MODELING THE MARGINAL REVENUE OF WATER IN SELECTED AGRICULTURAL COMMODITIES: A PANEL DATA APPROACH

by

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LIST OF ABBREVIATIONS

ADF	Augmented Dickey-Fuller
DF	Dickey-Fuller
DW	Durbin Watson
DWAF	Department of water affairs and forestry
IPS	Im, Peseran and Shin
LSDV	Least square dummy variables
NWA	National water act
SUR	Seemingly unrelated regressions

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

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

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

1.2 WATER CONFLICTS IN SOUTH AFRICA

Precipitation in South Africa's interior is highly irregular and unevenly distributed. With a mean annual precipitation of 500mm per annum, South Africa is likely to experience chronic water scarcity on a scale sufficient to impede development and harm human health (Elberhard, 1999). In the year 2000 thirteen of the twenty water management areas in South Africa was running a deficit on their water account with demand exceeding supply. Water supply and demand imbalances are expected to widen even more in future under current management strategies. Total water demand for South Africa is expected to increase from 13 280 to 17 248 million cubic meter per annum in 2025 potentially reducing the available surplus form 631 million cubic meter per annum to a deficit of 1 788 million cubic meter per annum (Blignaut and De Wit, 2004). This is likely to impact negatively on development and result in water conflicts among water users.

Water conflict in South Africa concerning water availability and allocation is prominent in areas that experience rapid economic growth in industries and/or are suitable for agricultural production. The Crocodile River Catchment in the Mpumalanga province matches this profile. Nine and a half per cent (129 308 ha) of the total land under irrigation in South Africa is situated in the Mpumalanga province (Agricultural Statistics of the National Department of Agriculture, 2003). The distribution of water resources in the Crocodile River Catchment has become a topic of conflict with several sectors competing for their fair share of the catchment's limited water. Irrigated agriculture, the primary user of water along the catchment, competes directly with domestic users and industries, and indirectly with forestry for the scarce water supply in this region. Forestry is classified as an indirect competitor because industrial plantations reduces stream flow significantly with their excessive abstraction of rainfall water, which leads to reduced availability of water to downstream users such as irrigation agriculture. The main irrigation commodities grown in the catchment are sugarcane, bananas, citrus, avocado and mangoes and the total water use by irrigation agriculture in the catchment is approximately 570 million cubic meters of water per year compared to the estimated 207 million cubic meters per year reduction in runoff due to afforestation (Bate *et al.*, 1999:16).

In order to resolve water conflict and improve water efficiency in areas such as the Crocodile River Catchment, it is necessary to know the economic value that the users place upon water. This study attempts to value water among certain irrigation commodities on a national level, namely avocados, bananas, grapefruit, mangoes, oranges and sugarcane, six commodities that are important in the agricultural sector in the Crocodile River Catchment. The value of water among sectors and among commodities within a sector can be a useful guideline to policy makers in structuring water management strategy for South African water resources.

1.3 THE OBJECTIVE AND METHODOLOGY OF THE STUDY

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

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

In order to achieve the objective of this study, the methodology developed by Moore (1999), a production function approach, will be applied. A quadratic functional form is fitted to the revenue function with a SUR (Seemingly Unrelated Regressions) model utilising panel data for South Africa for the period 1975–2002, with six cross-sections namely avocado, banana, grapefruit, mango, orange and sugarcane.

1.4 OUTLINE OF THE STUDY

The structure of the study is as follows: in chapter two the measurement and management of water in South Africa is discussed. South African and international literature is reviewed in chapter three and chapter four contextualises the methodology applied in this study. The fifth chapter details the econometric estimation techniques, whilst chapter six contains a data exposition and empirical analysis of the estimation results. Chapter seven summarises the objective of the study and the main findings, and concludes with suggestions for further research.

CHAPTER 2

THE MEASUREMENT AND MANAGEMENT OF WATER IN SOUTH AFRICA

2.1 INTRODUCTION

The first chapter recognized the fact that water is a scarce resources in South Africa and that water management strategies are vital in securing water for future development. In this chapter the measurement and current management of water in South Africa is contextualised. The economic theory of water and the underlying principals of the cost and value of water is discussed in section 2.2. Section 2.3 considers the current legislation regarding water management in South Africa as described in the National Water Act of 1998 as well as supply and demand-side management in South Africa.

2.2 WATER AS AN ECONOMIC GOOD

Water has traditionally been regarded as a public good. In the past, public organisations provided water for irrigation and domestic uses free of charge or at heavily subsidized rates that did not relate to the quantity consumed. In the last decade there has been a gradual realisation that global water stocks are limited and that supply-augmentation cannot meet the ever-increasing demands for water. In economic terms there are three aspects to the problem of meeting increased demand in future. The first is the rising marginal cost of water provision; the second aspect is the abundance of water or the lack thereof and the third is associated with the future threats of non-sustainable management strategies. Since the global realisation of water scarcity, economic institutions and incentives have internationally promoted conservation and efficient use of water. With that, the focus has shifted from supply to demand management strategies to close the increasing gap between demand and supply of water.

Water has two main uses: it can either be consumed directly as a consumption good or used as a factor of production in agriculture, forestry and industry, etc. In this study we focus on water as a factor in production. Some characteristics of water resembles that of a normal good, implying that demand affects price, while in other respects demand is expected to be highly inelastic, reflecting the fact that water is an essential good (Nieuwoudt *et al.*, 2004). If we assume that water is a normal good and that water markets are operating under a perfect competitive market, then water markets will allow supply and demand to set the equilibrium price (equal to the marginal cost of water). If the price (market determined or administered) of a good reflects its real cost, there exists an economic incentive for that good to be allocated rationally. Alternatively, if the price of water does not reflect the full economic cost, there is little incentive to economise. This is currently the case for many countries, including South Africa, where governments provide water at a cost lower than the full economic cost.

Table 2.1: Underlying principles for the cost and value of water

<table>
<tr><th colspan="4">Cost of water</th><th colspan="3">Value of water</th></tr>
<tr><td>Environmental externalities</td><td colspan="2"></td><td rowspan="5">Full costs</td><td>Intrinsic value</td><td></td><td rowspan="5">Full value</td></tr>
<tr><td>Economic externalities</td><td rowspan="2"></td><td rowspan="4">Full economic costs</td><td>Adjustment for social benefits</td><td rowspan="4">Economic value</td></tr>
<tr><td>Opportunity costs</td><td>Net benefits for indirect use</td></tr>
<tr><td>Capital charges</td><td rowspan="2">Full supply costs</td><td>Value to user of water</td></tr>
<tr><td>Operation and maintenance charges</td><td>Net benefits from return flows</td></tr>
</table>

Source: Adapted from Blignaut, J.N. and M de Wit. 2004. Sustainable options: Development lessons from applied environmental economics.

The cost of water has two broad components, the cost of provision (fixed and variable costs) and the opportunity cost forfeited in alternative use. Table 2.1 summarises the underlying principles for the cost and value of water and show that the cost of water can be divided into five levels, level one is the costs associated with operation and maintenance of supplying water, level two includes capital cost, level three is the opportunity cost of water, the cost related to economic externalities is reflected in level four and the last level captures the costs associated with environmental externalities. If water charges cover levels one and two, the full supply cost of water is recovered. The full economic cost is captured when levels one to four is included in the price of water and if all levels are taken into account when water is priced, the full cost of water is captured in the price.

In South Africa, raw water charges tend to be equal to the cost of operation and maintenance including a depreciation and capital component. It is evident from Table 2.1 that South African water prices only recover the full supply cost and doesn't reflect the full cost (full economic cost plus the environmental externalities) or the full economic cost (full supply plus the opportunity cost and the cost associated with economic externalities) of water.

That said; water is not a typical economic good as it has characteristics of a normal as well as a necessary good, which makes it even more difficult to classify water in a specific economic market structure. It is almost impossible to disentangle political and economic aspects related to water strategies. The application of economic theory to determine water prices that reflects the full cost of water relies on effective measurement instruments and suitable indicators of efficient water utilisation. This study introduces a measurement instrument, namely shadow prices, to determine the efficiency of water utilisation among various irrigation commodities.

2.3 WATER MANAGEMENT IN SOUTH AFRICA

In the past, the South African government met the growing demand for water with increases in supply, rolling out capital for new infrastructure such as dams and transfer schemes. However, as easily accessible water sources become fully utilised, expanding supply will entail going further afield to find new sources. Expensive supply-side strategies such as importing water from neighbouring countries (which is conditional on the availability of water resources in neighbouring countries as well as their willingness to trade) or desalinisation of seawater will result in rising costs that will be borne by all water users. The alternative is to apply demand-side measures to make sure that the water that is currently available is utilised efficiently. Demand-side management provides a more sustainable long-term solution to the problem of water scarcity than supply-side because it takes into account the value of water in relation to its cost of provision, treating water as a commodity.

2.3.1 The National Water Act of 1998 (NWA)

The National Water Act of 1998 (Act no. 36 of 1998) of South Africa has provided for fundamental reform in the development and implementation of a new water pricing strategy. The NWA recognises that

- water is a scarce and unevenly distributed national resource which occurs in many different forms which are all part of a unitary, independent cycle;
- that while water is a natural resource that belongs to all people, the discriminatory laws and prices of the past have prevented equal access to water, and use of water resources;
- resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters;
- that the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users;
- that the protection of the quality of water resources is necessary to ensure sustainability of the nation's water resources in the interest of all water users; and
- the need for the integrated management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to enable everyone to participate.

From these realisations, four objectives of equal importance were identified, namely social equity, ecological sustainability, financial sustainability and economic efficiency. The NWA stipulate that Government, as trustee of the nation’s water resources, must ensure that water is protected, used, developed, conserved, managed and controlled in an equitable and sustainable manner for the benefit of all people. The purpose of the act is to ensure that the objectives are met while taking the following factors into account:

- meeting the basic human needs of present and future generations;
- promoting equitable access to water;
- redressing the results of past racial and gender discrimination;
- promoting the efficient, sustainable and beneficial use of water in public interest;
- facilitating social and economic development;
- providing for growing demand for water use;
- protecting aquatic and associated ecosystems and their biological diversity;
- reducing and preventing pollution and degradation of water resources;
- meeting international obligations;
- promoting dam safety; and
- managing floods and droughts.

The Department of Water Affairs and Forestry (DWAF) is assigned the role of custodian of the country's water resources, and should guarantee basic human needs and ecological use as rights along with international obligations. Excluded from this role is the allocation to irrigation and other commercial agricultural activities. Priority is thus given to basic human needs and ecological sustainability above that of agriculture and other industries. Pre-existing water rights are respected, allowing farmers to use water until a call is made for the application of water licences.

In the context of increasing water resource scarcity, economic incentives may be necessary in water stressed areas in order to optimise the allocation of water resources between competing uses. The objective is to shift water use from low to high value uses. This may be achieved through an administered charge (includes a fee, price or tariff imposed under the Act) or market-orientated mechanisms. An administratively determined water charge, which will be over and above the charges for water management of resources, could be introduced in areas where water is used for predominantly low-value purposes. The basis for this economic charge will be to cover the opportunity cost of water as reflected in transactions taking place between water users. The NWA makes provision for public auctions, to determine the market-clearing price when issuing new permits of any remaining water, and water markets for trading in existing water use entitlements. Due to the possible external costs to the rest of the local economy, trading in water rights are subject to some control to protect the public interest as opposed to the interest of the contracting parties.

The NWA provides for supply as well as demand-side management strategies but stresses the importance of meeting the challenges presented by the existing and growing imbalances between the availability, supply and demand for water in South Africa in the new water pricing strategy (Government Gazette 1999).

2.3.2 Supply-side management: Working for Water Programme

Supply-side management is concerned with meeting the increased demand, securing new water resources by either investing in new infrastructure or exploiting the currently available water resources. Historically, rising water demands in South Africa were met through the establishment of a complex system of engineering supply-solution (Blignaut and De Wit, 2004). Supply-augmented strategies have become less attractive over the past decade internationally, as well as locally, due to the high costs involved and the lifespan of the solution.

The following factors were identified by DWAF as influencing the supply of water in South Africa:

- much of the country is semi-arid with low rainfall;
- rainfall patterns are erratic;
- regions of high runoff are often situated away from regions of maximum water demand;
- the country’s groundwater is limited and of poor quality;
- catchments have been infested by invader vegetation which uses more water than natural vegetation; and
- decreasing water quality has an impact on the availability of water of an appropriate standard for use.

The first four factors listed above are difficult, if at all possible, to affect in the short and medium term, the last two factors are however currently being targeted in South Africa. The Department of Water and Forestry Affairs has embarked on an extensive supply-side management strategy, the Working for Water Programme, with the emphasis on water conservation. The Working for Water Programme was established in 1995 with the main aim to eradicate invading alien plants from rivers, mountain catchments and other natural areas to improve water runoff, conserve biodiversity and restore the productive potential of the land (Marais *et al.*, 2001).

2.3.3 Demand-side management

Demand management strategies concentrate on reducing the demand for water rather than trying to meet the increased demand and include price structure reforms, restructuring allocation of water rights and water markets.

The following factors were identified by DWAF as contributing to the increase in demand for water in South Africa:

- the high population growth rate;
- rapid urbanisation;
- economic development;
- demands for basic services and higher levels of service;
- the need to sustain and rehabilitate ecological systems;
- the drive to provide accessible, drinkable water for everyone in the country; and
- ineffective mechanisms, including pricing structures to reduce demand.

In the past, pricing strategies were not designed to reduce demand and the price charged to agricultural users typically did not reflect the marginal cost of supplying the water to them. Agricultural water supply was subsidised in an attempt to encourage production and economic growth, which led to inefficient crop choices in agriculture. Distortions in crop choices arise when high-value crops are deprived of water because prior allocations made to growers of low-value crops. Efficient pricing of irrigation water would lead to a reduction in output from low-value water users and an increase in output from high-value users. Governments around the world, including the South African government, recognise the problems associated with past pricing strategies and are slowly adjusting water prices and allow for limited markets to operate.

Current water pricing strategies in South Africa are set according to the criteria stipulated in the NWA, namely that prices should promote equity, support ecological sustainability, must be financially sustainable and must account for the efficiency goals in terms of the economic and social nature of water. In order to capture the associated costs of water provision, tariff structures are set up in a manner that aims to address the goals of a particular pricing strategy. Financial pricing strategies focus on recovering operation, maintenance, servicing and capital investment costs for water delivery. Economic pricing aims to reflect and capture the opportunity cost of water and environmental pricing strategies try to internalise environmental externality costs associated with water use (Blignaut and De Wit, 2004).

Two general types of pricing exist: flat rates, independent of the amount of water consumed; and unit pricing based on the amount of water consumed. Flat rates imply that consumers can use as much water as they wish without regard for the price. Another common pricing scheme that encourages increased consumption is declining block rates, a high marginal price is levied on the initial volume of water consumed and subsequent ‘blocks’ are available at a lower price. Increasing block rates (higher volumes come at a higher price) encourage more efficient use, as the marginal price of water increases with increased volume consumed. This pricing strategy can be adapted to deal with peaks in water demand, for example, high block prices can be charged in summer when demand for water is very high. Water markets is an alternative pricing strategy which could theoretically ensure sustainable usage, minimise wastage, ensure efficient allocation, and provide incentives for the development of water-efficient technologies, re-use and recycling. Although the NWA provides for water markets to address the problem of excess demand for water in water stressed areas, it currently only exists at an informal level. International (Chile, California, Mexico, Spain) and local (Berg River Basin) evidence has shown that water markets can be successful in reducing water demand and solving conflicts related to water allocation (Armitage, 1999).

2.4 CONCLUSION

The measurement of the cost and value of water as well as water management in South Africa is discussed in this chapter. It is evident from section 2.2 that water is not a typical economic good as it has characteristics of a normal as well as a necessary good, which makes it difficult to classify water in a specific economic market structure. This in return impacts on water management and the effectiveness of pure market structures. Current supply and demand-side management strategies are evaluated against the objectives set out by the NWA. Although the NWA provides for supply as well as demand-side management strategies it stresses the importance of the new water pricing strategy to meet the challenges presented by the existing and growing imbalances between the availability, supply and demand for water in South Africa.

The first two chapters established the importance of effective management of water resources in South Africa and stressed the need to value water in order to manage it. The following chapter contain theory and evidence of the valuation of water from South African and international studies.

CHAPTER 3

MEASURING THE VALUE OF WATER: THEORY AND EVIDENCE

3.1 INTRODUCTION

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

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

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

This chapter contain theory and evidence of the valuation of water. Section 3.2 and 3.3 reviews South African literature and international literature respectively. The standard approaches of estimating the value of irrigation water is discussed in section 3.4.

3.2 REVIEW OF SOUTH AFRICAN LITERATURE

Table 3.1 lists some of the studies conducted on the marginal value of water in South Africa, in particular for the agricultural industry. It is evident that across regions, as well as methodologies, the marginal values differ significantly.

Table 3.1: South African studies on the marginal value of water

Study	Year	Region	Method	Marginal value of water
Conradie	2002	Fish-Sundays River	Econometric model	R2.40/m³
Louw	2001	Berg River Basin	Mathematical programming model	R0/m³-R20/m³
Bate *et al.*	1999	Crocodile River Catchment	Water trading	18.76c/m³-22.75c/m³

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

Louw (2001) evaluated the impact of a potential water market on the efficient utilisation of water in the Berg River Basin. He utilised a positive mathematical programming model to develop a methodology to determine the true value of water and found significant differences in the value of water between areas in the basin, with the marginal value of water ranging between as low as R0/m³ and as high as R20/m³ in this region. These differences indicate that there are significant gains possible from trade between these areas. Bate *et al.* (1999) studied the value of water through actual water trading in the Crocodile River Catchment and found much lower values for water than the other studies (Conradie, 2002 and Louw, 2001). The outcomes obtained by the Bate *et al.* (1999) study correspond with the values of international studies (see Table 3.2), with water values ranging between 18.67c/m³ and 23c/m³. Bate *et al.* (1999) also found that the value of water is the highest in tropical fruit production and the lowest in sugarcane.

3.3 REVIEW OF INTERNATIONAL LITERATURE

International studies, on the marginal value of water, such as Moore (1999) and Faux and Perry (1999), found values ranging between 2.6c/m³ and 23.2c/m³ (Table 3.2). Moore (1999) estimated a panel data econometric model with a Kmenta-type error structure in order to obtain shadow price (marginal revenue) functions for water. Faux and Perry (1999) applied a hedonic price analysis to agricultural land sales to reveal the implicit market price of water in irrigation.

Table 3.2: International studies on the marginal value of water

Study	Year	Region	Method	Marginal value of water ($/acre-feet)	Marginal value of water (R/m³)
Moore	1999	California	Panel data study	$5-$15 per acre-feet	2.6c/m³-7.9c/m³
Faux & Perry	1999	Oregon	Hedonic price analysis	$9-$44 per acre-feet	4.7c/m³-23.2c/m³

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

The methodology developed in the Moore (1999) study was adopted in this study to estimate the marginal value of water among selected agricultural commodities.

3.4 STANDARD APPROACHES TO ESTIMATE THE VALUE OF IRRIGATION WATER

Before discussing the methodology employed in this study, let's consider some methods that are commonly used in the agricultural sector to estimate water values. Marais *et al.* (2001) examine some of the standard approaches to estimate irrigation water value, which are summarised as follows.

3.4.1 Crop function analysis

For crop function analysis the marginal productivity of water is calculated from controlled crop experiments. Crop-water relationships are estimated for a given treatment consisting of soil, variety, and labour input and fertiliser application, etc. The disadvantage of crop function analysis is that it is data intensive, relying on the physical relationship between yield and output.

3.4.2 Simple budgeting to calculate average values

Crop budget analysis is used when the actual productivity of water is not known. A maximum willingness to pay for water is estimated from a standard crop or farm budget based on the theory of Ricardian rents. A single point or small range of the crop-water production function is used to calculate a margin above specified costs. Ricordo's theory states that under perfect competition total revenue will be completely exhausted by factor payments, thus if no other input except water need to be rewarded from the profit, the residual is the total value of water. A second approach is where the value of water is as the difference between the total residual of irrigated agriculture and dryland farming in some area. The difference in profits is then attributed to the availability of water.

3.4.3 Programming models

Multiperiod programming models are constructed from enterprise budgets and are usually set up to maximise farm-level net returns, subject to resource constraints. The specification of the constraints determines if the model produces an average or marginal value of water. This technique is often used in estimating water values in agricultural production.

3.4.4 Marginal and average value of products

Average values are easier to calculate than marginal values of water and in some cases convey the same information but where a marginal adjustment in water use patterns is expected, the average value of water is a poor indicator of the value of marginal productivity. As water constraints tighten, farmers are expected to move from low value crops to high value crops or move to water saving technology, causing the marginal value of water to increase as water is reallocated. Irrigation farms have therefore the ability to release water at the margin, so that allocative efficiency can be achieved.

3.5 CONCLUSION

The literature review of South African and international studies yielded a wide range of values for water. Building on the general domestic and international frameworks reviewed in this chapter, this study focuses on the agricultural sector, and specifically on irrigated commodities. The following chapter provide a framework of the methodology, developed by Moore (1999), employed in this study to estimate the value of water in selected agricultural commodities.

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

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

Since water prices are generally set administratively rather than being market-determined; water prices serve neither a rationing nor an allocative function (Moore, 1999) and are thus normally modelled as a fixed input. Based on this, the marginal revenue function for water is estimated under the assumption that production is quantity-rationed rather than price-allocated. Farmers are constrained by the availability of water rather than the cost or price of water; one reason could be that the cost of water relative to the total production cost is very small. In this study cropland is modeled as a composite input, firstly as a factor that includes capital, labour and land, and secondly as a factor of variable inputs in addition to land. This approach is adopted from earlier studies such as Just *et al.* (1983 and 1990), for the same reasons that these studies were developed: to address the problem of data limitations.

The theory of revenue maximization is discussed in section 4.2; section 4.3 describes how the marginal revenue function is obtained. Section 4.4 and 4.5 contain mathematic foundation of the shadow cost function and ability to pay respectively.

4.2 REVENUE FUNCTION

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

The revenue function is defined as:

$$R(p, w, comp) = \max_{y}\{p \cdot y : y \in Y(w, comp), p > 0\} \tag{4.1}$$

Where p is a vector of output prices, y is a vector of crop outputs, w is the water used in production and comp is the composite input factor. The revenue function is maximised with respect to output, which is a function of production factors: water and composite input factor.

4.3 MARGINAL REVENUE FUNCTION OR SHADOW PRICE FUNCTION

The first order derivative of the revenue function with respect to the fixed inputs, water or composite factor, is a vector of shadow prices that shows the change in marginal revenue due to a change in water or composite factor. The shadow price (marginal revenue) function of water can then be defined as:

$$\frac{\partial R(p, w, comp)}{\partial w} = \lambda(p, w, comp) \tag{4.2}$$

and

$$\frac{\partial R(p, w, comp)}{\partial comp} = \mu(p, w, comp) \tag{4.3}$$

These shadow price functions (equations 4.2 and 4.3) of the fixed inputs measure the unit cost as an opportunity cost, or foregone revenue at the margin.

4.4 SHADOW COST FUNCTION

The shadow cost function measures the economic cost for the revenue-maximizing firm with two inputs: water and composite and can be specified as:

$$\mathrm{C}^{*}(\lambda(\mathrm{p},,\mathrm{w},\mathrm{comp}),\mu(\mathrm{p},\mathrm{w},\mathrm{comp}),\mathrm{y}(\mathrm{p},\mathrm{w},\mathrm{comp}))=\lambda(\mathrm{p},\mathrm{w},\mathrm{comp})\mathrm{w}+\mu(\mathrm{p},\mathrm{w},\mathrm{comp})\mathrm{comp} \qquad (4.4)$$

This shadow cost function can be converted into an equilibrium cost function by assuming an optimal choice of w and comp. If allocation institutions determine the amount of water available (w), then the equilibrium will be an institutional equilibrium. The assumption of an optimal choice for the composite input implies that the shadow price of the composite input, μ, equals its market price, mp. Moore and Dinar (1995) tested this assumption empirically and showed that irrigators in central California operate in equilibrium in cropland, with land as a variable input rather than a fixed input. The equilibrium cost function can then be specified as

$$\mathrm{C}^{*}(\lambda(\mathrm{p},\mathrm{w},\mathrm{comp}),\mathrm{mp},\mathrm{y}(\mathrm{p},\mathrm{w},\mathrm{comp}))=\lambda(\mathrm{p},\mathrm{w},\mathrm{comp})\mathrm{w}+\mathrm{mp}\cdot\mathrm{comp}^{*}(\mathrm{p},\mathrm{w},\mathrm{mp}) \qquad (4.5)$$

where $\mathrm{comp}^{*}(\mathrm{p},\mathrm{w},\mathrm{mp})$ is the equilibrium demand for composite input.

4.5 PROFIT FUNCTION AND ABILITY TO PAY

Given that the composite input is in equilibrium, $\mathrm{comp}^{*}(\mathrm{p},\mathrm{w},\mathrm{comp})=\mathrm{comp}$, the firm profits can be measured by:

$$\pi(\mathrm{p},\mathrm{w},\mathrm{mp})=\max\{\mathrm{R}(\mathrm{p},\mathrm{w},\mathrm{comp})-\lambda(\mathrm{p},\mathrm{w},\mathrm{comp})\mathrm{w}-\mathrm{mp}\cdot\mathrm{comp},\mathrm{p}>0\} \qquad (4.6)$$

The irrigator’s ability to pay for water is the residual value: revenue minus costs and profits. The ability to pay for water then emerges as a residual from the profit function:

$$\lambda\mathrm{w}=\mathrm{R}(\mathrm{p},\mathrm{w},\mathrm{comp})-\mathrm{mp}\cdot\mathrm{comp}-\pi(\mathrm{p},\mathrm{w},\mathrm{mp}) \qquad (4.7)$$

4.6 CONCLUSION

In this study the revenue function (equation 4.1) is estimated econometrically using a quadratic functional form with a SUR (Seemingly Unrelated Regressions) model. The quadratic functional form is applied often in agricultural production estimation (Huffman, 1988; Moore and Dinar, 1995 and Moore, 1999). Its full specification includes linear, squared, and cross product terms for all exogenous variables.

$$\begin{aligned} R_{it}(p, w, comp) = c_{it} + \beta_1 p_{it} + \beta_2 comp_{it} + \beta_3 p_{it}^2 + \beta_4 comp_{it}^2 + \beta_5 w_{it}^2 + \beta_6 p_{it} comp_{it} \\ + \beta_7 p_{it} w_{it} + \beta_8 comp_{it} w_{it} + \sum_{i=1}^{6} \alpha_i w_{it} + \sum_{i=1}^{6} \delta_i comp_{it} \end{aligned} \tag{4.8}$$

The marginal revenue function for water (equation 4.2) is then derived from the estimated quadratic revenue function as the first order derivative with respect to of the revenue function.

$$\lambda_{it}(p, w, comp) = 2\beta_5 w_{it} + \beta_7 p_{it} + \beta_8 comp_{it} + \sum_{i=1}^{6} \alpha_i \tag{4.9}$$

This study focus is on the shadow price of water and therefore the shadow price for composite input, shadow cost functions and the irrigators ability to pay will not be estimated.

CHAPTER 5

PANEL DATA ESTIMATION TECNIQUES

5.1 INTRODUCTION

Here we discuss the relevant panel data econometric techniques applied in this study, namely fixed effects models, random effects model and seemingly unrelated regressions (SUR) model. In the next section of this chapter the use of panel data estimation is examined according the structure of a panel specification, the advantages and limitations of this method.

5.2 WHAT IS A PANEL AND WHY DO WE USE PANEL DATA?

The term "Panel data" refers to the pooling of observations on a cross-section of countries, households, firms, commodities etc. over several time periods. When the panel consists of many cross-sections and only a few time periods it is referred to as a "cross-section orientated" panel (wide but short). Similarly, a "time-series oriented" panel is a panel that consists of a few cross-sections but quite a number of time periods (Baltagi, 2001). The earliest panel specifications (equation 5.1) did not allow the intercept and coefficient for cross-section to differ, these estimated coefficients were fixed.

$$y_{it} = \alpha + \beta_1 X_{1,it} + \beta_2 X_{2it} + \ldots + \beta_k X_{k,it} + \varepsilon_{it} \qquad \text{for } i = 1,\ldots N \text{ and } t = 1,\ldots T \qquad (5.1)$$

Panel data regression differs from the regular time-series and cross-section regression in that it has a double subscript on its variables, i denoting the cross-section, for example individuals, households, firms, commodities etc. and t denoting time.

Although not very flexible, these specifications already recognised the benefits, such as increased degrees of freedom and potentially lowering the standard errors of estimated coefficients, of joint estimation of coefficients. Later specification, however, did allow for intercept and/or slope coefficients to vary across cross-sections and/or time.

Baltagi (2001:5) summarised several benefits of combining cross-sectional and time-series data as follows:

- Controlling for individual heterogeneity. Panel estimation allows us to recognise that cross-sections such as individuals, households, firms, commodities etc. might not be homogenous and to control for this heterogeneity. Pure time-series and cross-section studies not controlling for this heterogeneity run the risk of obtaining biased results.
- Panel data is more informative, more variability, less collinearity among the variables, more degrees of freedom and more efficiency. With additional, more informative data, panel studies can produce more reliable parameter estimates (given the data is poolable). Panel data studies are less likely to be plagued by the problem of multicollinearity that is common in time-series studies.
- Panel data are better able to study the dynamics of adjustment and are also suited to study the duration of economic states like unemployment and poverty. Panels can relate the individual's experiences and behaviour at one point in time to other experiences and behaviour at another point in time.
- Panel data are better able to identify and measure effects that are not detectable in pure cross-section or pure time-series data. Fewer restrictions can be imposed in panels on a distributed lag model than in a pure time-series study.
- Panel data models allow us to construct and test more complicated behavioural models than purely cross-section or time-series data.
- Panel data are usually gathered on micro units that allow panel studies to more accurately measure at the micro level and overcome the problem of bias estimators resulting from aggregation over firms or individuals.

Although panel data techniques allow us to overcome many problems associated with pure cross-sectional or time-series estimation techniques there are some limitations to panel data. Baltagi (2001:7) summarised some of these limitations as follows:

- Design and data collection. Designing panel surveys, collection and management of panel data is a complex task.

- Distortions or measurement errors. Measurement errors in the collection of data may arise due to unclear questions, memory errors, deliberate distortion of responses, misreporting, etc. Panel data users can check for inconsistencies of responses, unlike cross-sectional data users that have no choice but to believe the reported values, but if ignored it poses the same threat as with pure time series or cross-sectional estimation.
- Selectivity problems such as self-selectivity, non-response and attrition. Non-response will lead to efficiency loss due to missing data and serious identification problems for the population parameters. Non-response occurs also in cross-section data but is more serious in panels because subsequent waves of the panel are still subject to non-response.
- Short time series dimension. Typical panels involve annual data covering a short time span for each individual. Asymptotic arguments rely crucially on the number of individuals tending to infinity. Increasing the time span of the panel increases the chances of attrition and increases the computational difficulty for limited dependent variable panel data models.

From the above listed benefits and limitations it is clear that although panel data techniques may improve parameter estimates and allow us to estimate relationships that are not possible when using pure time-series or cross-sectional techniques, caution should be taken when choosing panel over other estimation techniques. Panel data regression models can either take the form of a one-way or a two-way error component regression model. One-way error component regression models – specifically the fixed effects, random effects and SUR models are discussed in the following section.

5.3 ONE-WAY ERROR COMPONENT REGRESSION MODEL

The modern panel data specification:

$$y_{it} = \alpha + X'_{it}\beta + u_{it} \tag{5.2}$$

where y_{it} is the dependent variable, α is a scalar, X'_{it} and β are k-vectors of non-constant explanatory variables and parameters for i = 1,…N cross-sections and t = 1,…T time periods.

Most panel data application utilise a one-way error component model for the disturbances. If we assume cross-section heterogeneity in the error term of equation 6.2 then the error can be specified as:

$$u_{it} = \mu_i + \nu_{it} \tag{5.3}$$

where μ_i denotes the unobservable individual specific effect and is time-invariant, accounting for the special effect that is not included in the regression. The remainder disturbance ν_{it} varies with cross-sections and time. The error of a panel then becomes the sum of a well-behaved error component (ν_{it}) and an individual specific effect (μ_i). These individual specific effects can be cross-section specific effects (μ_i) or time-series specific effects (μ_t) and can be modeled utilising fixed or random effects models.

5.3.1 Fixed effects (LSDV and WITHIN)

$$y_{it} = \alpha_i + X'_{it}\beta + u_{it} \tag{5.4}$$

The fixed effects model allows the intercept term α_i to differ across cross-sections while keeping the slope coefficients constant. The fixed effects model assumes that the individual specific effects are fixed parameters to be estimated and the remainder disturbance is independently and identically distributed. It is further assumed that the remainder disturbance and the X_{it}'s are independent. A fixed effects model is appropriate if the focus is on a specific set of cross-sections for example N firms, and the inference is restricted to the behaviour of these sets of firms.

5.3.1.1 Least squares dummy variables (LSDV) estimation

LSDV models estimate the individual specific effects by making use of dummy variables and OLS regression. This fixed effects model estimates K parameters for the X-regressors, one parameter for the intercept and N-1 parameters for the individual fixed effects. The model is very appealing due to its simplicity, but the loss of degrees of freedom when estimating a large number (N+K) of coefficients places huge restrictions on the regression. The problem of estimating too many parameters can be solved by the Within, Q, estimation.

5.3.1.2 Within, Q, estimation

The Within estimation differ from the LSDV models in that the individual effects are no longer estimated. The fixed effects are calculated by demeaning the data, subtracting the within mean from each variable, and estimating OLS using the transformed data. The Within model for cross-section individual effects becomes a simple regression:

$$\mathrm{y}_{\mathrm{i}} - \overline{\mathrm{y}}_{\mathrm{i}} = (\mathrm{X}_{\mathrm{it}} - \overline{\mathrm{X}}_{\mathrm{i}\bullet})'\beta + (\nu_{\mathrm{it}} - \overline{\nu}_{\mathrm{i}\bullet}) \tag{5.5}$$

Where $\overline{y}_i$, $\overline{X}_{i\bullet}$ and $\overline{v}_{i\bullet}$ denotes the average of each variable for each cross-section over the time period. The individual cross-section effects can be solved under the assumption $\sum_{i=1}^{N} \mu_i = 0$, then the first order conditions to recapture the individual effects are:

$$\hat{\alpha} = \overline{\mathrm{y}}_{\bullet\bullet} - \hat{\beta}\overline{\mathrm{X}}_{\bullet\bullet} \tag{5.6}$$

$$\tilde{\mu}_{\mathrm{i}} = \overline{\mathrm{y}}_{i\bullet} - \hat{\alpha} - \hat{\beta}\overline{\mathrm{X}}_{i\bullet} \tag{5.7}$$

The total individual effect is the sum of the common intercept and the constructed individual component.

The Within method avoids the problem of too many parameter estimates but an important disadvantage arise when demeaning the data in that X-regressors that are themselves dummy variables cannot be used because you will “wipe-out” the individual effects. One will thus not be able to use dummy variables, which capture for example sex, race or religion, in your specification when the Within model is used.

5.3.2 Random effects

An alternative specification that can deal with the problem of too many parameters and the loss of degrees of freedom with fixed effects is the random effects model. This specification is based on the assumptions that the individual effect (μ_i) is random, i.e. drawn from a specific distribution and the X-regressors are independent of the μ_i and ν_{it} for all i and t. The random effects model is an appropriate specification if we are drawing N individuals randomly from a large population. The benefit of this approach is that you concede variation across the cross-sections but don't estimate "N-1" of these variations. However, this approach introduce a more complicated variance structure and OLS is no longer appropriate.

5.3.3 Seemingly unrelated regressions (SUR)

The SUR approach to panel estimation is popular since it captures the efficiency due to the correlation of the disturbances across equations. A set of equations, which allow for different coefficient vectors, is estimated as a system. According to Baltagi (2001:105), Avery (1977) was the first to consider the SUR model with error component disturbances. M regressions are estimated jointly to find the most efficient variance-covariance matrix, under the restriction that the X-regressors are the same.

$$y_j = Z_j\delta_j + u_j \qquad \text{for } j = 1,\ldots M \tag{5.8}$$

With the residuals from each equations:

$$u_j = Z_\mu \mu_j + \nu_j \tag{5.9}$$

where $Z_\mu = (I_N \otimes \iota_T)$ and $\mu'_j = (\mu_{1j}, \mu_{2j}, \ldots. \mu_{Nj})$ and $\nu'_j = (\nu_{11j}, \nu_{12j}, \ldots. \nu_{1Tj}, \ldots, \nu_{N1j}, \ldots, \nu_{NTj})$ are random vectors with zero means and covariance matrix = $\begin{bmatrix} \sigma^2_{\mu_{j\iota}} I_N & 0 \\ 0 & \sigma^2_{\nu_{j\iota}} I_{NT} \end{bmatrix}$. Thus each error component follows the same standard Zeller (1962) SUR assumptions imposed on classical disturbances. In this case, the covariance matrix between disturbances of different equations has the same one-way error component form, but we need to consider the additional cross-equations variance components to be estimated.

The SUR weighted least squares are estimated by using a feasible GLS specification assuming the presence of cross-section heteroskedasticity and contemporaneous correlation.

$$\Omega = \mathrm{E}(uu') = \begin{bmatrix} \sigma_{11}\mathrm{I}_\mathrm{T} & \sigma_{12}\mathrm{I}_\mathrm{T} & \cdots & \sigma_{1\mathrm{N}}\mathrm{I}_\mathrm{T} \\ \sigma_{21}\mathrm{I}_\mathrm{T} & \sigma_{22}\mathrm{I}_\mathrm{T} & & \vdots \\ & & \ddots & \\ \sigma_{\mathrm{N}1}\mathrm{I}_\mathrm{T} & \cdots & & \sigma_{\mathrm{NN}}\mathrm{I}_\mathrm{T} \end{bmatrix} = \Sigma \otimes \mathrm{I}_\mathrm{T} \tag{5.10}$$

where Σ is the symmetric matrix of contemporaneous correlations

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1\mathrm{N}} \\ \sigma_{21} & \sigma_{22} & & \vdots \\ & & \ddots & \\ \sigma_{\mathrm{N}1} & \cdots & & \sigma_{\mathrm{NN}} \end{bmatrix} \tag{5.11}$$

with a typical element $\hat{\sigma}_{\mathrm{ij}} = \dfrac{\sum_{\mathrm{t}} (\mathrm{y}_{\mathrm{it}} - \hat{\mathrm{y}}_{\mathrm{it}})^2}{\max(\mathrm{T}_\mathrm{i}, \mathrm{T}_\mathrm{j})}$ (5.12)

The downside to the SUR model is that it cannot be applied to a panel with a large number of cross-sections or a small number of time periods. The average number of periods used to estimate, must at least be equal to the number of cross-section used.

5.4 CONCLUSION

In this chapter we dealt with the relevant panel data econometric techniques that are applied in this study, namely fixed effects models, random effects model and seemingly unrelated regressions

(SUR) model. In chapter six these techniques are employed to estimate revenue functions for selected agricultural commodities.

CHAPTER 6

DATA EXPOSITION, EMPIRICAL RESULTS AND ANALYSIS

6.1 INTRODUTION

Based on the methodology discussed in chapter four and the panel data estimation techniques in chapter five, this chapter contain the empirical estimation results. Section 6.2 is an exposition of the data used in the study. It includes the results of the unit root and cointegration tests performed on the data. The empirical results are evaluated in section 6.3.

6.2 DATA EXPOSITION

The data for the study constitute a time-series oriented panel data set for the period 1975–2002, with six cross-sections namely avocado, banana, grapefruit, mango, orange and sugarcane. The data set contains South African agricultural data of 168 observations. The number of time periods (t = 28) exceeds that of the cross-sections (n = 6), which allowed us to use a SUR model to estimate the revenue functions in equation 4.1. Table 6.1 contains a list and description of the variables used in the estimation.

Table 6.1: Variables and description

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

Source: Own summary

The data was mostly obtained from the Abstract of Agricultural Statistics that are published annually by the National Department of Agriculture. The "Abstract" contains meaningful information on field crops, horticulture, livestock, important indicators and the contribution of agriculture in South Africa. The price variable used in the estimation was calculated as a weighted price of export and domestic prices, with weights equal to the volume sold in the specific market as a fraction of the total volume sold. Water used in the production of each commodity is not directly reported but was constructed utilising information on average practice irrigation technologies reported in various WRC studies as well as crop specific information from the "Abstract". The composite input factor is assumed to be a fixed variable under the revenue maximization in equation 4.1 representing variable inputs as well as capital, labour and land. Moore (1999) made the case for using cropland under production as a proxy for the composite input factor because other inputs in agriculture is closely associated with cropland. Earlier studies treat cropland in this way as a means to address limitations in their data set. The same approach is adopted in this study where the number of hectares under irrigation is used as a proxy for the composite input factor.

Table 6.2: Summary of unit root tests results

Variable	**R**	**P**	**W**	**Comp**
Individual intercept				
Levin, Lin & Chu t*	11.29	3.60	-2.97***	-0.04
Breitung t-stat	1.29	-1.96**	-0.87	-2.48***
Im, Pesaran and Shin W-stat	8.85	3.02	-2.35***	-1.75**
ADF - Fisher Chi-square	3.33	10.91	52.46***	45.73***
PP - Fisher Chi-square	16.78	20.70*	54.76***	53.28***
Hadri Z-stat	7.39***	6.78***	2.75***	4.40***
Intercept and trend				
Levin, Lin & Chu t*	5.18	-2.13***	-6.297***	-5.74***
Breitung t-stat	4.60	-1.15	0.160	0.36
Im, Pesaran and Shin W-stat	2.21	-5.10***	-6.236***	-6.79***
ADF - Fisher Chi-square	21.57**	52.69***	96.55***	66.84***
PP - Fisher Chi-square	40.77***	105.66***	78.07***	76.32***
Hadri Z-stat	6.85***	3.41***	3.83***	3.03***

***1% level of significance, ** 5% level of significance, *10% level of significance.

Table 6.2 is a summary of the test-statistics obtained under the different test discussed in Appendix 3. It is evident from the test results that although the water and composite factor seem to be stationary for both intercept and intercept trend tests the revenue variable fail to pass the majority of the tests and we conclude that it is non-stationary. Tests for cointegration relationships will be performed before we can apply stationary panel data regression on the data.

The McCoskey and Kao test for cointegration showed that there is at least one cointegrating relationship present in the data and panel data techniques were applied in the estimation of the revenue function. From Table 6.3 it is evident that the calculated test statistic of -5.911 is smaller than the critical value of 1.96. The null hypothesis of cointegration is not rejected on a 5% level of significance and concludes that there exists at least one cointegrating relationship.

Table 6.3: McCoskey and Kao cointegration test result

Commodity	Avocado	Banana	Grapefruit	Mango	Orange	Sugar cane
Adf-value	-6.0447	-5.5155	-3.7944	-5.9472	-4.1877	-6.3796
LM test statistic						-5.3115
Critical value						1.96
McCoskey and Kao statistic						**-5.9111**

Source: Own analysis

6.3 EMPIRICAL ESTIMATION RESULTS

One-way error component models were fitted to the data but since the number of cross-sections is less than the number of coefficients, a random effects model could not be estimated. Economic theory places one restriction on the marginal revenue function of water (equation 4.2) in that the function must be positive. Intuitively we would expect that the function would have a negative slope and a positive intercept. Fixed effects models (Within and Least squares dummy variable) were fitted to the data but yielded positive slope coefficients for the marginal revenue functions of water and were disregarded, as it did not adhere to economic theory. The fixed effects models did not perform well in the statistical evaluation of the coefficients, most were insignificant on a 5 per cent level of significance. See appendix A1 for the results obtained for the fixed effects models.

A quadratic revenue function was subsequently fitted to the data with a cross-section SUR model. The Durbin-Watson test for first-order serial correlation and the LM tests for serial correlation tested positive for the presence of serial correlation (see appendix A2 for the specification of these tests). Both the LM test statistics exceed the critical values and the DW-statistic is smaller than the lower critical value (1.67<1.83). Due to strong heterogeneity across cross-sections, individual rho-values were calculated for each of the cross-sections instead of a pooled rho. The large differences amongst some of the rho-values confirmed that the degree of serial correlation differs across cross-sections. Table 6.4 contain the individual rho-values with which the cross-sections were corrected.

Table 6.4: Individual rho-values used in serial correlation correction

Commodity	Avocado	Banana	Grapefruit	Mango	Orange	Sugar cane
ρ -value	0.77	0.78	0.59	0.78	0.14	0.96

Source: Own analysis

After correction of the data by the individual rho-values, the test for serial correlation failed to reject the null hypothesis of non-serially correlated error terms, indicating that the problem of serial correlation no longer exists. Table 6.5 contains the test statistics, critical values and the results of the serial correlation test before and after the correction.

Table 6.5: Serial correlation test results

Serial Correlation test	**Test statistic**	**d.f.**	**Critical Value**	**Decision**
LM test (fixed effects)	8.18	N(0,1)	1.96	Positive serial correlation
LM test	93.13	χ_2^2	5.99	Positive serial correlation
Durbin-Watson test	1.67		dl = 1.83	Positive serial correlation
			du = 1.88	
After correction				
LM test (fixed effects)	0.67	N(0,1)	1.96	No serial correlation
LM test	4.39	χ_2^2	5.99	No serial correlation
Durbin-Watson test	1.91		dl = 1.81	No serial correlation
			du = 1.89	

Source: Own analysis

A problem of heteroscedasticity was expected due to the nature of agricultural production data, and was addressed by imposing a White's cross-section heteroscedastic structure on the error term in the original model. The cross-section SUR model allows for contemporaneous correlation between cross-sections. A feasible GLS specification was estimated and both cross-section heteroscedasticity and contemporaneous correlation was accounted for.

Table 6.6: Estimates of the quadratic revenue function: A SUR model

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

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

***1% level of significance, ** 5% level of significance, *10% level of significance.

The final SUR model, after correction for serial correlation and adjustment for heteroscedasticity, is summarized in Table 6.6. A high Adjusted R-squared value of 0.99 indicate that the SUR model represents a good fit to the data, supported by a significant F-statistic of 1661.25 (p-value = 0.00).

The slope coefficients for water, the composite factor and price are the same for all cross-sections (commodities) while the intercept differs for each of the commodities. We do not allow for variation in the slope of the marginal revenue function of water among commodities but we do allow for variation in the intercept of the commodities through the SUR model specification. From equation 6.1 it is now possible to calculate the marginal revenue for a specific year for each of the six agricultural commodities. Table 6.7 shows the calculated marginal revenue of water for each commodity for the years 1999 and 2002, but it can be calculated for any year in the sample of 1975 to 2002. These years were chosen because it is towards the end of the sample period and the values obtained for 1999 are comparable to the results of Olbrich and Hassan (1999).

Marginal revenue functions for each of the six cross-sections (commodities) were derived from the estimated revenue function. The marginal revenue function, equation 4.2 from chapter 4, is then:

$$MR_{it} = C_i - 8.57W_{it} + 0.18Comp_{it} + 4.23P_{it} \qquad (6.1)$$

The coefficient of W^2 (-4.29), which determines the slope of the marginal revenue function, is not only negative but also significant (t-statistic=-4.07). The coefficients of the interaction variables that contain W, which influences the intercept of the derived marginal revenue function of water, are all significant at the 5 percent level, and the combinations of these coefficients yield positive intercepts for each commodity. The slope coefficient of water for avocado and grapefruit were both insignificant even at a 10 percent level of significance and we concluded that these coefficients are not significantly different from zero.

Table 6.7: Marginal revenue and net terminal value of water

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

Source: Own summary

To compare the two studies we also ranked the commodities according to their marginal value of water from the most efficient commodity in water use relative to revenue generated to the least efficient commodity. Our results correspond largely to those obtained by Olbrich and Hassan (1999) who made use of a different method (net terminal value). The net terminal value represents the present worth at the end of the cycle or rotation of the stream of net benefits generated in future years (Olbrich and Hassan, 1999). Both studies found that mangoes are the most efficient agricultural commodity among the six commodities evaluated and sugarcane the least efficient. The shadow price of water or the opportunity cost of water in mango production for the year 1999 of R20.64/m³ is much higher than the forgone revenue in the sugarcane production of R2.67/m³ for the same year. The results are also similar to the study of Louw (2001) in the Berg River basin, where the marginal value of water ranges between R0/m³ and R20/m³. Louw (2001) also found tropical fruit to yield a higher marginal value of water than sugarcane.

A result obtained from our model that needs further explanation is the change in the ranks of banana and orange from the year 1999 to 2002. In 2002 bananas outperformed oranges with the marginal value of water equal to R8.25/m³ and R7.97/m³ respectively. In 1999 oranges (marginal revenue of water = R7.02/m³) is ranked more efficient than bananas (marginal revenue of water = R6.2/m³). Inspection of the raw data showed that the revenue in the orange production was 25.5 per cent higher in year 2002 than in 1999, whilst the revenue in the banana production grew by 20.1 per cent. The growth in the orange production can be contributed to growth in the overall output of 9.4 per cent as well as a price increase of 9.3 per cent. The overall production of bananas decreased by 8.3 per cent from 1999 to 2002 but a growth of 30.9 per cent in the price led to a net growth in the revenue. That said, it should be noted that, firstly, the magnitude of the difference between the marginal value of water for bananas and oranges is relatively small (25c/m^3 in 2002 and 82c/m^3 in 1999), and secondly, Olbrich and Hassan (1999) ranked bananas and oranges as equally efficient.

6.4 CONCLUSION

All the unit root tests on the panel data series rejected the null hypothesis of stationarity and were conclusive that all the variables were non-stationary. The McCoskey and Kao test for cointegration showed that there is at least one cointegrating relationship present in the data and panel data techniques were applied in the estimation of the revenue function. Tests for serial correlation were positive and the data was corrected for serial correlation and heteroskedasticity. The final model is a SUR model and marginal revenue functions were derived. The marginal revenue for each of the six agricultural commodities was calculated for the years 1999 and 2002 and compared to the results of Olbrich and Hassan (1999) and Louw (2001).

CHAPTER 7

CONCLUSION

7.1 RESTATING THE OBJECTIVE OF THE STUDY AND MAIN FINDINGS

The pressure on South Africa's limited water resources is both significant and increasing. To the extent that water pricing can be used to assist in the allocation of water between different uses and users, and to encourage the more efficient use of water and promote the sustainability of the water resource, water pricing policy is likely to be a very important element of an overall strategy seeking to manage the water resources in an equitable, efficient and environmentally sustainable manner.

Water availability is an important constraint to economic and social development, and will become even more so in the future if this scarce resource is not managed effectively. In order to manage this scarce supply of water, we need to value it. The main objective of this study is to estimate marginal revenue functions for each of the six commodities chosen. Once these functions have been estimated, the respective marginal revenues for each of the six commodities was estimated and compared with results of other studies. This study focused on the value of water in the agricultural sector, in particular the marginal revenue of water for six irrigation commodities namely avocados, bananas, grapefruit, mangoes, oranges and sugarcane. Comparing the marginal value of water for different commodities allow us to rank commodities according to their revenue efficiency relative to water use in and during the production processes. A quadratic production function was fitted with a SUR model specification in a panel data context from 1975 to 2002 to obtain marginal revenue functions for each of the six commodities.

We found that mangoes are the most efficient commodity in its water use relative to revenue generated (marginal revenue of water equals R25.43/m^3 in 2002) and sugarcane the least efficient (marginal revenue of water equals R1.67/m^3 in 2002). These results conform to other related studies. The marginal revenue values obtained differ significantly across commodities and emphasise that commodities are not equally efficient in their application of water in their production processes.

7.2 CONCLUDING REMARKS

The question now arises: what is the contribution of a study like this one, in which the value of water is estimated? The marginal revenue or the shadow price of water is not an indication of the true “market” price. Neither is it an indication what the administered price should be. It serves as a guideline for allocation policies, to determine the industries or commodities within an industry in which water can generate the largest revenue per unit of water input. It is also an indication of how market players might react to the presence of pricing strategies such as water markets. It is evident from the large spread in the forgone revenue between the mango and sugarcane industry that the mango industry would be able to bid away water from the sugarcane industry in a region where these two commodities compete for the same scarce water resource.

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

7.3 THE WAY FORWARD

Further research on measuring the value of water using farm-level data instead of aggregated data for South Africa will be meaningful. Expanding the database to include region specific information will allow us to evaluate the impact of water strategy reforms on different regions. The revenue function estimated in this study could be refined in order to capture the capital input factor using separate variables for labour costs, fixed capital costs and variable costs. The disadvantage of the methodology employed in this study is that it does not account for social costs such as employment, equity or fairness but only address the goal of efficient water use. Further research that are geared to evaluate the value of water incorporating more of the objectives set out in the National Water Act of 1998 will proof to be invaluable.

REFERENCE LIST

Armitage, R.M. 1999. *An Economic Analysis of Surface Water Rights Transfers in selected areas in South Africa*. WRC Report 870/1/99.

Baltagi, B.H. 2001. *Econometric Analysis of Panel Data. Second Edition.* John Wiley And Sons, New York.

Bannock, G., Baxter, R.E. and Davis, E. 1998. *The Penguin Dictionary of Economics. Sixth Edition.* London: Penguin Books.

Bate, R., Tren, R. and Mooney, L. 1999. *An Econometric and Institutional Economic Analysis of Water Use in the Crocodile River Catchment, Mpumalanga Province, South Africa.* WRC Report No 855/1/99.

Blignaut, J.N. and De Wit, M.P. 2004. *Sustainable Options. Development Lessons form Applied Environmental Economics*. Cape Town: UCT Press.

Conradie, B. 2002. *The Value of Water in the Fish-Sundays Scheme of the Eastern Cape*. WRC Report No. 987/1/02.

Department of Agriculure. 2004. *Abstract of Agricultural Statistics*. The Directorate: Agricultural Statistics of The National Department of Agriculture. Http://Www.Nda.Agric.Za/ (Access November 2004).

Department of Water Affairs and Forestry. 2002. *National Water Resource Strategy:* First Edition, Pretoria. DWAF.

Dinar, A. and Subramainian, A. 1998. Policy Implications from Water Pricing experiences in various countries. *Water Policy* 1: 239-50.

Elberhard, R. 1999. *Suppy Pricing of Urban Water in South Africa.* Volume 2. WRC Report 678/2/99.

Faux, J. and Perry, M. 1999. Estimating Irrigation Water Value using Hedonic Price Analysis: A Case Study in Malheur County, Oregon. *Land Economics* 75(3): 440-52.

Grimble, R.J. 1999. Economic Instruments for Improving Water Use Efficiency: Theory and Practice. *Agricultural Water Management* 40:77-82.

Harris, D. and Inder, B. 1994. A Test of the Null Hypothesis of Cointegration. In Hargreaves, C. (ed.) *Non-stationary Time Series Analysis and Cointegration.* Oxford University Press. Oxford. 133-152.

Huffman, W.E. 1988. An Econometric Methodology for Multiple-Output Agricultural Technology: An Application of Endogenous Switching Models. *Agricultural Productivity*. Washington: Resources for The Future.

Im, K.S., Peseran, M.H. and Shin, Y. 1997. *Testing for Unit Roots in Heterogeneous Panels. Mimeo*. Department of Applied Economics, University of Cambridge.

Just, R.E., Zilberman, D. and Hochman, E. 1983. Estimation of Multicrop Production Functions. *American Journal of Agricultural Economics* 65(Nov): 770-80.

Just, R.E., Zilberman, D., Hochman, E. and Z. Bar-Shira. 1990. Input Allocation in Multicrop Systems. *American Journal of Agricultural Economics 72*(Jan): 200-9.

Levin, A. and Lin, C.F. 1993. Unit Root Tests in Panel Data: New Results. *Discussion Paper*. *Department of Economics, University of California*, San Diego. 93-56.

Louw, D.B. 2001. *The Development of a Methodology to Determine the true Value of Water and the Impact of a Potential Water Market on the Efficient Utilization of Water in the Berg River Basin.* WRC Report No. 943/1/02.

Maddala, G.S. and Wu, S. 1999. A Comparative Study of Unit Root Test with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics.* Special Issue, 631-652.

Marais, C., Turpie, J., Mullins. D, Conradie, B., Khan, A., Goldin, J., Van Zyl, H., Grobbelaar, E., Vink, N. and Ndzinge, V. 2001. *A Cost Benefit Analysis framework for the National Working for Water Programme.* Sega (34) Socio-economic evaluation of Working for Water projects. Nathan Associates Inc.

McCoskey, S. and Kao, C. 1998. A Residual-Based Test of the Null of Cointegration in Panel Data. *Econometric Reviews* 17: 57-84.

McCoskey, S. and Kao, C. 1999. Testing the stability of a production function with urbanization as a shift factor. *Oxford Bulletin of Economics and Statistics. Special Issue.*

Moore, M.R. 1999. Estimating Irrigators' Ability to Pay for Reclamation Water. *Land Economics* 75(4): 562-78.

Moore, M.R. and Dinar, A. 1995. Water and Land as Quantity-Rationed Inputs in California Agriculture: Empirical Tests and Water Policy Implications. *Land Economics* 74(4): 445-61.

Nieuwhoudt, W.L., Backeberg, G.R. and Du Plessis, H.M.. 2004. The Value Of Water In The South African Economy: Some Implications. *Agrekon* 43(2): 162-83.

Olbrich, B.W. and Hassan, R. 1999. *A Comparison of the Economic Efficiency of Water Use of Plantations, Irrigated Sugarcane and Sub-Tropical Fruits. A Case Study of the Crocodile River Catchment, Mpumalanga Province.* WRC Report No. 666/1/99.

RSA. 1998. *National Water Act (No. 36 Of 1998*). Establishment of Pricing Strategy for Water Use Charges in Terms of Section 56(1) of The National Water Act, 1998. Department of Water Affairs and Forestry. Government Gazette 201615, 12 November 1999.

APPENDIX 1

FIXED EFFECTS MODELS

A1.1 Within model

Table A1.1 Results of Within specification

Dependent Variable: R?
Method: Pooled Least Squares
Sample: 1975 2002
Included observations: 28
Cross-sections included: 6
Total pool (balanced) observations: 168
White cross-section standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
P?	92.49091	26.32464	3.513473	0.0006
COMP?	-58.76026	28.31732	-2.075064	0.0397
W?	276.7781	2134.328	0.129679	0.8970
P?^2	-0.043670	0.008340	-5.236377	0.0000
COMP?^2	0.001315	0.000643	2.043692	0.0427
P?*COMP?	0.023764	0.007278	3.265237	0.0013
P?*W?	1.955535	0.693953	2.817964	0.0055
COMP?*W?	-0.028662	0.086119	-0.332817	0.7397
W?^2	3.319468	4.505127	0.736820	0.4624
C	102353.8	66363.65	1.542317	0.1251
Fixed Effects (Cross)				
_ADV--C	-91773.51			
_BAN--C	-100774.2			
_GRF--C	-64972.64			
_MAN--C	-70482.09			
_ORA--C	326842.8			
_SUC--C	1159.634			

Effects Specification

Cross-section fixed (dummy variables)

R-squared	0.927335	Mean dependent var	177825.2
Adjusted R-squared	0.920686	S.D. dependent var	277793.4
S.E. of regression	78234.18	Akaike info criterion	25.45785
Sum squared resid	9.36E+11	Schwarz criterion	25.73677
Log likelihood	-2123.459	F-statistic	139.4684
Durbin-Watson stat	0.475854	Prob(F-statistic)	0.000000

A1.2 Least square dummy variable model

Table A1.2: Results of LSDV specification

Dependent Variable: R?
Method: Pooled Least Squares
Sample: 1975 2002
Included observations: 28
Cross-sections included: 6
Total pool (balanced) observations: 168
White cross-section standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
P?	92.49091	26.32464	3.513473	0.0006
COMP?	-58.76026	28.31732	-2.075064	0.0397
W?	276.7781	2134.328	0.129679	0.8970
P?^2	-0.043670	0.008340	-5.236377	0.0000
COMP?^2	0.001315	0.000643	2.043692	0.0427
P?*COMP?	0.023764	0.007278	3.265237	0.0013
P?*W?	1.955535	0.693953	2.817964	0.0055
COMP?*W?	-0.028662	0.086119	-0.332817	0.7397
W?^2	3.319468	4.505127	0.736820	0.4624
_ADV--C	10580.28	45446.50	0.232807	0.8162
_BAN--C	1579.638	43012.35	0.036725	0.9708
_GRF--C	37381.15	11829.82	3.159908	0.0019
_MAN--C	31871.70	9158.836	3.479885	0.0007
_ORA--C	429196.5	101144.7	4.243392	0.0000
_SUC--C	103513.4	274568.0	0.377005	0.7067

R-squared	0.927335	Mean dependent var	177825.2
Adjusted R-squared	0.920686	S.D. dependent var	277793.4
S.E. of regression	78234.18	Akaike info criterion	25.45785
Sum squared resid	9.36E+11	Schwarz criterion	25.73677
Log likelihood	-2123.459	F-statistic	139.4684
Durbin-Watson stat	0.475854	Prob(F-statistic)	0.000000

APPENDIX 2

HYPOTHESIS TESTING

A2.1 TESTING FOR SERIAL CORRELATION

It is imperative that we test for the presence of serial correlation in our estimation results. Ignoring serial correlation when it is present will cause the estimators to be consistent but inefficient with biased standard errors.

A2.1.1 Durbin-Watson test for serial correlation

The panel data Durbin-Watson test (DW test) is an extension of the time-series DW test. The null hypothesis of no serial correlation is tested against the alternative of positive serial correlation as indicated in equation A2.1.

$$\begin{aligned} H_0 &: \rho = 0 \\ H_A &: |\rho| < 1 \end{aligned} \qquad \text{(A2.1)}$$

The test statistic is calculated as follows using the residuals of the *within* model rather than the OLS residuals.

$$d_\rho = \sum_{i=1}^{N}\sum_{t=2}^{T}\left(\tilde{v}_{it} - \tilde{v}_{i,t-1}\right)^2 / \sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{v}_{it}^2 \qquad \text{(A2.2)}$$

where $\tilde{v}$ is a vector of stacked *within* residuals.

As in the time-series case, the Panel data DW test statistic do not follow a well-known distribution and critical values (an upper (du) and lower (dl) critical value) must therefore be calculated. For large values of N, a d_ρ smaller than 2 indicates positive serial correlation.

A2.1.2 LM test for first order serial correlation

The LM test for first order serial correlation given fixed effects is constructed under the null and alternative hypothesis as follows.

$$
\begin{aligned}
&H_0 : \rho = 0, \text{given that } \mathrm{u_i} \text{ are fixed parameters} \\
&H_A : \rho > 0
\end{aligned}
\tag{A2.3}
$$

The null hypothesis states that the pooled correlation coefficient ρ is zero, which implies that the errors are uncorrelated over time for all cross-sections. This specific test for first order serial correlation has the advantage over the DW test in that the distribution of the test statistic is known and critical values need not be calculated. The test statistic is calculated using the *within* residuals implying that the test is applicable for both the fixed and random effects models, since the individual cross-section effects are effectively wiped out by the model specification.

$$
\mathrm{LM} = \sqrt{\frac{NT}{(T-1)}}\left(\tilde{v}'\tilde{v}_{-1} / \tilde{v}'\tilde{v}\right) \sim N(0,1) \tag{A2.4}
$$

The LM test statistic is normally distributed and once again the null hypothesis of no serial correlation will be rejected if the test statistic exceeds the appropriate normal critical value.

A2.1.3 Joint LM test for serial correlation and random individual effects

This null hypothesis of no first order serial correlation and no random effects are tested against the alternative of either serial correlation or random effects.

$$
\begin{aligned}
&H_0 : \sigma_\mu^2 = 0, \lambda = 0 / \rho = 0 \\
&H_A : \text{Both not equal to zero}
\end{aligned}
\tag{A2.5}
$$

When testing if the disturbance term follow a MA(1) process, test if $\lambda = 0$ under the null hypothesis and when testing if the disturbance term follow a AR(1) process, test if $\rho = 0$ under the null hypothesis.

The LM test statistic under the null hypothesis follows a chi-squared distribution with 2 degrees of freedom.

$$\mathrm{LM} = \frac{NT^2}{2(T-1)(T-2)}\left[A^2 - 4AB + 2TB^2\right] \sim \chi_2^2 \qquad \text{(A2.6)}$$

where $A = \left[\hat{u}'(\mathrm{I}_N \otimes J_T)\hat{u}/(\hat{u}'\hat{u}) - 1\right]$, $B = \hat{u}'\hat{u}_{-1}/\hat{u}'\hat{u}$ and $\hat{u}$ is the OLS residuals.

The null hypothesis is rejected if the LM test statistic exceeds the $\chi_2^2 = 5.99$.

A2.2 TESTING FOR HETEROSKEDASTICITY

The standard error component model given by equation 5.2 assumes that the regression disturbances are homoskedastic with the same variance across time and cross-sections. Assuming homoskedastic disturbances when heteroskedasticity is present will still result in consistent estimates of the regression coefficient, but these estimates will not be efficient. Also, the standard errors of these estimates will be biased unless one computes robust standard errors correcting for the possible presence of heteroskedasticity. If we consider the error term in equation A2.7 we can see that heterokedasticity can be generated by the remainder of disturbance ν_{it} in both the fixed and random effects models and that the error variance could change between time periods and cross-sections.

$$\mathrm{u}_{it} = \mu_i + \nu_{it} \qquad \text{(A2.7)}$$

$$\nu_{it} \sim IID(0, \sigma_i^2)$$

The hypothesis for the testing of heteroskedasticity is

$$H_0 : \sigma_i^2 = \sigma^2 \text{ for all i} \qquad H_A : \sigma_{\mathrm{i}}^2 \neq \sigma^2 \text{ for all i} \tag{A2.8}$$

The LM test is

$$\mathrm{LM} = \frac{T}{2}\sum_{i=1}^{N}\left[\frac{\hat{\sigma}_i^2}{\hat{\sigma}^2} - 1\right]^2 \sim \chi_{N-1}^2 \tag{A2.9}$$

where $\hat{\sigma}_i^2 = \frac{1}{T}\sigma_i^2$ and $\hat{\sigma}^2 = \frac{1}{NT}\sigma^2$

If the null hypothesis of homoskedasticity is true, the $\frac{\hat{\sigma}_i^2}{\hat{\sigma}^2}$ ratios should approximate unity and the test statistic should be very small. The null hypothesis will be rejected if the LM test statistic is larger than the chi-square critical value with N-1 degrees of freedom.

APPENDIX 3

A3.1 UNIT ROOT AND COINTERGRATION TESTS FOR PANEL DATA

A3.1.1 Introduction

Panel data can solve some of the shortcomings of pure time-series or pure cross-sectional data but at the cost of introducing a new issue namely how homogenous is the panel? Previous panel data tools did not deal with the possibility of non-stationarity. With large N and large T macro panels, non-stationarity deserves more attention. Some of the distinctive results that are obtained with non-stationary panels are that many test statistics and estimators of interest have normal limiting distributions (Baltagi, 2001). This is in contrast to the non-stationary time-series literature where the limiting distributions take on complicated functional forms. Several unit root tests applied in the time-series literature have been extended to panel data. The main difference between specific unit root tests for panel data is the degree of heterogeneity that the tests allow between different cross-sections.

The most widely used panel unit root tests are those developed by Levin and Lin (1993), Im, Peseran and Shin (1997) and Maddala and Wu (1999).

A3.1.2 Levin and Lins's LL test

Levin and Lin (1993), considered a stochastic process $\{\mathrm{y}_{\mathrm{it}}\}$ for i = 1,…,N and t = 1,…,T which can be generated by one of the following three models:

$$\Delta \mathrm{y}_{\mathrm{it}} = B_i \mathrm{y}_{\mathrm{it-1}} + \varepsilon_{it} \qquad \text{(A3.1)}$$

$$\Delta \mathrm{y}_{\mathrm{it}} = \alpha_i + B_i \mathrm{y}_{\mathrm{it-1}} + \varepsilon_{it} \qquad \text{(A3.2)}$$

$$\Delta \mathrm{y}_{\mathrm{it}} = \alpha_i + \delta_i t + B_i \mathrm{y}_{\mathrm{it-1}} + \varepsilon_{it} \qquad \text{(A3.3)}$$

where $\Delta \mathrm{y}_{\mathrm{it}}$ follows a stationary ARMA process for each cross-section unit and $\varepsilon_{it} \sim IID(0, \sigma^2)$

The null and alternative hypothesis can be specified as

$$\begin{aligned} &H_0 : B_i = 0 \text{ for all i} \\ &H_A : B_i < 0 \text{ for all i} \end{aligned} \qquad \text{(A3.4)}$$

The test requires B_i being homogenous across cross-sections. The null hypothesis that all the series in the panel are generated by a unit root process are tested against the alternative that not even one of the series is stationary. The test has a standard normal distribution.

A3.1.3 Im, Pesaran and Shin's test (IPS test)

This test allows for more heterogeneity. Im, Peseran and Shin constructed a panel test, first on a Dickey Fuller (DF) test, and then on an Augmented Dickey Fuller (ADF) test:

$$\Delta y_{i,t} = \rho y_{i,t-1} + \sum_{j=1}^{p_i} \theta_{i,j} \Delta y_{i,t-j} + \alpha_i + \varepsilon_{i,t} \qquad \text{where t=1,…T.} \qquad \text{(A3.5)}$$

The null and alternative are then specified as:

$$\begin{aligned} &H_0 : p_i = 0 \text{ for all i} \\ &H_A : p_i < 0 \text{ for at least one cross - section} \end{aligned} \qquad \text{(A3.6)}$$

The IPS test, tests the null hypothesis of a unit root against the alternative of stationarity and allows for heterogeneity, which is not allowed in the Levin and Lin test.

The final test statistic can be constructed by equation A3.7:

$$\bar{z} = \frac{\sqrt{N}\left[\bar{t}_{NT} - a_{NT}\right]}{\sqrt{b_{NT}}} \sim N(0,1) \qquad \text{(A3.7)}$$

where $\bar{t}_{NT}$ is the average ADF test statistic of all the individual cross-section test statistics, a_{NT} and b_{NT} are the means and variances that must be computed based on Monte Carlo simulated moments provided by Im *et al.* (2003).

A3.1.4 Maddala and Wu's Fisher test

Maddala and Wu (2000) concentrated on the shortcomings of the Levin and Lin test and the IPS test. They allow for different first-order autoregressive coefficients and test the null of non-stationarity (similar to IPS), but also tests for a unit root without including a trend or intercept.

$$\mathrm{P}(\lambda) = -2\sum_{1=1}^{\mathrm{N}} \ln(\pi_{\mathrm{i}}) \qquad \text{(A3.8)}$$

where π_i is the p-value of the ADF test statistic for cross-section i. The Fisher test statistic (A3.8) follows a chi-square distribution with 2N degrees of freedom.

A3.2 PANEL DATA COINTERGRATION TEST

A3.2.1 McCoskey and Kao test

The null hypothesis of cointegration is tested against the alternative of no cointegration.

H_0 : Cointegration

H_A : No cointegration

The residual-based test for cointegration comes from McCoskey and Kao (1998) and is constructed from the partial sums of the estimated residuals of a regression equation of non-stationary variables. It is a panel data version of the LM-statistic proposed by Harris and Inder (1994).

The test is given as:

$$L\overline{M} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(1/T^2)\sum_{t=1}^{T} S_{i,t}^{+2}}{\hat{\varpi}_{i1.2}^{2}}\right) \qquad \text{(A.3.9)}$$

where $S_{i,t}^{+} = \sum_{j=1}^{t}\hat{u}_{i,j}$ is the partial sum of the residuals, and the residuals, $\hat{u}_{i,t}$ can be estimated using fully modified (FM) estimation or dynamic OLS (DOLS). The test is combining evidence form averaging the LM-statistic across the cross-sections.

$$LM^{+} = \frac{\sqrt{N}(L\overline{M} - \mu_v)}{\sigma_v} \sim N(0,1) \qquad \text{(A.3.10)}$$

The final test statistic is a one-sided test, upper tail distribution, indicating that large values of the statistic correspond to estimating non-stationary residuals and will result in a rejection of the null hypothesis of cointegration (McCoskey and Kao, 1999: 676).