altering allocative efficiency.

The simulation model of this study is presented in eq. 5.4 to eq. 5.18. In this model $w^{'}_{new}$ and w' are the new and old price vector for each farm and $xsim_i^*$ and x_i^* the new and old cost-minimizing vector of input quantities for the i-th farm. $xsim_i$ is the simulated input vector, which maintains each farms' technical and allocative efficiency and x_i is the original input vector. For all these vectors subscripts "*k1*", "*k2*" indicate one of the non-water inputs, while subscript "*wa*" indicates water input. $ysim_i$ and y_i are the simulated and original outputs. λ_1 and λ_2 are vectors of constants. θ_i is the technical efficiency level and EE_i is the economic efficiency level that was determined in the first step for each farm. X_{fron} and Y_{fron} are parameters that are equal to the observed input vector and output vector of farms for which technical efficiency was found to be equal to one in the first step.

$$\underset{\lambda 1, \lambda 2, xsim_i, xsim_i^*, ysim_i}{Max} \; ysim_i - w'_{new} \, xsim_i \, , \tag{5.4}$$

subject to

$$-ysim_i + Y_{fron}\lambda_1 \geq 0, \tag{5.5}$$

$$xsim_i^* - X_{fron}\lambda_1 \geq 0, \tag{5.6}$$

$$-ysim_i + Y_{fron}\lambda_2 \geq 0, \tag{5.7}$$

$$\theta_i xsim_i - X_{fron}\lambda_2 \geq 0, \tag{5.8}$$

$$\frac{w'_{new} x'^*_i}{w'_{new} xsim_i} = EE_i \, , \tag{5.9}$$

$$ysim_i \leq y_i \, , \tag{5.10}$$

$$xsim_{wa,i} \leq x_{wa,i} \, , \tag{5.11}$$

$$xsim_{k,i} \leq xsim^*_{k,i} \, , \qquad \forall \text{k, if } x_{k,i} \leq x^*_{k,i} \tag{5.12}$$

$$xsim_{k,i} \geq xsim^*_{k,i} \, , \qquad \forall \text{k, if } x_{k,i} \geq x^*_{k,i} \tag{5.13}$$

$$w'_{new} xsim_{k1,i} \leq w'_{new} xsim_{k2,i} \, , \qquad \forall \text{k, if } w' x_{k1,i} \leq w' x_{k2,i} \tag{5.14}$$

$$w'_{new} xsim_{k1,i} \geq w'_{new} xsim_{k2,i} \, , \qquad \forall \text{k, if } w' x_{k1,i} \geq w' x_{k2,i} \tag{5.15}$$

$$\frac{xsim_{k,i}}{x_{k,i}} \geq \frac{xsim_{wa,i}}{x_{wa,i}} \, , \qquad \forall \text{k} \tag{5.16}$$

$$\lambda_1 \geq 0 \text{ and } \lambda_2 \geq 0 \qquad \text{(5.17) and (5.18)}$$

The model maximizes the gross margin of the farmers (Eq. 5.4). To reflect the situation that farmers start adjusting from an existing input mix, the original vectors x_i and y_i are used as starting values in the simulation. Equations 5.5 to 5.18 are the constraints in the model. Eq. 5.5 to 5.9 and 5.17 and 5.18 of the model form the representation of the technology found in the first step and incorporate the efficiency levels of the farmers. Eq. 5.9 in combination with

5.5 and 5.6 equals the economic efficiency given the new prices with the economic efficiency under the original prices, while eq. 5.7 and 5.8 make sure that the technical efficiency is maintained. Furthermore these equations assure that results remain within the technological possibilities defined by the frontier. Eq. 5.10, 5.11and 5.16 are based on micro-economic principles. Eq. 5.10 introduces in the model that a rise in the price of water will not lead to a rise of output. Eq. 5.11 ensures that the water demand curve will not be upward sloping (i.e. demand will not increase with higher prices). Eq. 5.16 adds to this that the relative use of the water compared to other inputs will decrease with an increase in the price of water. Eq. 5.12, 5.13, 5.14 and 5.15 finally assure that farmers' preferences for using certain inputs are maintained. These constraints are added because it is not considered very likely that radical shifts in the use of the non-water inputs will occur due to a water price increase.

Figure 5.1 illustrates the method graphically using a simple numerical example. In the starting situation Decision Making Units (DMUs) A-G, which are farmers in this study, use two inputs (X_1 and X_2) to produce a single output (Y). For simplicity it is assumed that all units face the same input prices (P_1 and P_2), which are set equal to three for both inputs (relative price curve 1). The technical efficiency frontier is formed by DMUs A, B, C and D. Moreover at the original prices DMU A is allocative and economic efficient, with relative price curve 1 tangent to the technical efficiency frontier.

We can now apply the model described above to estimate the effect of a price change of one of the inputs. Assume now that the price of input 1 increases to seven for all units. This change in relative prices of inputs 1 and 2 causes the slope of the relative price curve to alter (relative price curve 2). As a result, the technical efficient DMUs will move on the efficiency frontier, which represents their technical possibilities. They maintain their level of economic efficiency, because this reflects an inherent characteristic of these DMUs, namely the way they perceive prices. DMU A, for instance, moves from point A to the point A', where the new relative price curve is tangent to the frontier. DMU B moves from point B to point B'. The preservation of the economic inefficiency can be graphically shown as $0B/0B_0 = 0B'/0B'_0$. Summarizing, technical efficient DMUs move along the frontier and maintain their economic inefficiency level. By the movement along the frontier their input mix is changed. Similar to the DMUs on the frontier, DMUs with a TE below one (E, F, G) stay at the same technical and economic efficiency level, but change their input mix. Their new points of production are E', F' and G'.

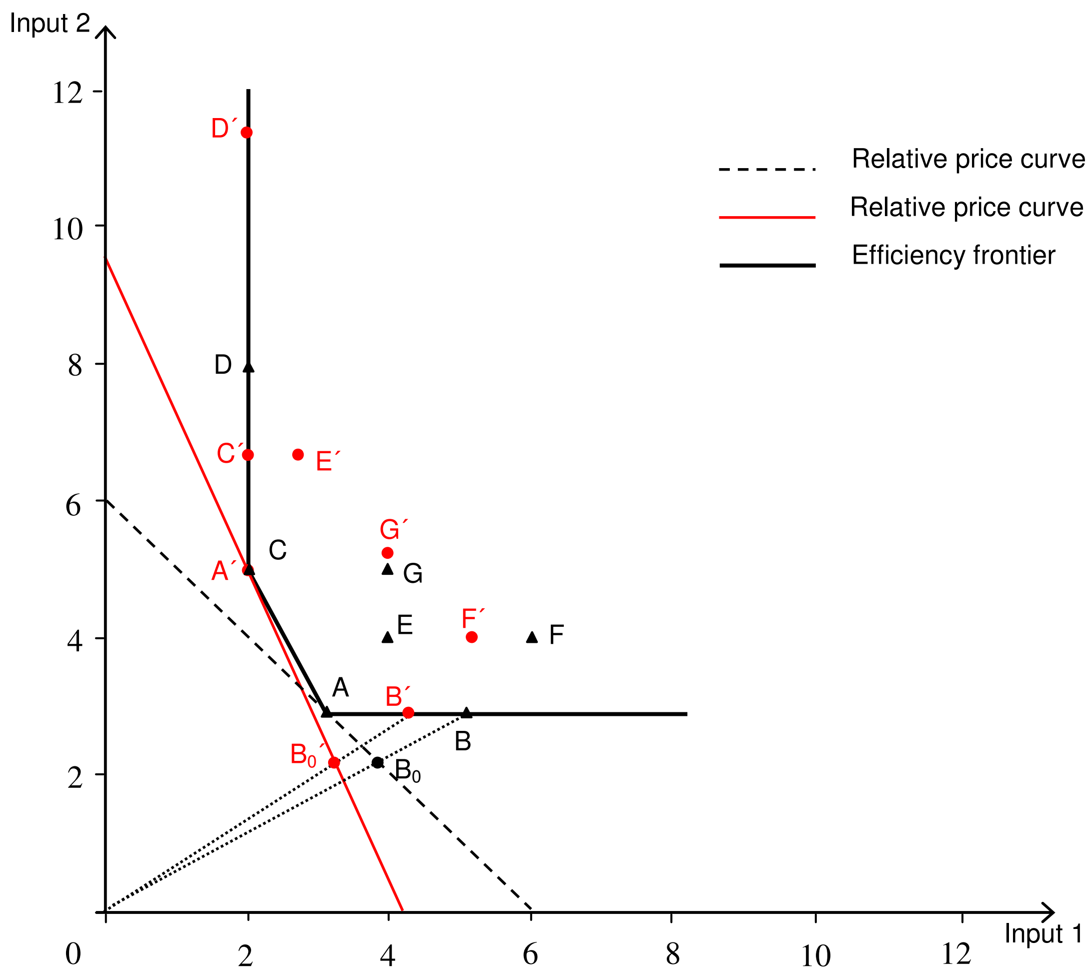


Figure 5.1 Simulating effect of relative price changes in a simple numerical example

By relying on input oriented efficiency measures the simulation model constructed takes an input perspective. Farmers maximize profit and respond to the price changes by changing their input mix. They are constrained by the technology frontier and their individual inefficiency levels. Implicitly the shifts in input mix will be related with changes in the crop mix, however these are not revealed by the model. Because the focus of the study is mainly on water use and farm profitability, the output is only looked at in monetary terms.

2.3.Data

The data collected in 2005 from small-scale irrigation schemes in Zeerust Municipality (North-West Province, South Africa) was used for this study. More detailed information concerning this data collection is provided in Chapter 3. The key elements are briefly repeated here.

Farmers in these schemes mainly produce vegetables. Questionnaires were used to collect data, with a total of 60 farmers interviewed, spread over 13 small-scale irrigation schemes. Random sampling was applied to select schemes and individual farmers, but representativeness was maintained by matching the number of respondents from each scheme with the number of farmers operational within them.

During the interviews, information was gathered on quantities and costs of inputs used in production, quantities and values of outputs and the quantity of water consumed. Expert knowledge of extension staff was used to supplement the information given by the farmers. A monetary value for the total output was calculated using the quantities and corresponding market prices of the different outputs. The inputs considered in the efficiency analysis include land, irrigation, labour, fertilizers and pesticides. Although the sample is relatively small, this case study reflects the typical situation of many rural areas in South Africa.

3. Results and discussion

3.1 Water pricing in South Africa

Water pricing is introduced in South Africa by the National Water Act (Republic of South Africa, 1998). The Act foresees three types of water use charges (DWAF, 2004). The first type is introduced to fund water resource management. This involves activities such as information gathering, monitoring water resources and controlling their use, water resource protection and water conservation. Unit charges (cents per cubic metre) are determined for each user sector and water management area. However for billing purposes these unit charges will be applied to the annual water use registered by or licensed to each user. The second type of charge is linked to water resource development and use of waterworks. It involves the costs of the investigation, planning, design, construction, operation and maintenance of waterworks, pre-financing of development, a return on assets and the costs of water distribution. The charge is directly related to the costs of managing water resources and supplying water from schemes and systems. Specific charges will be imposed on users of water from government water schemes and systems, and from schemes funded by other water management institutions such as catchment management agencies and water user associations to cover the costs of such schemes. Again these charges will be based on volumes of water used, and fixed and/or variable charges may be implemented. The third type of charge will only be introduced when effects of full financial pricing of water on resource use have been evaluated. It is meant to provide economic incentives to encourage more efficient use of water, water conservation and a shift from lower to higher value uses and will be based on the opportunity cost of water.

Currently commercial farmers in South Africa are already paying the first two types of charges. For the subsistence and emerging farmers a gradual introduction of these charging policies was foreseen. The operation and management charges for instance would be subsidised on a reducing scale over five years, after which depreciation charges would be phased in (Backeberg, 2006; Perret and Geyser, 2007). In most areas however smallholders are up to now still not paying for water.

Because they reflect differences in costs and scarcity, the charges determined by DWAF for the irrigation sector vary regionally per catchment and from scheme to scheme. For the period April 2008- March 2009 for instance, the water resource management charges vary between 0.003 R/m^3 in the Upper Orange and 0.014 R/m^3 in Levubu water management area. In the study area the charge is set at 0.0112 R/m^3 (DWAF, 2008b). The water resource infrastructure charges are generally higher. In the study area they range between 0.0149 R/m^3 and 0.1728 R/m^3 for the schemes for which they have been established (DWAF, 2008c).

3.2 Simulation of water pricing impacts

In a first step, the three efficiency measures described above (technical, economic and allocative efficiency) are calculated. The average technical efficiency is 0.51, indicating that substantial inefficiencies occur in farming operations of the sample farm households (see Chapter 4). Allocative and economic efficiencies are even lower, with an average value of

0.26 and 0.14 respectively. These scores suggest that farmers could considerably reduce costs by paying more attention to relative input prices when selecting input quantities. In South Africa these low values can be linked to the reported poor economic performance of the small-scale irrigation schemes in general as discussed in Chapter 3 and 4 (Perret, 2002a).

The simulation model described in section 2 is now applied to the South African farm budget dataset. The original situation, where water is a free input, is changed by introducing different water price scenarios (0.025 R/m³, 0.05 R/m³, 0.1 R/m³, 0.2 R/m³, 0.3 R/m³). These scenarios cover the range of water prices now paid by commercial farmers in the different WMA in South Africa. In figure 5.2 classes of water savings per farm are constructed (0%; 0-5%; 5-10%; …; stop) and for each water pricing scenario the share of farmers in each class is presented.

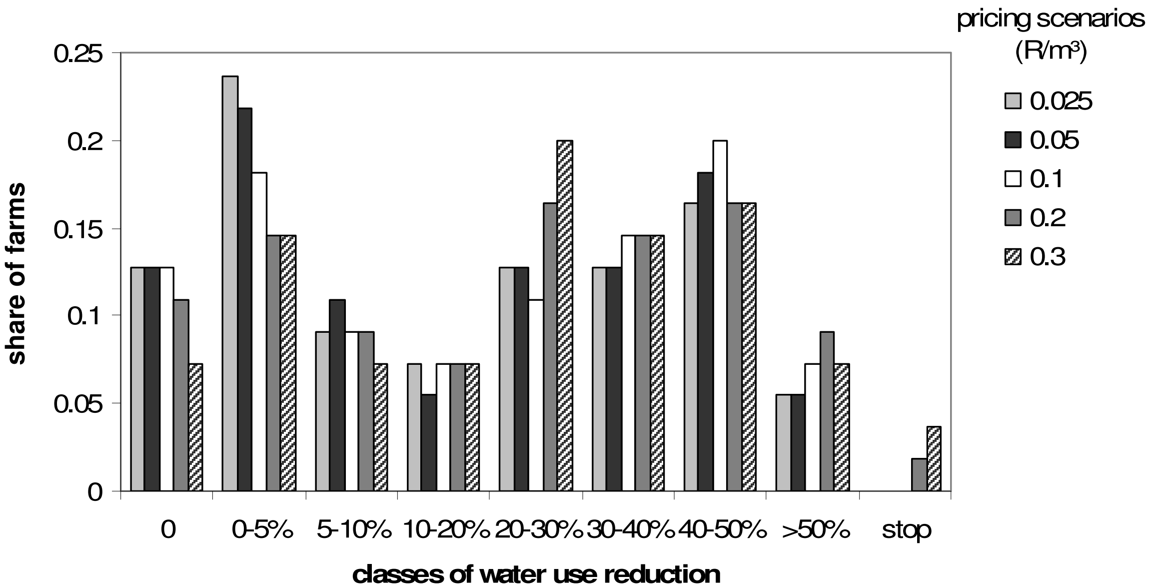


Figure 5.2 Classification of the reduction in water use under different water pricing scenarios

It is clear that already at low prices farms considerably save water. Such results were also found by Moore et al. (1994) and Schoengold et al. (2006). By allowing substitution between inputs in the model, water demand is clearly much more elastic then found by Albiac et al. (2007), Manos et al. (2006) or Gómez-Limón and Riesgo (2004). The result is not surprising given the low water use efficiency of the same farmers reported by Speelman et al. (2008) in an earlier study. The low water use efficiency of most farmers implies that the scope for improvements is large and the introduction of a water price provides an incentive to act. At higher water prices, water saving also increases at sector level because some farms that are not profitable anymore are expected to quit production. The different responses of the farmers at each price level (figure 5.2) further clearly confirm the finding of Gómez-Limón and Riesgo (2004) that farmers' elasticity of demand for water can vary a lot between farmers.

The model also gives insight in the evolution of water use efficiency, expressed as profit/m³, under different water pricing scenarios (figure 5.3)[11]. The introduction of a water price of 0.025 R/m³ immediately leads to an increase in water use efficiency of about 20%. However, further increases in the water price have only limited additional effects on the efficiency because the higher water prices do not only decrease water use but also severely affect the profit of the farmers.

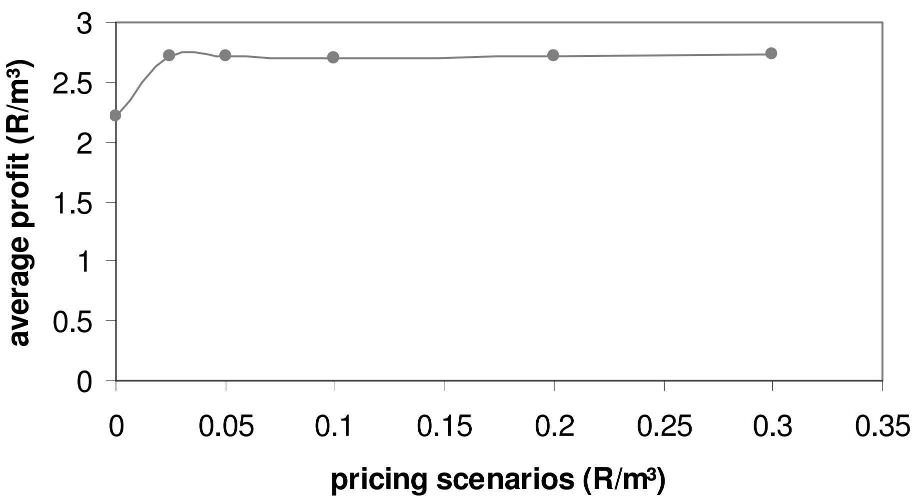


Figure 5.3 Evolution of water use efficiency at different water price levels

The effect of the different water pricing scenarios on the overall-use of the different inputs is shown in figure 5.4. Although not all farms react in the same way, at the lower price levels (below 0.1R:m³), there is a tendency of substitution between labour and water. Scheierling et

[11] The profit is measured here as the revenue minus the costs of inputs included in the model.

al. (2006) reported the same substitution. An explanation for this substitution can be that up to a certain point by investing more labour, water can be used more effectively and/or more carefully (Cai et al., 2008). The overall use of non-water inputs on the other hand decreases together with the water use, a result found in most studies (Gómez-Limón and Riesgo, 2004; Manos et al., 2006; Riesgo and Gomez-Limon, 2006; Bartolini et al., 2007). This implies that fertilizers and pesticides can be considered as complements to water in the production process. Relative use of the non-water inputs however increases. As shown in figure 5.3 the reduction in water use is higher than the reduction in the use of any other input. At higher water prices an additional factor for the decreases in the use of all inputs is the farms that go out of production. This reason was also reported by Bartolini et al. (2007) when studying the impact of water pricing on input use in irrigated production in Italy. Moreover the abandonment of fields also explains why labour use starts to decrease.

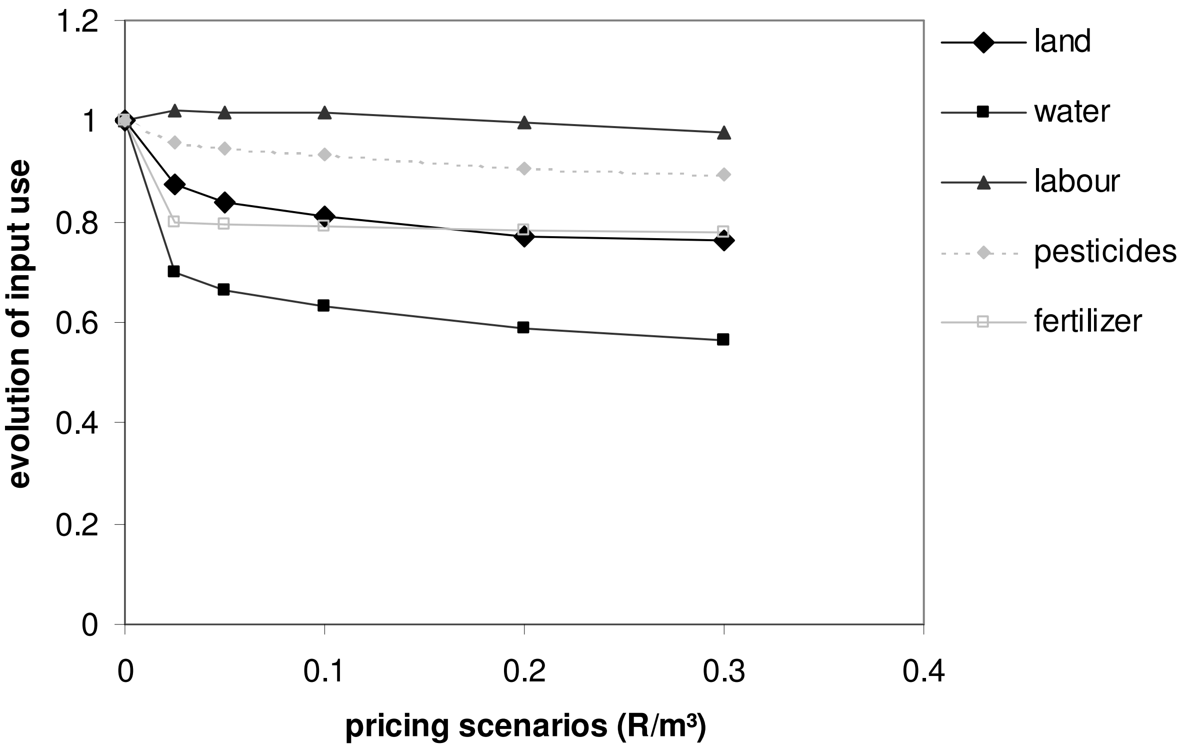


Figure 5.4 Evolution of overall input demand at different water price levels

In figure 5.5, total profit at sector level (aggregated profit) under different water pricing scenarios is compared with the actual profit. The aggregated profit appears to be quite stable at lower water price levels (below 0.025R/m³). At these levels irrigation water accounts for only a small part of the costs and as a consequence has only limited effect on the aggregated profits. This was also mentioned by Abu Zeid (2001). At a price of 0.3 R/m³ profit on sector level decreases with about 10%.

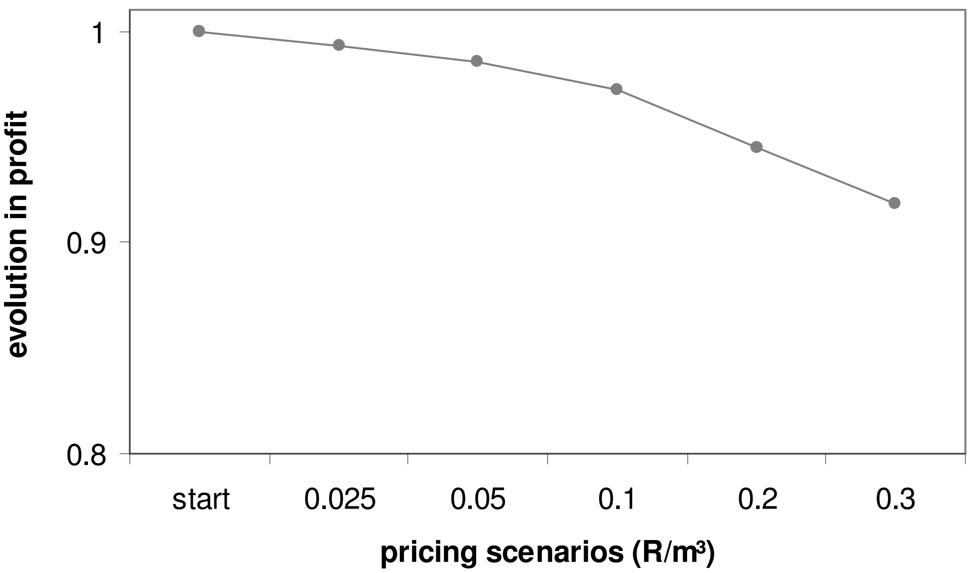


Figure 5.5 Evolution of profit (gross margin) at different water prices

Figure 5.6 shows the evolution of the profit of each farm in the sample at changing water prices and presents the cumulative distribution functions for the loss in profit at each price. For instance, at a price of 0.1 R/m³, the reduction in profit is less than 18% for 90% of the farmers. Comparison of figures 5.5 and figure 5.6 shows that at each level of price introduced, the relative loss in profit for most of the farms is higher than the loss in terms of percentage for the sector as a whole in figure 5.5. In other words looking at the evolution of total profit of the sector does not give an adequate picture of the effect of the introduction of a water price because information on individual farms is lost. Similar to Gómez-Limón and Berbel (2000) and Yang et al. (2003) a significant loss of farm income is found for many individual farms.

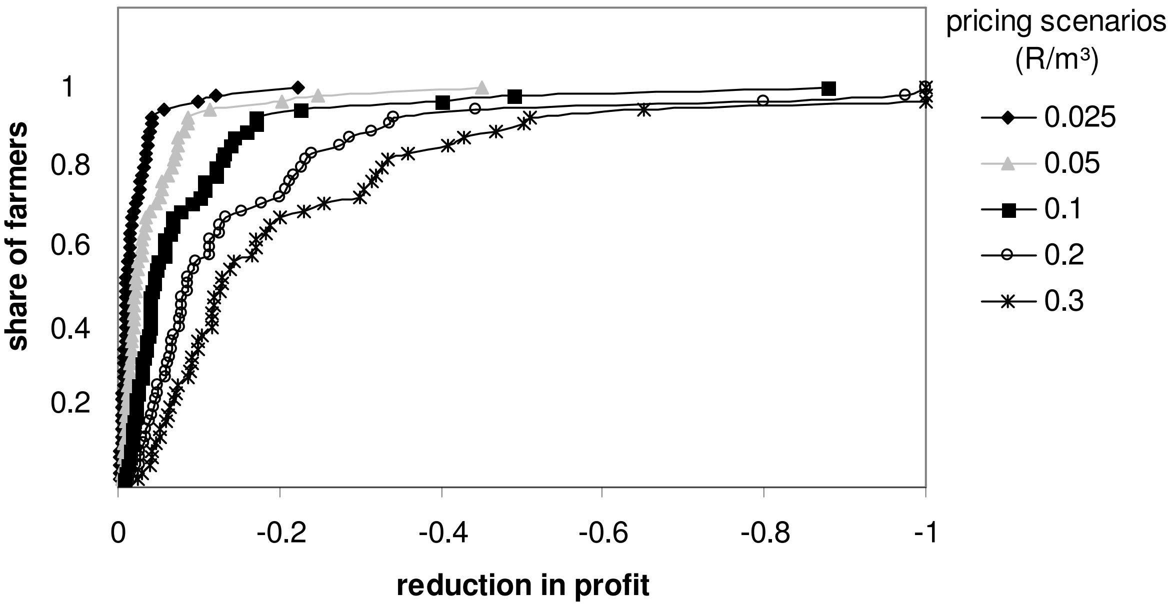


Figure 5.6 Cumulative distribution of reduction in profit for different water pricing scenarios

4. Conclusions

Water pricing is often seen as an important tool to improve efficiency of water use. Several authors however have warned for the limited effect in terms of water saving and the even negative economic and social side effects of this policy. Given the increasing pressure to release water for other uses and to find ways in which to improve irrigation performance, there is an urgent need for methodologies that allow estimating the effects of different water pricing scenarios. This chapter proposes a novel method to simulate the effect of changes in water price. An assumption made in the method is that farmers are responsive to price changes. This assumption originating from Schultz “Poor-but-efficient” hypothesis (1964), is sometimes questioned in the context of small-scale farming in developing countries, but is accepted by most economists.

An advantage of the model is that by using the observed technology frontiers from the DEA in the simulation model, estimation of farmer’s response to price incentives is improved. Farmers are allowed to make gradual changes in their input use, which better reflects possible options in reality. Another advantage is that incorporating the occurrence of inefficiencies at farm level allows looking at the individual response of farms. A drawback of the model, caused by the input oriented perspective, is the inability in the current form to reveal changes in cropping patterns. A disadvantage, which the model shares with most currently available LP models on water pricing is that it does not take into account the occurrence of technological progress.

When applied to South Africa, an important finding is that farmers are quite responsive to even small changes in water price. This can be explained by the low water use efficiencies reported in an earlier study and by the possibility of input substitution incorporated in the model. It seems that pricing gives farmers an incentive to the tackle the overuse. Another key finding which was also reported by other studies is the magnitude of the adverse effect on farm profitability. From a development perspective it is worrying that the smaller farms in terms of output (mainly the poorer farmers) are affected most and, at higher water prices, are not profitable anymore and would even quit production. As shown in chapter 3, even without water pricing a not negligible share of the farmers had negative gross margins, the introduction of an extra cost (water) evidently aggravates this problem. Further research could focus on developing a model that works with frontiers on crop instead of on farm level. In this way changes between crops could also be explicitly predicted.

CHAPTER 6

Valuing interventions in the water rights system

Abstract

The definition of water rights systems is important for the management of increasingly scarce water supplies. A way to estimate the efficiency of a particular water rights system is valuing willingness to pay by water users for improvements in its definition. A contingent ranking experiment is used in this study to evaluate the water rights system in South Africa, with special reference to smallholder irrigators. Three specific dimensions of water rights, relevant for the South African case, are considered: duration, quality of title and transferability. Results indicate that smallholder irrigators are prepared to pay considerably higher water prices if these prices are connected with advancements in the water rights system. This implies that by interventions in the water rights system the efficiency of the small-scale irrigation sector can be improved and that such interventions can also assist the government to reach the objective of improved cost recovery.

This chapter is based on:

Speelman, S., Farolfi, S., Frija, A., D'Haese, M., D'Haese, L. (2008). Evaluating the efficiency of the water rights system for smallholder irrigators in South Africa: a contingent ranking approach. Submitted to *Water Resources Management.*

1. Introduction

There is general agreement that if property rights are ill-defined, this can seriously impair the efficient use of natural resources (Randall, 1978; Ostrom, 2000; Heltberg, 2002; Linde-Rahr, 2008). Ill-defined water rights create high transaction costs (information search, negotiation, monitoring) for making decisions over water use and therefore limit the value people assign to water (Challen, 2000). This implies that if property rights to a resource are better defined, people are willing to pay higher values for its use because transaction costs are reduced (Herrera et al., 2004; Frija et al., 2008a). In this way sub-optimal property right systems constitute a form of inefficiency, which can be estimated by valuing willingness to pay for improvements in their definition. This chapter analyses how efficient the current water rights system in South Africa is for smallholder irrigators by economically valuing possible improvements in the definition of the water rights.

In South Africa the National Water Act (Republic of South Africa, 1998) replaced the previous system of water rights and entitlements, many of which were based on the ownership of riparian land, with a new system of administrative limited-period and conditional authorizations to use water (Nieuwoudt, 2002). However, various aspects of this new water rights system have already been criticized. Backeberg (2006) for instance discussed the negative effect of the short review period of the licenses on the investment decisions of farmers, while Nieuwoudt and Armitage (2004) pointed out that the reliability of each use allocation is highly variable since no guaranteed assurance of supply or quality is given. Louw and Van Schalkwyk (2002) warned that, for trade in water rights to be potentially successful, transaction costs should be kept low, which might not be the case under the current conditions. The issues raised demonstrate that it is relevant to study efficiency of the system. It is furthermore appropriate in the South African context to focus on smallholder irrigators given their apparent low efficiency of water use (Speelman et al., 2008) and the problems of cost-recovery of government investments in these schemes (Perret and Geyser, 2007; Backeberg, 2006). On one hand the improvements in the definition of water rights can stimulate smallholders to use water more productively, encouraging cooperation and investment (Bruns, 2003, Bruns, 2007); on the other hand government can benefit from the higher willingness to pay for water by charging higher water prices and thus improve cost recovery.

For the evaluation of the degree of the efficiency of a prevailing institutional structure some authors (e.g., Herrera et al., 2004; Linde-Rahr, 2008; Frija et al., 2008a) have recently used classic contingent valuation methods. To our knowledge, this study is however the first that uses contingent ranking (CR), a form of choice experiment. CR is a survey-based technique for modelling preferences for goods, where goods are described in terms of their attributes and the level these take. Respondents are presented with various alternative descriptions of a good, differentiated by their attribute levels, and are asked to rank the various alternatives. By including price as one of the attributes of the good, willingness to pay can be indirectly calculated from people's rankings (Hanley et al., 2001; Street et al., 2005).

Originating from marketing and transportation science, choice experiments have recently been shown to be useful in valuing environmental programs, because these typically consist of several components and the technique enables to value not only an intervention as a whole, but also its various attributes (see Foster and Mourato, 1997; Hanley et al., 1998; Blamey et al., 1999; Hanley et al., 2001; Bateman et al., 2006; Burton, 2007; Kanyoka et al., 2008). This last feature is particularly interesting for valuing water right interventions because like environmental programs, such interventions usually consist of several components, e.g. changes in transferability, duration or enforcement. It is then practical to be able to divide the intervention into its different components to assess people's willingness to pay for each intervention attribute. Another advantage of CR is the avoidance of an explicit elicitation of respondents' willingness to pay by relying instead on the ranking of a series of alternative packages of characteristics (Foster and Mourato, 2002; Bateman et al., 2006). Moreover compared with for instance binary choice models, CR is a relative informational efficient method, with the gains in estimation efficiency yielding significantly narrower confidence intervals on derived WTP measures, thus enhancing the reliability of the mean WTP estimates (MacKenzie, 1993; Holmes and Adamowicz, 2002; Alriksson and Öberg, 2008). Possible problems in using the method are the often complex nature of the statistical design, the selection of the appropriate attributes and levels and the cognitive difficulty associated with ranking choices (Hanley et al., 1998; Hanley et al., 2001). In this light the design of the study is essential for its success.

2. Methodology

2.1 Analytical Framework

The econometric analysis of data collected from a CR experiment is based on McFadden's conditional logit model, which is grounded in the random utility framework (Hanley et al., 2001). The indirect utility function U_{ij} is decomposed in two parts (eq. 6.1): an observable element $b(X_{ij}, Z_i)$ which describes the preferences of respondent i as a function of the attributes of the alternatives presented to the individual X_{ij} and the characteristics of the individuals Z_i and secondly a stochastic element ε_{ij}, which represents those influences on individual choice that cannot be observed by the researcher (Foster and Mourato, 1997; Blamey et al., 1999).

$$U_{ij} = b\,(X_{ij}, Z_i) + \varepsilon_{ij} \qquad (6.1)$$

Typically it is assumed that the ε_{ij} are independently and identically distributed with an extreme-value (Weibull) distribution, resulting in a conditional logit model. The probability of one option being chosen over another can be written as in eq. 6.2.

$$P\,(U_{ik} > U_{il}, \forall\ k \neq l) = \frac{\exp(bX_{ik})}{\sum_j \exp(bX_{ij})} \qquad (6.2)$$

The conditional logit model only allows the identification of the most preferred alternative and not fully exploiting all the information contained in the CR experiment. Beggs et al. (1981) therefore developed an extension to the basic conditional logit model, which is capable of not only identifying the most preferred alternative but also the exact ordinal ranking of all of the remaining elements. This model is known as the rank-ordered logit model. The rank-ordered logit model relies on the repeated application of the conditional logit specification to the set of alternatives remaining after successive first choices have been eliminated from the available options (Hanemann and Kanninen, 1999; Foster and Mourato, 2002). The probability of obtaining a particular ranking can then be expressed as shown in eq. 6.3 (Hanemann and Kanninen, 1999).

$$P(U_{i1} > U_{i2} \ldots > U_{iJ}) = \prod_{j=1}^{J} \frac{\exp(bX_{ij})}{\sum_{k=j}^{J} \exp(bX_{ik})} \quad (6.3)$$

The model in equation 6.3 does not allow preferences to vary across individuals in accordance with their socio-economic characteristics. Individual specific variables can however be entered in the utility function in interaction form with attributes that change across the alternatives to be ranked (Foster and Mourato, 1997; Blamey et al., 1999). The coefficients obtained for these interaction terms permit to evaluate the effect of socio-economic characteristics on the ranking.

Once the parameter estimates have been obtained, a WTP compensating variation welfare measure that conforms to demand theory can be derived for each attribute (Hanley et al., 2001). When it is assumed that utility is a linear function of the attribute levels like in equation 6.1, WTP can simply be expressed as:

$$WTP = \frac{-b_c}{b_y} \quad (6.4)$$

where b_y is the coefficient of the cost attribute and b_c is the coefficient of any of the attributes. Equation 6.4 corresponds with the marginal rate of substitution between the price attribute and the other attribute in the equation and is technically called the implicit price.

2.2 Application of the contingent ranking experiment

Typically the design of a choice experiment involves a number of key stages (Hanley et al., 1998; Hanley et al., 2001; Bennett and Adamowicz, 2001; Holmes and Adamowicz, 2002). First the problem at hand has to be clearly characterized. Then the attributes and their levels should be chosen. Researchers must be careful that the attribute space is constructed such that it is relevant for the policy questions being asked. Finally, experimental design procedures are used to construct the choice tasks that will be presented to the respondents. The next paragraphs discuss the implementation of these steps for this study.

Characterization of the problem

Internationally there is growing understanding that water rights are important and that a lack of effective water rights systems creates major problems for the management of increasingly scarce water supplies (Matthews, 2004; Bruns et al., 2005a). Nevertheless, better information is needed on the gains of changes in water rights systems (Bruns, 2003). This study evaluates the recently reviewed water rights system in South Africa, with specific reference to smallholder irrigators. The system now legally consists of administrative limited-period and conditional authorizations to use water (Nieuwoudt, 2002). A process of licensing of existing and potential new water users is carried out progressively over time in different parts of the country, according to the circumstances prevailing in particular areas or water resources (DWAF, 2004). In practice the responsible water management authority[12] issues a notice calling for license applications, after which users and prospective users should prepare and submit such applications. If granted to the user the license has following characteristics (DWAF, 2004):

- will be specific to the user to whom it is issued and to a particular property or area;
- will be specific to the use or uses for which it is issued;
- will be valid for a specified time period, which may not exceed 40 years;
- may have a range of conditions attached to it; and
- must be reviewed by the responsible authority at least every five years.

Several aspects of this new water rights system have already been criticized. It is therefore relevant to investigate where changes in the system are required and which changes would have the largest impact.

Design of the attribute space

An influential approach to analyze rights to natural resources categorizes six dimensions: duration, exclusivity, quality of title, flexibility, transferability and divisibility of rights (Bruns, 2006). Such subdivision highlights how attributes of rights may be adjusted separately

[12] In theory the Catchment Management Agency (CMA) will be responsible for authorising water use, however till the CMA is fully operational regional offices of the Department of water affairs (DWAF) are entrusted with this task.

along various dimensions, specifying rights (and implicitly leaving other attributes of rights undefined). As was shown by Challen (2000) and Crase and Dollery (2006), this deconstruction can also be applied to water rights.

In order to keep the size of the CR experiment within manageable proportions only the most relevant dimensions for the case of South Africa were included. These dimensions were identified based on a literature review. Duration, transferability and quality of title were selected because some degree of attenuation is reported for these dimensions (see Perret, 2002a; Nieuwoudt, 2002; Louw and Van Schalkwyk, 2002; Nieuwoudt and Armitage, 2004; Gillit et al., 2005; Backeberg, 2006).

In terms of duration the National Water Resources Strategy Paper of South Africa (DWAF, 2004) foresees a water license with a specified duration of maximum 40 years. However, this license has to be evaluated at least every 5 years. At each evaluation conditions attached to licenses may change (for instance the volumes and timing of abstractions, the volume that may be stored etc…). If necessary, in this way the government can take timely measures to maintain the integrity of the water resource, achieve a balance between available water and water requirements, or accommodate changes in water use priorities (DWAF, 2004) This 5-yearly revision will clearly influence investment decisions of farmers, as they might perceive licenses to be insecure (Nieuwoudt and Armitage, 2004; Backeberg, 2006). Psychologically farmers may consider a license that will be revised every 5 years as a license of only 5 years (Backeberg, 2006). Levels for the duration in this study are therefore set at 5 years, which is considered as base situation, and 10 years. The 10 years level was chosen here because this is considered long enough not to deter most investments, while still allowing government to respond relatively quickly to changing circumstances.

Transferable water rights and water markets are believed to improve water productivity through the transfer of water to users who can obtain the highest marginal return from using it (Nieuwoudt and Armitage, 2004; Gillit et al., 2005; Bruns and Meinzen-Dick, 2005; Zekri and Easter, 2007). In South Africa provisions are made in the National Water Act regarding transferability. It is stated that permanent transfers, constituting trade in water use authorizations, will be subject to all requirements for license applications. This means that the water management agency has to approve every transfer. One of the criteria that will be used in the evaluation is that a balance should be maintained between the interest of the parties involved in the trade and the general public interest (DWAF, 2004). For transfers of water rights among irrigators in a same irrigation scheme this type of procedure seems to create unnecessary transaction costs and insecurity, limiting efficiency gains from water transfer. In addition, legislation is not very clear about the introduction of these arrangements and the conditions under which trade will be permitted (Perret, 2002a; Backeberg, 2006). It was therefore also considered relevant to include the option of not-transferable water rights in the experiment. This results in three levels regarding transferability being introduced in the experiment: no possibility to transfer, administrative transfer and market transfer.

The dimension of quality of title encompasses the capacity of the title to adequately describe the resource or item. In this respect an important aspect of the water licenses in South Africa is that although quantities will be specified in the license, they are not guaranteed (Republic of South Africa, 1998); this clearly decreases the security of the water allocations (Nieuwoudt and Armitage, 2004). As levels for the quality of title dimension non-guaranteed and guaranteed supply were chosen in this study.

Finally, to be able to economically value the considered attribute changes, a pricing vehicle has to be included. Here we use the unit price of water (R/m³) to evaluate respondent's willingness to pay for the changes in the different attributes[13]. The price attribute is set at three levels 0.06 R/m³, 0.09 c/m³ and 0.12 c/m³. The price of 0.06 R/m³ corresponds to the order of magnitude of the water prices expected to be introduced in the study area in the near future (DWAF, 2008b; DWAF, 2008c). Table 6.1 provides an overview of the attributes and attribute levels considered.

[13] Average exchange rate at the time of data collection 1Rand= 0.13 US$

Table 6.1 Attributes and levels used in the choice sets

Attributes		**Levels**	
Transferability	not transferable	agency based transfer	market transfer
Duration	5 year	10 year	
Security	guaranteed quantity	quantity not guaranteed	
Price	6 c/m³	9 c/m³	12 c/m³

Design of the ranking sets

All possible combinations of four attributes, two with two different levels and two with three different levels produce 36 water right definitions. This is called a full factorial design. Clearly, it would not be feasible to ask respondents to rank the full set of 36 options from most to least preferred. Consequently, it was necessary to find some means of grouping the options into smaller sets (Foster and Mourato, 1997; Bennet and Adamowicz, 2001; Alriksson and Öberg, 2008). This was done in three stages as described below and illustrated in figure 6.1.

In the first stage an orthogonal design was constructed using the Orthoplan-function in Spss. Such orthogonal design allows isolating the effects of individual attributes on the choice, also called the main effects. This ability to "design in" orthogonality is an important advantage over revealed preference random utility models, where attributes in reality are often found to be highly correlated with each other. In our case the orthogonal design resulted in nine options.

Because ranking nine options was still considered a difficult task, it was decided to limit the number of options to be ranked against each other to four. To construct a set of four options a procedure developed by Street et al. (2005) is used. This design procedure results in a design with desirable structural properties such as minimum attribute-level overlap and balance, allowing more information to be gathered from the same sample (Burgess and Street, 2005; Street et al., 2005). Because of these properties the technique has proved to always give an optimal or near-optimal design for the estimation of main effects, and near-optimal designs for the estimation of main effects plus two-factor interaction effects. The basic idea of the construction technique is simple: the options from the orthogonal design will represent the first option in the choice sets; then a systematic set of level changes is applied to obtain the second option in the choice sets; and another systematic set of changes is applied to get the third option, and so on. In this way, starting from the orthogonal design, nine choice sets with four options in each of them were obtained.

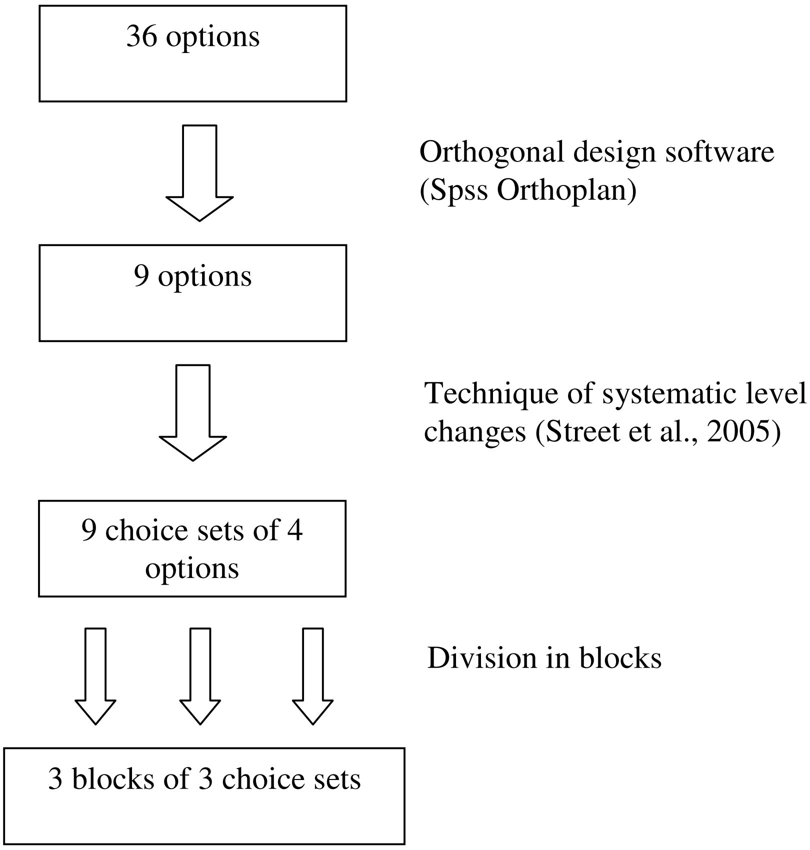


Figure 6.1 Procedure of designing ranking sets

Following Holmes and Adamowicz (2002), it was decided to divide the choice sets in blocks to avoid the respondents' fatigue effect, which could cause consistency to decrease. Each respondent is then assigned randomly to a particular block. This resulted in three blocks of three choice sets. Finally, because part of the respondent population was expected to be illiterate, a graphical representation of the attribute levels was used. An example of a choice set is presented in figure 6.2.

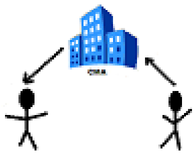
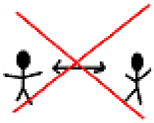
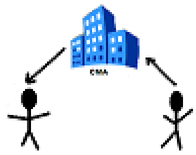
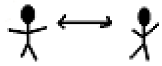
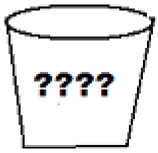
Attributes	Option 1	Option 2	Option 3	Option 4
Transferability				
Duration	5 years	10 years	10 years	5 years
Quality of title				
Price	12c/m^3	6c/m^3	9c/m^3	12c/m^3
Rank				

Figure 6.2 Choice set example

Data collection

The data were collected in April 2008 in the Limpopo province of South Africa. Two regions, where clusters of smallholder irrigation schemes are located were selected: the region around Mafefe and the region around Trichardtsdal (figure 6.3). Although geographically close to each other these regions are separated by an embranchment of the Drakensbergen mountain range. The difference in cropping patterns between the regions reflects the degrees of water scarcity. Within these regions seven irrigation schemes were identified from the national database of small-scale irrigation schemes (Denison, 2006). Both larger irrigation schemes with over 100 farmers and smaller schemes with only 30-40 farmers were included in the sample. In this way a sample exemplary for the situation of smallholder irrigation schemes in the rural areas of South Africa was established.

Figure 6.3 Situation of the selected regions within South Africa

Contacts with the scheme management were made through the extension services responsible for the schemes. They also provided a list of all active farmers on the schemes and further background information regarding each individual scheme. From the lists, about 30% of the farmers were randomly selected. A team of enumerators consisting of PhD and Master students from Limpopo University in Polokwane interviewed these farmers on field. Before starting the questionnaire the purpose of the study was explained and respondents were given information regarding the actual water rights system. In a stepwise manner, they were made familiar with the graphical representation of the attribute levels included in the CR experiment. The questionnaires included not only the CR experiment, but also detailed information regarding farming activities, alternative income sources and institutional aspects of water management. Table 6.2 gives an overview of some of the respondent specific variables included in the analysis. In total 138 farmers were interviewed, but only 134 questionnaires were completed and could be included in the analyses. These 134 questionnaires provided 402 completed choice sets for analysis.

Table 6.2 Definition of respondent specific variables included in the rank ordered logit model

Name	**Definition**	**Description**
com	Degree of commercialisation	Share of irrigated production marketed (in terms of value)
iryshare	Income dependency on irrigation	Share of household income from irrigation
age	Age of farmer	
edu	Years of schooling of farmer	
insttrust	Institutional trust	Summated score for trust in water management institutions. A four-point scale ranging from "*no confidence at all*" to "*a great deal of confidence*" was used to assess trust in the catchment management agency and the department of water affairs.
short	Frequency of water shortage	Five point scale assessing frequency of occurrence of water shortage, ranging from 1 "*often*" to 5 "*never*"

3. Results and discussion

3.1 Socio-economic characteristics of sample population

Detailed information regarding irrigation activities, income sources and institutional aspects of water management was collected. The findings in this section are very similar to that of other studies on smallholder irrigation schemes in South Africa (e.g. Perret, 2002a; Van Averbeke and Mohamed, 2007; Hope et al., 2008). This conforms the representativeness of the sample. The average age of the farmers is 58 years, indicating that farming population at this type of irrigation schemes is aging. The average number of years of schooling of the farmers is 5.6 years. Both these figures are typical for this type of irrigation schemes in the South African context, as is the average irrigation plot size of 1.2 ha.

All schemes in the sample are irrigated by surface irrigation, which is still the prevailing method at smallholder schemes. In the Mafefe region most farmers only cultivate their irrigated land during the wet summer season, with maize as the most important crop. Around Trichardtsdal production is more diversified, with most farmers producing both in summer and in winter. An overview of the differences in distribution of crops among the farmers in both regions and in the winter and summer season is presented in table 6.3. The income share from irrigation reported by the sample population ranges between 1% and 100% with an average of 29%. The two most important income sources for the households in the sample are pensions and child grants. Also consistent with the other studies on smallholder irrigators is the finding that production is mainly for household consumption. The average degree of commercialisation, calculated as the value share of production that is marketed, is 38% in this study.

Table 6.3 Distribution of crops among farmers

	Mafefe (n=77)		Trichardtsdal (n=57)	
	Winter (n)	Summer (n)	Winter (n)	Summer (n)
No crops	49	0	6	2
Bambara groundnuts	0	0	0	9
Beans	2	2	25	1
Beetroots	8	0	23	0
Butternuts	0	2	0	3
Cabbages	5	1	33	1
Carrots	0	1	9	0
Chillies	0	0	1	0
Coriander	10	1	0	0
Cowpeas	0	8	1	5
Green pepper	1	1	1	0
Groundnuts	1	21	0	18
Maize	0	75	0	55
Millet	0	1	0	1
Onions	10	1	18	0
Peas	0	0	9	0
Potatoes	1	0	6	2
Pumpkins	0	3	0	3
Sorghum	0	2	0	0
Soybeans	1	7	6	3
Spinach	7	0	21	0
Sugar beans	5	0	5	0
Sugar cane	0	1	0	1
Sweet potatoes	0	11	8	13
Tomatoes	13	3	26	4
Watermelon	0	4		3
Wheat	4	0	0	0

Farmers were also questioned about the occurrence of water shortages. Figure 6.4 presents the degree of water shortage. A large majority of the farmers reported that water shortages are sometimes occurring. It has to be noted however that in the winter season (= dry season) 37% of the farmers reduces their cultivated area, and about the same percentage does not produce. The main reason mentioned for this is lack of sufficient water supply, suggesting that for full utilization of the irrigated area, occurrence of water shortage would probably be significantly higher.

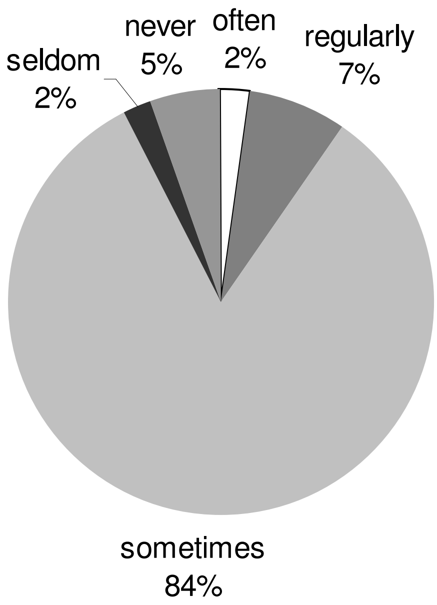


Figure 6.4 Stated occurrence of water shortage

Finally the trust of respondents in water management institutions was monitored. The farmers had to indicate on a four-point scale how much confidence they have in the functioning of each institution. Figure 6.5 provides insight in the trust in the catchment management agency (CMA) and the department of water affaires (DWAF). Surprisingly, notwithstanding the fact that it is a higher-level institution, more respondents have more trust in the DWAF than in the CMA. An explanation for this can be that respondents are still less familiar with the CMA and its tasks because it is a new institution created very recently in the context of the 1998 Water Act and because in the Olifants catchment, where both study sites are located the CMA is still not operational.

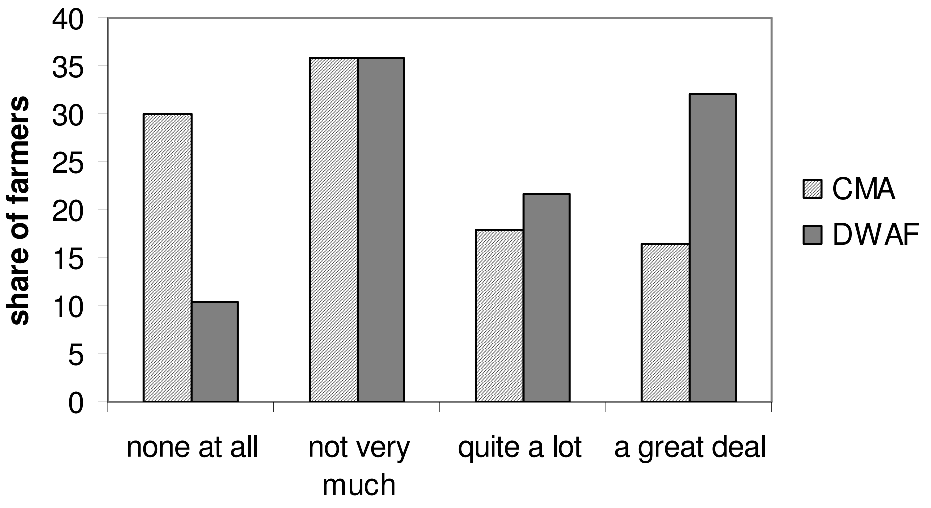


Figure 6.5 Confidence levels in water management institutions

3.2 Rank ordered logit results

The results of the rank ordered logit models were obtained using the statistical package STATA version 9. Following the recommendations of Holmes and Adamowicz (2002) the two qualitative attributes shown in table 6.1 were effect coded. When using effect coding, the base level is assigned code –1. For the quality of title dimension "*non-guaranteed supply"* was the base level, while for the transferability the base level was "*no possibility to transfer"*. In the interpretation of the results, this base level takes the utility level of the negative of the sum of the other estimated coefficients, and the other levels take the utilities associated with their coefficient.

Table 6.4 presents the rank ordered logit estimates for two different model specifications. The first model represents the most basic attribute specification. All the coefficients are significantly different from zero at the 5% significance level, meaning that they all are significant determinants of choice. The signs of the attribute parameters are as expected. Guarantee of water supply, increased duration of the license and improvements in transferability all increased the probability that an option was chosen. Oppositely, a higher water price decreased the choice probability.

Model 2 introduces respondent specific variables into the indirect utility function. Conform the general expectations results indicate that the more commercially oriented farmers are, the more importance they attach to the possibility of market transfer. Respondents more dependent on irrigation for their income are more concerned about the quality of the title and are also more concerned about price increases. If an income source constitutes a higher share of one's livelihood it is not surprising that quality of the title for this source is higher valued. Moreover in the sample population higher irrigation income shares are usually correlated with lower overall incomes, explaining the significant interaction found between income share from irrigation and the price attribute. Older respondents on the other hand seem to attach less importance to price increases. Being more educated has a positive effect on the valuation of the duration of the license, but the effect on valuing quality of the title is opposite. The effect of the "*education*duration*" interaction term could have its origin in the often found positive relationship between education and investments in productivity. This implies that better educated people are more inclined to make such investments, but as explained by Backeberg (2006) these investment decisions are negatively affected by a short duration of the licences. A possible explanation for the interaction between education and quality of title is that the more educated people are, the more they consider themselves capable of dealing with non-guaranteed water supply by adjusting for instance cropping patterns. As expected experiencing more water shortage increases concerns about quality of title. For farmers who never experience water shortage guaranteed supply obviously is less of an issue. Having more trust in the institutions responsible for water management finally decreases the importance attached to the duration of the license. It should be noted however that the "*trust*duration*" interaction was just not significant at a 90% level.

Table 6.4 Rank ordered logit results: determinants of ranking

	Model 1			Model 2		
Attribute	**coefficient**	**SE**	**p-value**	**coefficient**	**SE**	**p-value**
Duration	0.0957	0.0136	0.000	0.1152	0.0408	0.005
Quality of title	0.6284	0.0382	0.000	1.1495	0.2850	0.000
Price	-0.0478	0.0147	0.001	-0.1746	0.0857	0.042
Agency based transfer	0.2300	0.0496	0.000	0.2386	0.0487	0.000
Market transfer	0.3598	0.0514	0.000	0.2157	0.0732	0.003
Com*market transfer				0.3746	0.1527	0.014
Iryshare*quality of title				0.8666	0.4306	0.044
Iryshare*price				-0.1267	0.0698	0.069
Age*price				0.0028	0.0013	0.036
Edu*quality of title				-0.0577	0.0192	0.003
Edu*duration				0.0064	0.0029	0.030
Insttrust*duration				-0.0109	0.0068	0.111
Short*quality of title				-0.1155	0.0656	0.079
Model statistics						
LogL(initial)	-1277.58			-1277.58		
LogL(final)	-1051.47			-1029.65		
Pseudo R^2	0.177			0.194		

A major purpose of the CR experiment was to obtain the implicit values of marginal attribute changes. Table 6.5 presents the estimates of the implicit prices derived from model 2. The estimation of the implicit prices is based on equation 6.4, putting the individual specific characteristics at the average level[14]. In this way implicit prices for average respondents are obtained. The results indicate that the opportunity to transfer water licenses is highly valued. However, for the small-scale irrigators in the sample installing water markets as compared to a system of administrative transfer does not seem to add much value. An additional point that has to be considered here is to which extent water markets can decrease the administrative burden and associated costs of the agency based transfer. High importance furthermore is attached to secured water supply. A similar result was also found by Alcon et al. (2008). They found that farmers would be willing to pay considerably more (up to 2 times more) for more certain water supply. In addition, the results suggest that increasing the review period of the licenses is an interesting intervention, since apart from the economic gain reported in table 6.5, this would certainly decrease administrative costs.

Table 6.5 Valuation of attribute changes

Attribute change	**Implicit WTP**
From “No transfer” to “agency based transfer”	14.6 c/m³
From “Agency based transfer” to “market transfer”	2.4 c/m³
From “No secured supply” to “secured supply”	12.6 c/m³
From “5 years” to “10 years”	9.7 c/m³

Overall the estimations of the WTP indicate that significant inefficiencies exist in the current water rights system. Tackling these inefficiencies will not only be favorable for the efficiency of water use of smallholder irrigators, but given the size of the benefits can also add significantly to the government objective of cost recovery.

4. Conclusions

As competition for water grows across the globe, water users and water management organizations seek better institutional arrangements for coordinating use and resolving conflicts (Bruns et al., 2005b). Improved water rights are one option to increase water productivity, to raise benefits from existing and new investments in water use and enhance

[14] In a model with covariates this formula becomes $WTP=-(b_c+\gamma_1\cdot S_1+\ldots+\gamma_n\cdot S_n)/(b_y+\eta_1\cdot S_1+\ldots+\eta_m\cdot S_m)$, where S_i are the interaction variables included in the model at the average level, γ_i the coefficients of interaction with the investigated attribute and η_i the coefficients of interaction with the price attribute (Han et al., 2008)

rural livelihoods. The estimation of how inefficient a current water rights system is or what the impact of different improvements could be, has so far received little attention in literature (Linde-Rahr, 2008).

This study demonstrates how CR can be used to measure the extent to which water rights can be improved along different dimensions. It is applied to the case of smallholder irrigators in South Africa. While this sector is considered important for poverty reduction in rural areas, it clearly struggles with problems of low water use efficiency and insufficient cost recovery. Taking into account this context it is highly relevant to evaluate the expected impact of water right reforms on this specific stakeholder. The results of the CR experiment indicate that for the smallholders, there are significant economic gains attached to the improvement of the water rights.

Policy makers can use such results to guide water right reforms. Besides the information on the economic gains, it gives them direct information concerning the priorities of the target group. This knowledge can help government to increase support for the interventions. Of course when deciding on reforms the cost side should also be taken into account. Some reforms, like for instance the increase of the review period, might lower costs, while others will have a price tag attached to them. It is furthermore important to go beyond a purely economic evaluation and to also consider other objectives like equity and environmental sustainability. This is an area of further research. The analysis provided in this study should therefore be used as a part of a broader framework.

CHAPTER 7
Discussion and conclusions

1. Recapitulation of the study design

The overall objective of this research was to inform decision making in water management for the small-scale irrigation sector in South Africa. Emphasis was placed on the impact of economic instruments and institutional changes in achieving two core objectives namely improved efficiency and cost recovery. Analyses were based on the conceptual framework developed in Chapter 1. Several tools and analyses techniques to evaluate the need for interventions and their impact were developed.

In Chapter 1 the problem was defined and the conceptual framework was explained linked to literature and economic theory. Chapter 2 described the background for this study in more detail. In a first part, this chapter gave an overview of the recent development of the water policy framework in South Africa. The most important outcomes of the policy development process and the implications were discussed. The second part of Chapter 2 focused on the small-scale irrigation sector in South Africa. The role of the sector was theoretically explored and its history was discussed. Knowledge of the origin of the schemes helps to understand the current status, which is discussed in the last section of Chapter 2. The current conditions and typical characteristics of this type of schemes were described in detail and the challenges for the sector were identified.

In Chapter 3 and 4 the current water use on small-scale irrigation schemes was evaluated and discussed, linked to the objectives of efficiency and cost recovery. In Chapter 3 economic water values in smallholder production were calculated using detailed farm budgets. It was further investigated if significant differences between values existed at crop, farm and scheme level. These analyses provided an idea about the profitability of small-scale irrigation farming and consequently about the capacity of the sector to ensure cost-recovery. Chapter 4 investigated the efficiency of smallholder producers. Using DEA, first technical efficiencies were assessed, after which the concept of sub-vector efficiency was introduced to evaluate efficiency of water use. To be able to derive policy implications, the relationship between technical and water use efficiency was examined and the determinants of the water efficiency were identified in a Tobit model.

Chapter 5 and 6 looked at the impact of possible water management policy interventions. In Chapter 5 the impact of the introduction of water pricing on irrigation water use and on the farmers' production systems was analysed. A two-step mathematical programming model in GAMS was developed to simulate smallholders' response to different levels of water charges. Finally in Chapter 6 the efficiency of the current water rights system was evaluated from the perspective of smallholder irrigators. The possible gains of improving the water rights system were determined in STATA by estimating the WTP for improvements using data from a contingent ranking experiment.

2. General discussion and conclusions

In the first chapter of this research, seven hypotheses were developed. These will be verified and discussed in the subsequent paragraphs. Furthermore, general discussion of the results in the light of the proposed conceptual framework will be provided.

2.1 Water values

The results of the economic valuation of irrigation water in smallholder vegetable production (Chapter 3) revealed that irrigation water values were in the range of those found in other studies (Molden et al., 1998; Hussain et al., 2007) for irrigated vegetables in semi-arid areas throughout Sub-Saharan Africa. However, analyses at plot level yielded negative gross margins for 27% of the plots, while at farm level 13% of the farmers seemed to be operating with a loss. In these calculations market prices were used for inputs and to convert output produced into monetary terms. The results therefore indicate that without input subsidies the smallholder irrigation sector would have difficulties to be viable (**H1 confirmed**). This raises serious questions about the sustainability of the sector and the capacity to ensure cost recovery. It is clear that farmers' productivity has to increase substantially to be able to contribute to water supply costs and infrastructure investment costs. Moreover this finding also indicates that at the current productivity levels smallholders are not ready to play the role in the market that is expected from them. In such a context investment and financial support by the public sector to smallholder irrigation schemes can only by justified by the equity objective of the NWA (Perret and Geyser, 2008).

Furthermore, irrigation water values were also shown to vary a lot between different crops within the farms and between different farmers (**H2 confirmed**). The type of the irrigation scheme and the crops grown were the two most important determinants for the variability of the values. These two factors explain nearly 50% of the variability. On average, higher water values were found for food gardens and community schemes as compared to the values at the typical small-scale irrigation schemes. The higher participation in scheme management by irrigators on the former type of schemes could explain this finding.

2.2 Efficiency of smallholder irrigators

The analysis of the efficiency of smallholder irrigation farmers (Chapter 4) showed that most smallholders in the study area fail to reach their overall technical efficiency levels when it concerns water use. The average overall technical efficiency for the VRS specification is 0.84, while under the same specification the average sub-vector efficiency for water is only 0.67. At this moment farmers have no financial incentive to limit their water use or to invest in water saving technologies (Nsanzugwanko et al., 1996; Perry, 2001; Oster and Wichelns, 2003; Wichelns, 2004). The current low water use efficiencies further imply that by improving water use efficiency considerable water savings (up to 40%) are possible (**H3 confirmed**). Thus, when accompanied by water use efficiency improvements (up to the level of the most efficient farms in the sample), reallocation of irrigation water to other water using sectors is possible, without endangering smallholder production.

Sub-vector efficiencies for water were also shown to be highly correlated with the overall technical efficiency. If farmers that are using a lot of water and are scoring badly in water use efficiency, fail to improve their water use efficiency they will see their income being affected most by the introduction of a water price. The same farmers also have a low technical efficiency and consequently are already more vulnerable. This therefore raises questions about the viability of the operations of these poor performers under the introduction of a water price (**H6 supported**).

The results of the Tobit models show that cultivated area, landownership, fragmentation and crop choice have a significant impact on the sub-vector efficiency for water (**H4a confirmed**). This finding can be used by policy makers and extension services to better aim efforts to improve water use efficiency. If the significant positive effect of landownership on the sub-vector efficiency could be confirmed for a larger sample, this would emphasize the importance of land rights, supporting land reforms where people are made owner of the land they work. A second practical example is the positive and significant effect of crop choice on the sub-vector efficiency, which should incite extension services to encourage farmers to select crops with higher profit per m³ of water (assuming that markets are available and that smallholders can not influence market price). Finally, farmers' characteristics like age, gender or educational level had no significant impact on the sub-vector efficiency for water (**H4b rejected**).

2.3 Condition of the smallholder irrigation sector

The analyses in Chapter 3 and Chapter 4 give insight regarding the water management objectives for the small-scale irrigation sector in South Africa. The low water use efficiency levels found in this study support the call for improved water use efficiency. It was shown that even using the technology currently available, it is possible to increase the water use efficiency of farmers substantially (up to 40%). As argued by authors like Ringler (2001), Rosegrant et al. (2002), Cai and Rosegrant (2004), Molden and Bos (2005), Kassam et al. (2007) and others this can free water for other sectors.

The low levels of profitability found on the other hand imply that the cost recovery objective will be difficult to achieve under the current conditions. The finding of Perret and Geyser (2007) and Backeberg (2006) that the capacity of the sector to ensure cost recovery is low, is hereby confirmed. Compared to the low income, which is usually derived from irrigated production by the smallholder irrigators, costs of irrigation services are quite high. It is nevertheless crucial to start considering water as an economic good. Farmers should realise that at least O&M costs of irrigation schemes should be covered for the sake of a sustained functioning at present, but also to prevent future failures and quicker degradation, which might even incur higher costs. Moreover, water charges can act as incentives towards increased water and land productivity.

2.4 Impact of the introduction of water charges

When applying the two-step simulation model developed in Chapter 5 to the South African sample, an important finding is that farmers are quite responsive, even to the introduction of a relatively low water price (**H5 confirmed**). The current low water use efficiencies reported above and the possibility of input substitution incorporated in the model explain why responsiveness is higher than found in a European context by authors like Albiac et al. (2007), Manos et al. (2006) or Gómez-Limón and Riesgo (2004). Moreover most of the earlier studies looked at increases of water prices rather than at an introduction of charges. So unlike for farmers in this study, water prices were already a factor taken into account in the operations of the farmers these authors studied.

A second important finding from the simulation model is that similar to results of Gómez-Limón and Berbel (2000) in Spain and Yang et al. (2003) in China, significant loss of farm income is found for many individual farms when water prices are introduced. As shown in Chapter 3, profitability of farms was often already low before the introduction of water charges. In that context it is not surprising that water price introduction can be problematic for these farmers and that some even have to quit production (**H6 confirmed**). Investigation of the impacts of water pricing illustrates the dilemma the South African government is facing: to choose for the neo-liberal policy of giving up subsidies to the agricultural sector and creating a black farming elite of small commercial farmers with economically viable farming operations or to focus on social objectives, food security, and rural development concerns, which requires maintaining at least part of the subsidies. Finally, the finding that increases in water price will lead to a decrease in the use of other agricultural inputs confirms the findings of other studies (Manos et al.,2006; Albiac et al., 2007).

2.5 Efficiency of the water rights system

The estimation of the WTP for improvements in the water rights system (Chapter 6) indicates that significant inefficiencies exist in the current system. The fact that smallholder irrigators are prepared to pay considerably higher water prices when these prices are connected with advancements in the water rights system implies that smallholders believe that the advancements significantly improve efficiency. Considerable economic benefits are therefore attached to making improvements in the water rights framework (**H7 confirmed**). A higher WTP for water is also interesting in the light of the cost recovery objective of the South

African government. Improvements of the water rights system would allow government to increase water charges.

When looking at the results in more detail, the opportunity to transfer water licenses is highly valued by the smallholders. However, compared to a system of administrative transfer, introduction of water markets is not particularly favoured by the small-scale irrigators in the sample. Given the trend towards smallholder commercialisation (Denison and Manona, 2006b), it is nevertheless interesting to note that more commercially oriented farmers attach more importance to the possibility of market transfer. Farmers are furthermore willing to pay considerably more if water supply is more secure. A similar result was obtained in a study in Spain by Alcon et al. (2008). Moreover the higher the irrigation income share of smallholders is, the more important they find a secure supply. Finally the results suggest that increasing the review period of water licenses is an interesting policy intervention. This does not only increase farmers' WTP for water, but will also decrease administrative costs.

2.6 Methodological contributions

A systems approach was proposed in Chapter 4 to analyse the efficiency of water use in irrigated production. The advantage of this systems approach compared to simple measures like output per m^3, is that it also takes into account the differences in non-water inputs across farms and therefore is able to give a more adequate picture of their performance (Coelli et al., 2002). While the concept of sub-vector efficiencies was already used for other inputs in other sectors, this was the first time it was applied to water use in the irrigation sector. Moreover, the proposed method allows to benchmark individual producers against the production frontier of the best performing producers. This gives information concerning the scope for improving efficiency (Malano et al., 2004; Malana and Malano, 2006).

In Chapter 5 a novel method to simulate the effect of changes in water price was developed. Classical models (for example Albiac et al. 2007; Manos et al., 2006; Gómez-Limón and Riesgo, 2004; Doppler et al., 2002; Berbel and Gómez-Limón, 2000; Gómez-Limón and Berbel, 2000) that simulate the impact of water pricing, use predetermined theoretical ratios between inputs and outputs. These ratios are only rough approximations of empirical data of actual farms. Moreover, as a consequence of the fixed ratios, substitutions between different

inputs are not considered. Another shortcoming of most models is that they work at an aggregated level, i.e. using average technology. Because of this average technology the models can not accurately describe the differences of policy impact between farms, which depend on the farm conditions and the farmer's attitude and behaviour. The combination of the use of average technologies and the simplification of fixing the ratios between inputs and outputs leads to overly abrupt changes in the price response (Jonasson and Apland, 1997).
The method developed in this study uses observed technology frontiers, based on empirical data in a simulation model. By doing so, estimation of farmer's response to price incentives is improved. Because of the possibility of input substitution changes are less abrupt and incorporating the occurrence of inefficiencies at farm level allows estimating the individual response of farms.

Choice experiments and contingent ranking exercises have recently been used to value environmental programmes (Foster and Mourato, 1997; Hanley et al., 1998; Blamey et al., 1999; Hanley et al., 2001; Bateman et al., 2006; Burton, 2007). In Chapter 6 it is argued that because of their capacity to study multidimensional programmes, they are also suited for studying possible interventions in a water rights system. In this way choice experiments and contingent ranking can be used to meet the current demand for better information regarding benefits of changes in water rights systems. Up to date, discussion of benefits is mostly descriptive and based on information from past reforms, but there is a clear call for quantification of potential benefits (Bruns and Meinzen-Dick, 2005). In Chapter 6 it is shown that in the choice experiments it is not only possible to value an entire intervention, but also WTP for individual aspects and preferences for aspects can be deduced. Furthermore differences in preferences along different strata of the population can be revealed. These characteristics allow governments to prioritise and target interventions.

3. Limitations and future research

A first limitation is that for practical and financial reasons data samples used in this study are relatively small and collected in two water management areas (see Chapter 1). However, as has been explained, the samples reflect the typical situation of small-scale irrigation schemes in rural areas in South Africa. As described in the different chapters, scheme and household characteristics are very similar to those described in other studies of small-scale irrigation schemes in South Africa (see for example: Hedden-Dunkhorst and Mphahlele, 2000; Kamara et al., 2002; Perret, 2002a; Perret et al., 2003; Denison and Manona, 2006a; Van Averbeke and Mohamed, 2007; Hope et al., 2008). This confirms that the samples can be considered exemplary for the situation of smallholder irrigation schemes in the rural areas of South Africa. As a consequence the insights provided by the analysis of the samples are considered relevant.

Second, the agricultural data collected for this study in both data collection phases pertain a one year period. Nevertheless, climatic conditions in the years under consideration were not extreme (FAO, 2008; Shewmake, 2008). It is therefore assumed that these years represent a normal situation.

Third, in Chapters 2 and 3 the smallholder farmers are analysed in a neoclassical economics framework. Farm budgets were calculated and efficiencies were determined based on the market value of their output. Given the subsistence nature of their operations the smallholder irrigators might not entirely fit in this framework. The current aim of agricultural policy and rural development policy to shift from subsistence orientation towards market orientation (Van Averbeke and Mohamed, 2007; Tapela, 2008) nevertheless emphasizes the importance of analysing the production system of this type of farmers within the framework used.

A fourth limitation is that the analysis of the gains of improvements in the water rights system focussed on the small-scale irrigation sector. However, to be able to take optimal decisions for the entire society, the exercise should also include other stakeholders. Preferences for changes in certain dimensions of the water rights system will probably differ across stakeholders. This is an area of future study.

Fifth, the effect of IMT was not studied. It is an important aspect of water policy reform in South Africa to delegate water resources management to regional and localised levels, involving stakeholders. However, experiences with IMT and management by WUAs in other countries have been mixed (Yildirim and Cakmak, 2004; Pasaribu and Routray, 2005; Vandersypen et al., 2007; Wang et al., 2007; Zekri and Easter, 2007: Vandersypen et al., 2008) and in South Africa authors like Shah et al. (2002) warn for the possible transaction costs involved in collective self-management at larger irrigation schemes. Therefore, research to develop a framework in which the performance of WUAs can be monitored, is needed. To date very few WUAs have been formally established in smallholder irrigation schemes in South Africa (Perret and Geyser, 2007). Hence, although it would be highly relevant, it was impossible to include in this dissertation a performance analysis of WUAs, like the one conducted by Frija et al. (2008b).

A final limitation is related to the control of the practical implementation of this research. Stakeholders such as the DWAF and the Water Research Commission were consulted to identify the research questions and the study results will be communicated to these parties. However, there are no plans for workshops or seminars on these results. Therefore it is not sure if and how the information from the results or the developed methodologies will be used.

Clearly this dissertation can not be seen as an end point in the analysis of water management policy towards the small-scale irrigation sector. There are several ways in which analysis proposed in this study can be extended or fine-tuned.

A first possibility for future research is to introduce multiple objectives in the simulation model for the evaluation of water charges. Currently the objective function only includes profit maximization, but simulation of farmers' behaviour would be improved if risk aversion would also be included. This would require gathering information on individual farmers' risk attitude and establishing a relation between production choices and this risk attitude. Another extension of the model would be to work at crop level rather than at farm level. In that way changes in crop choice by farmers could also be predicted.

Further research could also aim at evaluating the gains of an improved water rights system in a broader framework. It is particularly important that the cost side of reforms is also considered. Some reforms, like improved quality of the title will have a price tag attached to them, but for example water markets or the increase of the review period can decrease administrative burden and associated costs.

A final path for future research is to go beyond purely economic evaluation of water rights system interventions such as the introduction of water markets or extension of the duration of the right, including other objectives like equity and environmental sustainability.

It has for instance been stated by several authors (Farolfi and Perret, 2002; Bruns, 2003; PRI, 2005; Chong and Sunding, 2006) that unrestricted water markets can lead to undesirable outcomes like the concentration of rights in the hands of a group of holders or excess water withdrawals. Therefore considering the effects on equity or on the environment is highly relevant. Similarly the extension of the duration might restrict possibilities for government to take actions to maintain the integrity of the water resource.

The issue of concentration of rights is furthermore particularly relevant when considering inter-sectoral markets. In South Africa Farolfi and Perret (2002) showed that productivity of water in the mining sector is far higher than that of smallholders' irrigation. They concluded that when inter-sectoral water markets are established such a gap allows for the mining sector to offer prices for water rights ten to twenty times higher than the smallholders. Therefore in case a free water-right market would really be implemented, this would result in the total transfer of water rights allocated to the smallholding irrigation sector towards the mining sector. Although this might be an optimal scenario from an economic point of view, it clearly does not correspond with rural development objectives or with the South African equity objective.

Summary

With the growing water scarcity, the increasing competition across water-using sectors and the increased concern about environmental sustainability, the need for more efficient water use has worldwide increased in importance. Moreover cost-recovery is now widely acknowledged as a cornerstone of sustainable water management. These two trends also constitute a major challenge for the small-scale irrigation sector in South Africa. In the light of these challenges, the objective of this research is to contribute to improved water management for small-scale irrigation schemes in South Africa. This study is structured using a conceptual framework identifying two stages in decision support: ex-post analysis of the existing water use situation in the small-scale irrigation sector and ex-ante analysis of the impact of potential water resources management policies. The analyses are based on primary data collected during two phases of data collection in South Africa.

In a first analysis the economic production value of irrigation water at the small-scale irrigation schemes was determined using the residual imputation method. This gives a first indication on how efficiently water is used, but also sheds light on the potential for cost recovery. Smallholders at this type of schemes mainly produce vegetable crops and the average water values estimated were in line with those from earlier studies for this type of crops. Results however also show that without government subsidies on inputs, the profitability of many smallholders was low. Achieving full cost recovery therefore appears to be problematic if the sector fails to increase productivity.

In the next part the concept of sub-vector efficiencies is introduced as a measure for the efficiency with which water is used. The sub-vector efficiencies are calculated using Data Envelopment Analysis. The low sub-vector efficiencies for water demonstrate that smallholders fail to reach their overall technical efficiency levels when it concerns water use. Therefore, even using the technology currently available there is a potential to reallocate a fraction of the irrigation water to other water demands without threatening the role of small-scale irrigation. The low sub-vector efficiencies furthermore are an example of the fact that without water pricing, farmers have little incentive to limit their water use or to invest in water saving technologies.

In a third empirical chapter an innovative two-steps simulation model was developed to study the impact of introducing of a water price. The model uses a representation of the technology and the individual efficiencies of smallholders in a profit maximisation model. Farmers appear to be quite responsive and adjust their water use, even when a relatively low water price is introduced. Pricing water can thus be used to provide incentives for water use reduction and/or efficiency improvement. However, the introduction of a water price is also shown to significantly decrease farm profit. Smaller farms in terms of output (mainly the poorer farmers) are affected most by this and, at higher water prices, are not profitable anymore and without government support would even have to quit production.

The last part of the study investigates the potential to improve the water rights system in South Africa. Using a contingent ranking experiment the WTP of smallholders for specific interventions can be estimated. The results show that farmers are prepared to pay considerably higher water prices if this is connected with advancements in the water rights system. This implies that interventions in the water rights system can improve the efficiency of the small-scale irrigation sector. A higher WTP for water is also interesting in the light of the cost recovery objective of the South African government, because it allows the government to increase water charges.

In general, this research confirms that improvement of the water use efficiency and cost recovery are major challenges for the small-scale irrigation sector in South Africa. It was shown how economic analyses can be used to inform policy making to address these challenges.

Finally some issues for further research were identified in this study: (1) developing a framework for performance analysis of WUAs; (2) extending the water pricing simulation model incorporating multiple objectives; (3) studying the cost side of water rights system improvements in order to be able to do a cost-benefit analysis and (4) going beyond a purely economic evaluation of the water rights system improvements, also taking into account social and environmental objectives.

Samenvatting

Met de groeiende waterschaarste, de toenemende competitie voor water tussen de verschillende sectoren van de economie en de toegenomen bezorgdheid omtrent het leefmilieu en duurzaamheid, is de aandacht voor meer efficiënt watergebruik wereldwijd sterk toegenomen. Bovendien wordt nu ook algemeen erkend dat kostendekking een hoeksteen moet vormen van duurzaam waterbeheer. Deze twee trends vormen ook een belangrijke uitdaging voor de kleinschalige irrigatiesector in Zuid-Afrika. De doelstelling van dit doctoraat is om in het licht van deze uitdagingen bij te dragen tot een beter waterbeheer voor de kleinschalige irrigatiesector in Zuid-Afrika door middel van economische analyses. Het onderzoek volgt een conceptueel kader dat twee stappen in beleidsondersteuning identificeert: economische analyse van het bestaande watergebruik in de kleinschalige irrigatiesector en economische analyse van de impact van potentiële beheersmaatregelen. De analyses in dit doctoraat zijn gebaseerd op primaire data door de auteur zelf verzameld gedurende twee dataverzamelingsfases in Zuid-Afrika.

In een eerste analyse werd door middel van de "residual imputation method" de economische productiewaarde van irrigatiewater in de kleinschalige irrigatieschema's bepaald. Dit geeft enerzijds een eerste beeld van de efficiëntie waarmee water gebruikt wordt, maar ook van het potentieel om kostendekking te bereiken. De betrokken landbouwers produceren voornamelijk groenten. De gemiddelde waarde die voor water bekomen werd, ligt in de lijn van waarden in eerdere studies. De resultaten tonen echter wel aan dat zonder overheidssubsidies voor inputs, de winstmarge van veel producenten erg laag is. Onder de huidige productieomstandigheden lijkt kostendekking dan ook moeilijk haalbaar.

In een volgend deel wordt het concept van sub-vector efficiënties geïntroduceerd als maatstaf voor de efficiëntie waarmee water gebruikt wordt. De lage sub-vector efficiënties berekend door middel van "Data Envelopment Analysis" tonen dat de kleine boeren in de studie hun algemene technische efficiëntie niet bereiken wanneer het om watergebruik gaat. Zelfs met de huidige irrigatietechnologie is er dus ruimte voor gevoelige verbeteringen in watergebruiksefficiëntie waardoor een deel van het irrigatiewater naar andere gebruiken

overgeheveld zou kunnen worden. De lage watergebruiksefficiëntie is ook een indicatie voor het feit dat wanneer water niet geprijsd is, er weinig stimuli zijn om water efficiënter te gebruiken of om te investeren in water besparende technologie.

In een derde empirisch hoofdstuk werd een innovatief twee-staps simulatiemodel ontwikkeld om de impact van het invoeren van een waterprijs te onderzoeken. Het model gebruikt een schatting van de technologie en de individuele efficiënties van de producenten in een winstmaximisatiemodel. Producenten blijken zelfs voor lage prijsniveaus gevoelig te zijn en passen hun watergebruik aan. Dit geeft duidelijk aan dat het invoeren van een waterprijs kan leiden tot vermindering van het watergebruik en verbeterde efficiëntie. Een gevolg van de waterprijs is echter ook dat de winstmarge van de boeren daalt. Vooral voor de kleinere producenten in termen van output (de armste boeren) is dit problematisch omdat ze bij hogere waterprijzen niet winstgevend meer zijn en dus zonder steun hun productie zouden moeten staken.

Het laatste deel van het doctoraat onderzoekt de mogelijkheid om verbeteringen aan te brengen in het systeem van waterrechten. Door middel van een "contingent ranking" experiment kan de bereidheid tot betalen (WTP) van de kleine boeren voor bepaalde verbeteringen geschat worden. De resultaten tonen aan dat de boeren bereid zijn om meer te betalen voor water indien het systeem van waterrechten verbeterd wordt. Dit impliceert dat interventies in het systeem de efficiëntie van de kleinschalige irrigatiesector kunnen verbeteren. Bovendien is een grotere (WTP) ook interessant in het licht van het objectief van kostendekking, omdat het de overheid toelaat om de waterprijs te verhogen.

Algemeen bevestigt het onderzoek dat efficiënt watergebruik en kostendekking belangrijke uitdagingen zijn voor de kleinschalige irrigatiesector in Zuid-Afrika. Er werd aangetoond hoe economische analyses gebruikt kunnen worden om het beleid te informeren bij het aangaan van deze uitdagingen.

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Scientific Curriculum Vitae

Stijn Speelman was born in Duffel on January 26, 1979. He completed secondary education at the Sint-Gummaruscollege in Lier in 1997. In 2002, he obtained the degree of Bio-Engineer, option agriculture (with specialisation in soil science and agriculture from tropics and subtropics) at the K.U.Leuven with great distinction. His thesis was rewarded with the Development Cooperation price. Still at the K.U.Leuven he finished a specialisation programme in economics of institutions with great distinction in 2003.

In October 2003 he started working as full-time assistant at the Department of Agricultural Economics (Ghent University). He was responsible for the exercises and practicals of the courses Development Economics, Human Development Economics and Agricultural Economics of Developing Countries and was supervisor for about 15 dissertations. In the framework of his PhD, he did research at the University of Pretoria, South Africa in 2005 (July-September) and 2008 (March-May). Furthermore, he is also involved in a research project, which focuses on the dynamics of Agricultural systems and food security in Burundi. In October 2008 he successfully completed the Doctoral Training Program at the Faculty of Bioscience Engineering, Ghent University.

He participated in many national and international scientific conferences, seminars and workshops with oral and poster contributions. In addition he is author and co-author of various international peer-reviewed publications.

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