Estimating the Marginal Value of Agricultural Irrigation Water

A Methodology and Empirical Application to the Berg River Catchment

Submitted in partial fulfilment of the degree of Masters of Commerce specialising in Economic Science

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Abstract: This study aims to facilitate effective and efficient intersectoral water allocation policy in South Africa, where limited water supplies are increasingly constraining necessary economic development. The study develops an economic model of irrigated agricultural production that recognises the multi-output nature of irrigated agriculture as well as the institutional setting in which commercial irrigation water is allocated in South Africa. This model is then used to econometrically estimate the marginal value of commercial irrigation water in the Berg Water Management Area (WMA), using a Translog functional form, Tobit censored regression model, including controls for heterogeneity, and accounting for heteroscedasticity. The estimates are obtained for 16 irrigated crops in the region and range from an overall mean of 4.84 R/m^3 for peaches to 0.14 R/m^3 for wheat, but vary significantly between sub-regions and according to soil productivity as well as between crops. Furthermore, the estimates differ substantially from the average value of production per m^3 of irrigation water, reflecting a revenue-water elasticity that differs from unity for all crops. The results imply that there exist potential efficiency gains through the intersectoral reallocation of water away from agriculture. A further implication is that reallocation within the agricultural sector would be most efficiently undertaken by farmers themselves, due to the large number factors that affect irrigation water productivity but are unobservable by policymakers or are difficult to account for in the formulation of policy.

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Introduction

Water as a Constraint on Economic Development

The approaching limit to readily available water resources for household, industrial and agricultural users in South Africa is placing a constraint on economic development for the country as the processes of industrialisation, urbanisation and population growth continue. At a national level, South Africa already uses over 30 percent of its available freshwater resources; at 40 percent, it will likely reach the limit for the economical exploitation of this resource (Muller, 2013, p.7). At a regional level, around 50 percent of the major South African supply schemes were in water balance deficit in 2012. Furthermore, inter-sectoral competition for water supply has begun to increase as demand from industry and urban users grows, and as options to augment supply to meet growing demand become more difficult and costly. Yet, in the presence of this natural resource constraint, there is a national drive to stimulate growth in the economy to alleviate poverty, reduce inequality and increase the welfare of citizens (National Planning Commission, 2011). For the country to proceed down a path of sustainable and inclusive economic growth, both water and economic policy must adapt to reflect the changing dynamics in water resource availability and demand.

This is exemplified in the Berg Water Management Area (Berg WMA), where limited water supplies are placing a forcing difficult economic trade-offs. Specifically, the National Development Plan (NDP) has identified Saldanha Bay as an area of strategic economic growth and infrastructure development through an Industrial Development Zone (IDZ), including a port and industrial hub. The planned developments in Saldanha Bay are expected to generate much needed economic growth and job creation in Saldanha Bay and surrounding areas, but will lead to increased demand for water. Saldanha Bay, however, draws its fresh-water supplies from the Berg WMA, in which all readily available water has already been fully allocated to existing users.

Policy Disconnect

Despite the constraint being placed on economic development by constrained water supplies, there currently exists a general disconnect between the planning for water resources and economic development in South Africa. Both tend to treat the other as exogenous factors in their planning process, and this can lead to conflict between policymakers and stakeholders (GreenCape, 2015). The failure to recognise the dependence of economic development on water resources, and the resulting failure to coordinate economic and water policy, leads to the inefficient allocation of scarce water supplies. If not addressed, this is likely to increase the constraint water places on economic development and poverty alleviation in the future.

In the Berg WMA, the policy disconnect has resulted in local planners in Saldanha Bay favouring water resource interventions that are not supported by national government, nor by industry. The local municipality in Saldanha Bay has proposed a desalination plant to augment water supply – a proposal not supported the Department of Water and Sanitation (DWS) nor local industry (GreenCape, 2015). In addition, there has been no investigation into the full costs and benefits of potential policy interventions.

The result of the disconnect between water resources and economic development planning, as well as increasing fiscal constraints for both local and national government, is that the development of additional water supply infrastructure to supply the Berg WMA is likely to be preceded by an increase in water demand from the planned developments of the Saldanha Bay IDZ. In the short- to medium-term, water demand in Saldanha Bay will exceed water supply and this may result in economic development being constrained in the area (GreenCape, 2016).

Policy and Economic Principles

In a situation of a fixed water supply constraint and intense competition for water, an important objective of water allocation policy is to allocate the available water resource to those agricultural, residential, industrial, recreational or environmental, and other uses in such a way as to make the most productive use of water available for these purposes (Ward & Michelsen, 2002). Specifically, the economically efficient allocation of water occurs when the marginal benefit from the use of water is equal across users, or sectors (Dinar, Rosegrant & Meinzen-Dick, 1997, p.4). If not, the allocation will not be Pareto efficient, since society would benefit by allocating water to those uses that generate the highest marginal benefit from water, up to the point where the marginal benefit is equal to the marginal benefit in alternate uses. In terms of water policy, this implies that policies will improve economic efficiency when they reallocate water between users if the marginal benefit gained by the gainer exceeds the marginal benefit lost by the loser. In other words, the marginal benefit should exceed the opportunity cost of the reallocation.

The objective of achieving economically rational water policy is set out in in the National Water Act (1998), which recognises the need to establish suitable institutions to protect social and economic development through the use of water. Specifically, Catchment Management Agencies (CMAs) are established under the Act and tasked with designing allocation strategies for each major catchment in South Africa (*National Water Act No. 36,* 1998, Chapter 7). These allocation strategies must consider the “efficient and beneficial use of water in the public interest” as well as the “socio-economic impact” of water allocation decisions (*National Water Act No. 36,* 1998, Section 27).

In the short-term, it may be economically rational to meet the water demands of the Saldanha Bay IDZ through a reallocation of existing supply in the Berg WMA. The National Water Act (1998) sets the legal framework through which policymakers could implement such a reallocation of water resources. In the context of the Berg WMA and the proposed Saldanha Bay IDZ, two provisions in the Act are particularly relevant. First, the reallocation of water supply between existing and new water users is possible in regions experiencing water stress, such as the Berg WMA, through a process called “compulsory licensing” (*National Water Act No. 36,* 1998, Chapter 4). Second, priority is given to “water use of strategic importance” in the Act (*National Water Act No. 36,* 1998, Section 6-1) This implies that water can allocated to strategic projects, such as the Saldanha Bay IDZ, before the remaining supply is allocated between other municipal, industrial and agricultural users.

Such a reallocation will only be a *Pareto improvement* if the marginal benefit of the water transferred to the Saldanha Bay IDZ is greater than, or equal to, to opportunity cost of the transfer. Furthermore, if such a reallocation is to result in a welfare improvement, the water will need to be reallocated at the minimum possible opportunity cost – that is, from the existing water uses in the Berg WMA that generate the lowest marginal benefit from water use. In sum, policymakers will need to decide whether it is optimal to meet the demands of the Saldanha Bay IDZ through reallocation, and if so, how the reallocation should occur so as to minimise the opportunity cost of the reallocation.

In the longer-term, the decision on whether to invest in supply augmentation infrastructure for the purposes of supplying the IDZ should also be guided by economic efficiency criteria. Thus, the marginal cost of supplying water through an augmentation project (such as a desalination plant) will need to be less than, or equal to, the lowest marginal benefit from water generated by existing users in the Berg WMA. If this condition is not satisfied, then it will be optimal to instead meet the water requirements of the IDZ by reallocating existing supply at the minimum opportunity cost.

It follows that a necessary condition for policymakers in the Berg WMA to make short- and long-term water supply and allocation decisions is knowledge of the minimum water opportunity cost of the Saldanha Bay IDZ. If well-functioning markets for water existed, policymakers would be able to use the market price for water as representation of its marginal value - a hypothetical well-functioning water market would allocate water resources to activities yielding the greatest marginal benefit for water, and the price paid for water would also represent the marginal value of water in that use.[1] However, since there are high costs associated with capturing and holding water and water supply is subject to a regular stream of unexpected changes, it is typically expensive or impossible to define, establish and enforce the property rights required for a well-functioning water market (Ward, 2007). As such, well defined institutions that could serve to efficiently allocate water are typically lacking; this is the case in South Africa where commercial agricultural water is institutionally allocated. Since price provides a poor guide to the marginal value of water in the absence of effective markets, policymakers must base policy decisions on an estimate of the marginal value of water to alternate users in a given catchment.

Sectoral Focus

The *a priori* expectation is that an economically rational reallocation of water supplies in the Berg WMA is likely to result from a reallocation of water away from the agricultural sector and towards industrial users, such as those in the Saldanha Bay IDZ. This expectation is primarily guided by estimates of the value of water in different sectors from previous studies, presented in *Tables 1* and *2*. The estimates suggest that the Industrial sector generates the greatest benefit from water use, followed by eco-tourism, mining and municipal use, whilst agriculture appears to generate the lowest marginal benefit from water use according to estimates by Conradie (2002), Williams *et al.* (2008), and Coningarth Consultants (2001) amongst others. Furthermore, agriculture is

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[1] This is a result of the assumption that a rational agent would purchase additional water until its marginal cost (price) equals its marginal benefit

the largest sectoral user of water - using 60 percent of the total national allocation (Department of Water Affairs, 2013). Thus, a small proportional reallocation of agricultural water would result in a large absolute reallocation of water supply. This suggests that a water reallocation policy in the Berg WMA should focus on the agricultural sector as the source of reallocation, as the largest and least efficient water user in the region.[2]

In addition, the estimates in *Table 2* suggest that the value of agricultural water varies considerably between studies and regions. Thus, policymakers in the Berg WMA should make use of estimates of the marginal value of irrigation water derived from a local study if the estimates are to be accurate and reliable. Furthermore, within regions the range of estimates is also large - in the Berg WMA, Louw (2002) estimates that the value of irrigation water can range between 0 to 5.99 R/m^3, with a median value of 0.48 R/m^3, at 2015 price levels. The variability in water values may be due to differences in crops grown, to differences in soil, or climatic conditions, to farming and irrigation practices, or some combination of these factors. A reallocation policy therefore requires an understanding of the sources and implications of this variation in the marginal benefit of water within the agricultural sector if a reallocation of agricultural water is to be economically optimal.

Table 1: **Water Value Estimates for Non-agricultural Sectors**

Study	*Sector*	*Method*	*Type of Estimate*	*Estimate (R/m^3)*	*2015 Price Level* [a]
Conradie (2002)	Municipal	Demand Function	Marginal Value	2.4	5.71
Williams *et al.* (2008)	Municipal	Contingent Valuation	Willingness to Pay	2.22	3.29
Coningarth Consultants (2001)	Industrial	Input/Output	Average Value	157.4	340.57
	Mining	Input/Output	Average Value	39.5	85.25
	Eco-Tourism	Input/Output	Average Value	44.4	96.07

[a] For comparability, original estimates are inflated to 2015 price level using the Consumer Price Index

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[2] It is worth noting, however, that the estimates presented do not account for the full value chain of output from the various industries. Accounting for these multiplier effects will likely result in higher marginal benefit estimates for water across the sectors.

***Table 2:* Agricultural Irrigation Water Value Estimates from Previous Studies**

Study	Area	Method	Type of Estimate	Estimate (R/m^3)	2015 Price Levels [a]
Conradie (2002)	Fish-Sundays River Scheme	Linear Programming	Marginal Value	0 - 0.35	0 - 0.82
Louw (2001)	Berg River Basin	Positive Mathematical Programming	Marginal Value [b]	0 - 2.52	0 - 5.99
Williams *et al.* (2008)	Letaba River Catchment	Contingent Valuation Method	Willingness to Pay/Marginal Value	0.86	1.28
Hosking *et al*. (2002)	Tsitsikamma Catchment	Contingent Valuation Method	Willingness to Pay/Marginal Value	0.125	0.29
Olbricht and Hassan (1999)	Crocodile River Catchment	-	Net Terminal Value	1 - 10.9	2.56 - 27.95
Hassan (2003)	Mpumalanga	Quasi-Input-Output	Direct Value Added	0.92 - 2.76	2.35 - 7.08
Conningarth Consultants (2001)	South Africa	Input-Output	Average Value	1.5	3.25

[a] For comparability, original estimates are inflated to 2015 price level using the Consumer Price Index

[b] Louw (2001) reports capitalised marginal values. Reported estimate is annual marginal value based on authors own calculations and 20 year horizon and a discount rate of 13%, as used by Louw (2001)

Objectives

This study forms one portion of a broader research project entitled *Towards Sustainable Economic Development in Water Constrained Catchments.* The aims of this broader project are to develop a policy planning approach that recognises the interdependency of economics and water resources, to conduct a cost-benefit analysis of proposed economic developments and water resource interventions relating to the Saldanha Bay IDZ, and build a hydro-economic model to manage regional water allocation in the Berg WMA - with the intention that the processes and outcomes from the research project can be applied in other constrained catchments in South Africa.

The purpose of this study is to contribute towards the economic analysis undertaken in the broader WRC research project. In line with this purpose, the objectives of the study are threefold. First, the study aims to establish the marginal value of agricultural water in the Berg WMA. Recognising the heterogeneity of previous estimates, the study will aim to estimate separate values of irrigation water for the major irrigated crops in the region as well as to incorporate location-specific heterogeneity into the estimates. The estimates will serve to guide policymakers in making economically rational intrasectoral water reallocation decisions.

The second objective of the study is to develop an econometric basis for estimating the marginal value of water to agriculture in constrained catchments in South Africa. The methodology is therefore developed so as to allow similar studies to be conducted in other regions using the model and methods of this study.

Third, the study aims to advance and facilitate a push for public policy that efficiently allocates scarce water resources and minimises the constraint on economic development imposed by limited water resources. This requires that policy surrounding economic development and water resources are taken in accordance with economic principles of efficiency and Pareto optimality and may require the consideration of policies that encourage the intersectoral reallocation of existing water supplies.

Methodology

Introduction

When water is an intermediate good in production, the demand for water is derived from its use in producing a final product. In agricultural production, the marginal economic benefit of water allocated to irrigation is quantified as the change in the value of agricultural products less changes in associated production costs. Therefore, methods that value irrigation water typically involve measuring the response of agricultural production due to a change in irrigation water applied (Ward & Michelsen, 2002, p.435). In order to accurately measure this relationship, it necessary to account for any factors that might have an independent effect on agricultural production. These include the levels of other inputs such as cropland, fertilizer and pesticides, and farm labour and capital. They further include conditions under which production takes place such as soil fertility, climate, production intensity and other management practices, and institutional settings and market conditions.

In order to meet the objectives of this study, two methodological considerations must be acknowledged. First, if the methodology of the study is to be adapted and applied in other water constrained catchments in South Africa, the methodology must make use of publicly-available data or data that is generated in the broader WRC research project. The most comprehensive source of publicly available data on agricultural production is the Census of Commercial Agriculture, conducted periodically by Statistics South Africa. The census reports annual figures on crop-level production values and area of planted cropland for irrigated agriculture at a regional level. However, the census does not report crop-level figures for other production inputs. Additionally, as part of the WRC research project, crop-level irrigation water requirements have been estimated for regions constituting the Berg WMA. Thus, the methodology is limited to estimation using two agricultural inputs - area of planted cropland and irrigation water requirements, a proxy for actual irrigation use

Second, according to the National Water Act (1998), commercial agricultural irrigation water is controlled through institutionally issued water licenses, which specify a quota of irrigation water that an agricultural entity may extract in a given period. The price charged for this irrigation water is institutionally determined, and is charged on the basis of the agricultural entity's licensed quota rather than the amount of irrigation water actually used. As such, commercial irrigation water in South Africa is not price-rationed, since it represents a fixed cost to an agricultural producer. Furthermore, quotas on irrigation water impose farm-level water constraints on irrigated agricultural production in South Africa.

A Model of Irrigated Agricultural Production

Agricultural producers engaged in irrigated production are required to make a variety of production decisions, including crop-choice, land allocation, and irrigation water application. Farmers engaged in irrigated agriculture are typically multi-output producers: they choose from a set of irrigated crops commonly grown in the region, and generally grow two or more crops, but not necessarily all crops in the choice set. In addition to a discrete choice on the set of irrigated crops to produce, the producer must decide on the quantity of cropland to allocate to each of these crops. These decisions are modelled as relatively long-run decisions, since they are either impossible or prohibitively costly to alter within a production season (Moore, Gollehon & Carey, 1994, p.860).

In addition to the crop-choice and land allocation decisions, the producer must make crop-level irrigation water application decisions; these decisions are conditional on the crop-choice and land allocation decisions. Additionally, crop-level irrigation is supplementary in most cases and, therefore, responds to short-run climatic conditions over the growing season. Thus, the irrigation water application decision is a short-run decision made within the irrigation season. As such, the appropriate model for analysing the relationship between agricultural production and irrigation water application is that of short-run multi-output production (Just et al., 1990; Moore, Gollehon & Carey, 1994; Moore, Gollehon & Carey, 1994).

Basic Assumptions

The model applies the theory of a multi-output competitive firm to an agricultural entity engaged in irrigated production. The agricultural producer is assumed to maximise multi-output short-term restricted profits within the irrigation season by optimally allocating variable inputs across all irrigated crops grown (Just et al., 1990). Inputs are assumed to be technically non-joint in production; this assumption implies that there is no technological interdependence between crops and enables the characterization of crop-level production and profit functions (Shumway, Pope & Nash, 1984, p.73). Finally, agricultural producers are assumed to be perfectly competitive, and therefore price takers in both input and output markets. Therefore, farmers optimise production decisions conditional on exogenous expected input and output prices.

Composite Input

In the short-run, crop-level irrigated production is largely determined by the quantity of crop-land with irrigation infrastructure allocated to that crop. Following the approaches of Moore (1999), Just *et al* (1983) and Just *et al.* (1990) among others, the crop-level land allocation is modelled as a composite input. The composite input is assumed to be composed of land, capital, and variable inputs (other than irrigation water).

The assumption that cropland represents a composite input is based on the hypothesis that farmers make short-run decisions around variable inputs in accordance with *satisficing behaviour* (Simon, 1965; Nelson & Winter, 2009). Satisficing behaviour is intuitively based on the premise that longer-run decisions have a larger quantitative impact on profit relative to short-run decisions; whilst in the long-run producer behaviour might be best approximated by profit maximization, in the short-run following a rule-of-thumb, following a distributers guideline, or mimicking neighbouring farmers with regards to the level of variable inputs applied to crops may conserve on information requirements with little sacrifice to profits (Moore, Gollehon & Carey, 1994). If short-run production decisions are taken in accordance with satisficing behaviour, levels of capital and variable inputs are determined by the area of land under cultivation. These inputs are applied to a particular crop in proportion to the amount of land allocated to that crop, with the proportion variable across crops.

The assumption that crop-land represents a composite input has found empirical support in studies by Hornbaker *et al.* (1989) and Just *et al.* (1983). Hornbaker *et al.* (1989) find cropland to be the main element in production plans of farmers - farmers base their production plans on variable input/land ratios which are derived from rules of thumb, by mimicking other farmers, or from guidelines supplied to farmers by various organizations. Thus variable inputs are largely applied in proportion to the planted crop-land. Just *et al.* (1983, p. 778) find that capital inputs such as tractors and equipment tend to be in excess capacity on many farms, and thus do not limit production decisions for farmers. Irrigation infrastructure represents a major capital input, but is allocated to each crop in amounts proportional to the land used. Thus, the effect of capital on production can be assumed to be reflected in the land coefficient. Labour input is less clear, but labour employed prior to harvest is likely to be proportional to land. Labour employed during the harvest period, on the other hand, is assumed to have little effect on the production decision as it is simply used to supplement existing labour so that no crop is left unharvested. Thus, any labour effects in the production function can be assumed to be captured in the land coefficient in the production model.

Quasi-Fixed Water Input

Modelling irrigation water as a fixed, allocable input (or quasi-fixed input) reflects the institutional setting of commercial irrigation water in South Africa. The model implies that multi-crop producers face a fixed farm-level quota for irrigation water over a specified period, and must allocate this water between crops optimally so as to maximise total farm income. Thus, the irrigated agriculture farm faces a constrained optimization problem.

In considering the appropriateness of the characterization of irrigation water use as a quasi-fixed input, one should note that it is not clear that commercial agriculture irrigation quotas are closely monitored, nor regularly enforced, in South Africa. It may be a concern that, although theoretically and legally water use is capped at the licensed amount, this is not the case empirically. However, there is also reason to believe that agricultural producers do adhere to their quotas, despite a lack of monitoring and enforcement; agriculture requires a high degree of supply assurance for irrigation water, particularly in the case of crops such as orchards and vineyards that represent a long-term investment. Risk-averse farmers are unlikely to make long-term crop-choice and land-allocation decisions that rely on extraction of irrigation water above the legal allocation since access to this water comes with a far lower assurance of supply. This is a particularly relevant concern in a region in which water supplies are already constraining, such as the Berg River WMA. In the short-run farmers may be inclined to extract water above the level of their quota, but this is likely to be limited by some degree of peer monitoring within farming communities.[3]

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[3] Furthermore, three studies - Kanazawa (1993), Moore and Dinar (1995), and Moore (1999), found that surface irrigation water is a quantity rationed input in American agricultural production. Since irrigation water is institutionally allocated to both American and South African commercial farmers, this suggests that surface irrigation water may be quantity rationed in South African agriculture as well.

An important modelling implication arises from the presence of a quasi-fixed input in a multi-output setting: joint production is introduced, despite the assumption of technically non-joint inputs. Production will be joint because the quasi-fixed input in constraining, implying that crops compete for irrigation water allocations. Apparent joint production still allows for the identification of individual production processes, but constrains the production of each individual crop to be dependent on the prices of all other irrigated crops grown by the producer (Shumway, Pope & Nash, 1984, p.76). This provides a statistical test for the presence of a quasi-fixed input; if the prices of other crops are found to be statistically significant determinants of crop-level production decisions, this implies joint production (Shumway, Pope & Nash, 1984, p.74). Under the assumption of technically non-joint inputs, statistically significant cross-price effects would imply the presence of a quasi-fixed input.[4]

General Form Model

Within the irrigation season, the multi-output agricultural enterprise engaged in irrigated production allocates a quasi-fixed irrigation water endowment between all irrigated crops grown, conditional on a fixed composite input. Therefore, the producer's optimisation problem is one of revenue maximisation; the short-run objective of the agricultural producer is to maximise multioutput revenue, subject to the total farm-level water constraint (Chambers, 1988; Moore, 1999). Thus, a revenue function (Chambers, 1988, pp.262-66) relating multioutput revenue to a fixed input endowment, is defined for the agricultural producer as:

$$R(\boldsymbol{p}, c_1 \dots c_m, W) = \max_{w_1 \dots w_m} \left[\sum_{i=1}^{m} r_i(w_i; c_i, \boldsymbol{p}) : \sum_{i=1}^{m} w_i = W \right], \quad i = 1, \dots, m \tag{1}$$

where $R(\cdot)$ is overall (multioutput) farm revenue, W is the farm-level water constraint, $\boldsymbol{p}$ is a vector of irrigated crop output prices, $r_i(\cdot)$ is the crop-level revenue for crop i, w_i is the irrigation water allocated to crop i, c_i is the composite input allocated to crop i, and p_i is the output price for crop i.

Following Squires and Kirkley (1991, p.113) and Moore (1999, pp.564-65) equation (1) can be used to derive the shadow price (marginal revenue) functions for the quasi-fixed water input endowments as:

$$\frac{dR(\cdot)}{dw_i} = \frac{\partial r_i(w_i; c_i, \boldsymbol{p})}{\partial w_i} = \lambda(\boldsymbol{p}, \boldsymbol{c}, W), \quad \forall\, i = 1 \dots m \tag{2}$$

The shadow price function, $\lambda(\cdot)$, derived in equation (2) represents the marginal change in the value of agricultural output that would result from an incremental change in the volume of water available for irrigated agricultural production. If the farmer is optimising production effectively, the shadow price of irrigation water will be equal across all crops grown and the farm-level allocation of irrigation water will be Pareto optimal. The

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[4] Should the prices of other crops be found to have a statistically insignificant effect on crop-level production this would imply that irrigation water is applied according to some other model of input application. Since water is not price rationed, the standard variable input model does not apply. However, irrigation water may also be applied according to satisficing behaviour.

crop-level revenue function $r_i(\cdot)$ can be estimated econometrically, following which the irrigation water shadow price function can be estimated according to equation (2).

Empirical Application

Crop-level revenue functions are estimated via regression analysis for 16 irrigated crops in the Berg River WMA, using data from the 16 magisterial districts[5] that make up the catchment for the three years 1993, 2002 and 2007. The estimated parameters from the revenue function are then used to estimate the marginal value of irrigation water for the different crops analysed.

Data

Data on crop-level gross farming revenue, area of irrigated cropland (representing the composite input), and number of farms were obtained from the Census of Commercial Agriculture for the three most recent years available (1993; 2002; 2007). The data aggregates the values from all farms at the magisterial district level and covers 16 major irrigated crops common to the region. The full list of crops covered can be seen in *Table 4*, below, and an illustrative example of the distribution of irrigated cropland for Paarl in 2007 is shown in *Figure 1*, below.

***Table 3*: Geographic Coverage**

Local Municipality	*Magestaerial District*
Bergrivier	Piketberg
City of Cape Town	Bellville Kuilsriver Simon's Town Somerset West Strand Wynberg
Drakenstein	Paarl Wellington
Saldanha	Hopefield Vredenburg
Stellenbosch	Stellenbosch
Swartland	Malmesbury Moorreesburg
Witzenberg	Ceres Tulbagh

***Table 4*: Crop Coverage**

Category	*Crop*
Field Crops	Wheat Lucerne
Citrus Fruits	Oranges Lemons Naartjies
Deciduous Fruits	Apples Pears Peaches
Viticulture	Table Grapes Wine Grapes
Vegetables	Potatoes Tomatoes Onions Pumpkins Carrots Cabbage

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[5] The Berg WMA supplies irrigation water to producers in seven local municipalities, which can be further differentiated into 16 magisterial districts. *Table 3* gives a breakdown of the geographical coverage of the region.

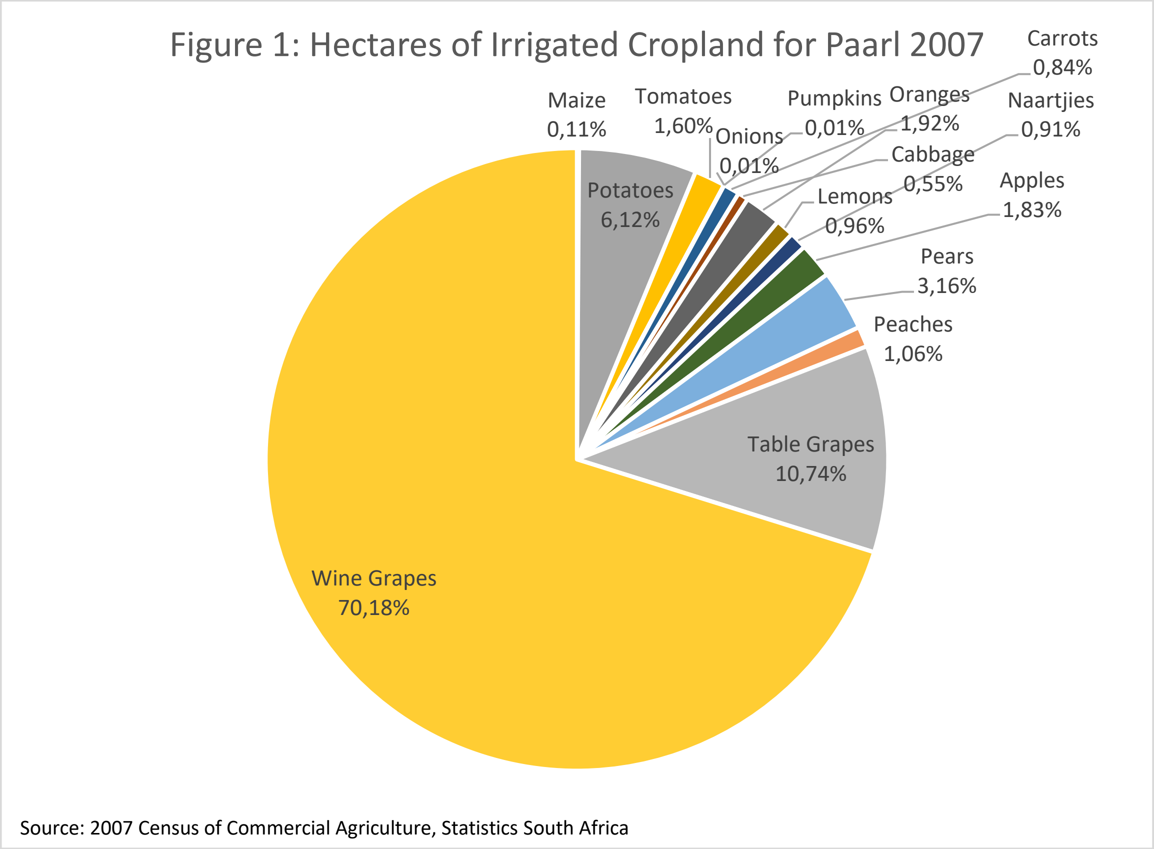

Figure 1: Hectares of Irrigated Cropland for Paarl 2007

Source: 2007 Census of Commercial Agriculture, Statistics South Africa

Data on annual crop prices are obtained from the Abstract of Agricultural Statistics (Department of Agriculture Forestry and Fisheries, 2013). One year lagged values for output prices were used and, therefore, represent expected output prices. Expected output prices are the relevant prices since farmers make crop-choice and land-allocation decisions prior to the output price being realized (Moore & Negri, 1992).

Additionally, a set of soil and climatic variables were obtained from the *Land Degradation in South Africa* dataset (Hoffmann *et al.*, 1999). These include a soil average slope and percentage of rainfall falling within the summer months, as well as a soil fertility index, soil erosion index and summer aridity index – all at the magisterial district level. These variables are listed and defined in *Table 5*, below.

Table 5: *Soil and Climatic Variables*

Variable	*Definition*	*Units*
Average Slope	Mean percentage change in altitude over a 1'x1' latitude and longitude grid surface	Percentage
Soil Erosion Index	determined by slope, soil type, rainfall intensity and land use	Index
Soil Fertility Index	A function of the clay content and base status of the soil	Index
Rainfall Seasonality	% of rain falling in the summer months (October to March)	Percentage
Summer Rainfall	Defined as the sum of the mean precipitation for the four hottest months of the year	mm

Source: Land Degradation in South Africa (Hoffman et al, 1999)

Note: All variable defined at the magisterial district level

Actual annual irrigation water use data are not reported in the Census of Commercial Agriculture, nor are these data obtainable from another source. Therefore, estimated annual irrigation requirements are used as a proxy for actual irrigation volumes. The estimates are obtained from van der Walt (2017). Specifically, the net irrigation requirement (IR_{ijt}) for crop i, in local municipality j and year t is calculated as the gross crop water requirement (ET_{ic}) for the relevant crop and local municipality, less effective rainfall in local municipality i in year t. Finally, this difference is divided by an irrigation efficiency factor (e_{ij})[6]. Specifically,

$$IR_{ijt} = \frac{(ET_{ij} - R^{e}_{jt})}{e_{ij}} \tag{3}$$

The potential pitfall in using this method to estimate irrigation water application is that, for a particularly dry year that forces farmers to under irrigate crops, the method will result in over estimates of crop irrigation volumes – farmers are assumed to compensate for lower effective rainfall by increasing irrigation volumes, which may not be feasible under drought conditions.

The mean annual effective rainfall for the Berg WMA was calculated as 453mm, 541mm and 556mm in 1993, 2002 and 2007 respectively. This compares to a long-term average annual rainfall for the region of 517mm.[7] Effective rainfall for the three years under consideration do not appear too dissimilar to the long-term average and the estimated irrigation requirements are assumed valid.

Because the data are grouped at the magisterial district level, the variables for crop revenue, irrigated cropland, and irrigation water are put on a per-farm basis by dividing by the number of farms present in the district. The average values are unbiased estimates of the corresponding farm-level values for a representative farm, and are compatible with the farm-level model specified by the model (Moore & Negri, 1992)[8]. Crop prices and gross farming revenue are converted to 2015 price level using the Consumer Price Index (Statistics South Africa, 2016).

Functional form

The Translog functional form (Christensen, Jorgenson & Lau, 1973) is used to estimate the crop-level revenue functions from which the shadow price estimates are then derived. The Translog function represents a flexible functional form, which allows the data to reveal the structure of the economic and physical relationships while imposing few characteristics on that structure (Casler, 1997). However, the greater flexibility is achieved at the expense of a reduction in degrees of freedom and increased multicollinearity between regressors since the full specification includes a large number of non-linear and interaction terms.

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[6] The irrigation efficiency factors were obtained from *The Irrigation Efficiency Training Manual* (2015). Irrigation systems were characterised as either drip irrigation (95% efficiency), micro-sprinkler (85% efficiency), centre pivot (90% efficiency), or sprinkler (90% efficiency).

[7] Author's own calculations using the *Land Degradation in South Africa* dataset (Hoffman *et al*., 1999).

[8] Putting the variables on a per-farm basis avoids the problems associated with non-aggregability of the Translog functional form.

Given the limited observations in the dataset, parsimony in parameters must be balanced against flexibility. Restrictions are therefore imposed on the number of interaction terms included in the specification. Specifically, other-crop average prices (included to control for the jointness in production imposed by a quasi-fixed water endowment) are interacted only with the irrigation water variable.

Thus, the functional form to be estimated is given by:

$$\begin{aligned}\ln(R_{it}) = {} & \alpha_i + \beta_{w,i}\ln(w_{it}) + \beta_{ww,i}\frac{\ln(w_{it})^2}{2} + \beta_{c,i}\ln(c_{it}) + \beta_{cc,i}\frac{\ln(c_{it})^2}{2} + \beta_{p,i}\ln(p_{it}) + \beta_{pp,i}\frac{\ln(p_{it})^2}{2} \\ & + \sum_{j=1}^{5}\beta_{j,i}\ln(\bar{p}_{jt}) + \sum_{j=1}^{5}\beta_{jj,i}\frac{\ln(\bar{p}_{jt})^2}{2} + \beta_{wc,i}\ln(w_{it})\ln(c_{it}) + \beta_{wp,i}\ln(w_{it})\ln(p_{it}) \\ & + \sum_{j=1}^{5}\beta_{wj,i}\ln(w_i)\ln(\bar{p}_{jt}) + \beta_{cp,i}\ln(c_{it})\ \ln(p_{it}) \qquad (4)\end{aligned}$$

where $\bar{p}_j$ are the average price levels for the 5 crop groups (field crops, citrus, deciduous fruit, viticulture and vegetables) and R_i, w_i, c_i and p_i represent the same variables as before.

It therefore follows that the estimated marginal revenue, or shadow price, of irrigation water is equal to

$$\begin{aligned}\lambda_t\left(w_{it}, c_{it}, p_{it}, \bar{\boldsymbol{p}}_{jt}, R_{it}\right) &= \frac{\partial R_{it}}{\partial w_{it}} = \frac{\partial \ln(R_{it})}{\partial \ln(w_{it})}\cdot\frac{R_{it}}{w_{it}} = \varepsilon_{Rw,i}\cdot\frac{R_{it}}{w_{it}} \\ &= \left[\beta_{w,it} + \beta_{ww,i}\ln(w_{it}) + \beta_{wc,it}\ln(c_{it}) + \beta_{wp,i}\ln(p_{it}) + \sum_{j=1}^{5}\beta_{wj,i}\ln(\bar{p}_{jt})\right]\cdot\frac{R_{it}}{w_{it}} \qquad (5)\end{aligned}$$

where $\varepsilon_{Rw,i}$ can be shown to be the elasticity of revenue with respect to irrigation water. Thus, the shadow price of irrigation water for crop i is a function of the revenue-water elasticity of crop i multiplied by the average value of output per m^3 of irrigation water applied to that crop. In turn, the revenue-water elasticity is a non-linear function of the level of irrigation water input, composite input and output prices.

Econometric Considerations

Several econometric issues are raised by the presence of corner solutions, aggregation, pooled time series and cross-sectional observations, spatial heterogeneity, and joint production. Not all of these issues can be addressed in the current application and with existing econometric techniques.

Corner Solutions and Censoring

The first econometric issue arises due to corner solutions, since farmers in every magisterial district do not find it optimal to grow all the irrigated crops produced in the region - non-zero production is observed to range between 37.5% of observations for irrigated wheat up to 83.3% for table grapes. The use of ordinary least squares in the presence of data censoring will result in inconsistent estimates of the model parameters (Wooldridge, 2002, p.524) as well as in the loss of information that can explain the decision to grow a crop (Moore & Negri, 1992). This is because factors which increase the expected income from a particular crop also increase the probability that the crop is cultivated. The opposite is true of factors which decrease the expected income from a particular crop.

Appropriate estimation should, therefore, make use of a limited dependent variable model such as the Tobit model (Tobin, 1958). The Tobit model decomposes the farmer's behaviour into a discrete-choice decision (on whether to participate in production of a particular irrigated crop) and an intensity decision (on the levels of inputs required to maximise revenue). A restriction of the Tobit model is that the same relationship is assumed to determine both an individual's quantity and participation decisions (Bockstael et al., 1990; Cameron & Trivedi, 2005). Two-part models such as the Cragg (1971) model provide an extension to the Tobit model that relaxes this assumption, but could not be used in the current application due to difficulty in achieving convergence of the maximum likelihood estimator. However, it is reasonable to assume that, in agricultural production, the characteristics that influence a farmer's decision to grow a certain crop are the same characteristics that influence the intensity with which that farmer cultivates the crop[9] (Bockstael *et al.*, 1990) Thus, the model is estimated using a Tobit model.

A further consideration is that the Tobit model employs strong distributional assumptions - estimation will be inconsistent if the error term is either heteroscedastic or non-normally distributed **(**Cameron & Trivedi, 2005). The logarithmic transformation of variables implicit in the translog functional form makes the normality assumption more plausible (Wooldridge, 2002). A conditional moments test of the null hypothesis of normally distributed errors is reported for each of the regressions (Pagan & Vella, 1989; Cameron & Trivedi, 2005). The issue of heteroskedastic errors is addressed below.

Aggregation and Heteroscedasticity

Heteroscedasticity is likely to arise due to data aggregation and the Tobit estimator will be inconsistent unless the heteroscedasticity is correctly addressed. Aggregate farm-level data can be expected to have unequal variability since the number of farms differs across magisterial districts, therefore districts with a larger number of farms will likely have a smaller error variance than districts with fewer farms (Moor & Negri, 1992). Therefore, heteroscedasticity is assumed to result from the number of farms, and the estimators are weighted according to the number of farms in each magisterial district.[10] To ensure that this correction solves the heteroscedasticity problem a Lagrange multiplier test of the null of heteroscedasticity is reported for each regression (Greene, 2005, p.769).

Joint Production and Contemporaneous Correlation

The presence of fixed, allocable inputs imposes joint production and it is therefore likely that the errors will be contemporaneously correlated across crops. As such, efficient estimation requires the simultaneous estimation

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[9] This is because the a factor, or input, that increases the expected profitability of a farmer growing a particular crop not only increases the probability that the farmer will choose to cultivate that crop (because it is more likely to be more profitable to cultivate than other irrigated crops) but also increases the intensity with which the farmer chooses to cultivate that crop (since higher intensity cultivation raises expected crop-level profits from that crop)

[10] This approach closely follows the correction for heteroscedasticity employed by Moore and Negri (1992) to estimate crop-level output supply equations.

of a system of equations (Wooldridge, 2002, p.163). Unfortunately, estimation of the Tobit model for a set of 16 crops via a systems framework is computationally intractable. Inefficient estimation is, therefore, ignored in favour of addressing the inconsistency associated with censored data and the model is estimated equation by equation.

Unobserved Heterogeneity

Unobserved individual heterogeneity is often a significant component in agricultural production models, and capture determinants of yield and productivity that are not explained by the observed regressors (Lacroix & Thomas, 2011). These unobserved effects could include soil fertility and drainage, climatic variables, or irrigation and management practices. They can also be largely time-invariant (e.g. soil fertility and long-term climatic conditions) or unexpected shocks specific to the growing season (e.g. input price shocks).

When panel data exist, analysis can potentially exploit the data structure to control for unobserved individual heterogeneity through the incorporation of either fixed or random effects. However, in the Tobit model inclusion of fixed effects introduces the incidental parameters problem which is generally expected to introduce a small sample bias into the parameter estimator (Greene, 2005, p.717). Furthermore, random effects estimation requires the assumption that unobserved heterogeneity is uncorrelated with the regressors in the model. This assumption would be unrealistic in the current application, since unobserved soil and climatic variables are most likely correlated with levels of irrigation water use.

In an attempt to control for some of the unobserved heterogeneity, year dummies as well as dummy variables (and interactions) representing general geological and climatic conditions are included in the regression specification. The year dummies control for any unexpected shocks to production that occur within the growing season, as well as controlling for any aggregate changes over time.

The primary source of remaining heterogeneity is assumed to result from differences in soil fertility across the region. Therefore, a dummy variable representing above average soil fertility[11] is included in the model. Additionally, interaction terms between the soil fertility dummy and the full set of irrigation water and composite input variables are included. Interaction terms between the year dummies and the soil fertility dummy are also included. These interaction terms allow the intercept in the revenue function to vary over time and across soil fertility. The relationship between revenue and the level of irrigation water and the composite input is also allowed to vary across soil fertility level.

A further five dummy variables to control for general geological, climatic and managerial conditions are included. These include dummy variables for a high average slope, high levels of erosion, higher than average summer

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[11] Constructed from the soil fertility index in the *Land Degradation* dataset (Hoffmann et al., 1999)

rainfall seasonality and high summer rainfall. A dummy variable representing above average farm size is included as a proxy for farming intensity, which is assumed to be inversely proportional to farm size.[12]

Regression Estimates

Table 6 presents some parameter estimates for the translog revenue functions for four crops - lucerne, peaches, table grapes and potatoes. For ease of reference, only a subset of the full 41 estimated parameters per crop are reported. [13] These results are broadly representative of the overall results. The full set of regression estimates can be found in *Table A1* of the Appendix.

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[12] In particular, the dummy variables are generated so that they are equal to 1 if the value of the variable in a particular magisterial district is greater than the average value of that variable across the whole of the Berg WMA, and equal to zero if it is below the average. Thus, the dummy variables represent above average levels of each of the 5 variables considered.

[13] In particular, the reported estimates are the conditional marginal effects – or the marginal effect on revenue conditional on non-zero production. These are the marginal effects of interest in the presence of corner solutions (Wooldridge, 2002, p.527).

Table 6: **Conditional Marginal Effects for Selected Variables and Crops**

Variable	(1) Lucerne	(2) Peaches	(3) Table Grapes	(4) Potatoes
Water Input				
$\ln(w_{it})$	0.154***	0.328***	0.182***	0.241***
	(0.00143)	(0.00337)	(0.00937)	(0.0205)
$\frac{\ln(w_{it})^2}{2}$	0.0496***	0.00801***	-0.0980***	0.0475***
	(0.000472)	(0.000519)	(0.00202)	(0.00362)
Composite Input				
$\ln(c_{it})$	-15.62***	0.435***	1.218***	7.474***
	(0.203)	(0.0106)	(0.0368)	(0.148)
$\frac{\ln(c_{it})^2}{2}$	-4.739***	-0.117***	-1.227***	2.111***
	(0.450)	(0.00528)	(0.0295)	(0.162)
$\ln(w_{it})\ln(c_{it})$	-1.304***	0.0750***	-0.0210***	-0.132***
	(0.0175)	(0.000762)	(0.00396)	(0.0124)
Own Output Price				
$\ln(p_{it})$	-0.0358***	0.338***	0.200***	-0.173***
	(0.00243)	(0.00478)	(0.00932)	(0.0289)
$\frac{\ln(p_{it})^2}{2}$	-0.00918***	0.0566***	0.0559***	0.223***
	(0.00108)	(0.00108)	(0.00216)	(0.00740)
$\ln(w_{it})\ln(p_{it})$	0.0534***	0.0237***	0.0422***	0.0346***
	(0.000108)	(0.000380)	(0.00108)	(0.00264)
Dummy Controls				
High Soil Fertility	-6.900***	5.204***	-2.708***	-13.62***
	(0.0142)	(0.0944)	(0.143)	(0.189)
High Slope	0.412***	1.444***	-0.594***	-1.021***
	(0.0393)	(0.0249)	(0.0693)	(0.294)
High Erosion	3.276***	0.270***	-0.259***	-0.407**
	(0.0180)	(0.0308)	(0.0641)	(0.165)
Above average summer rainfall seasonality	-4.332***	-1.808***	-0.539***	2.498***
	(0.0267)	(0.0311)	(0.0687)	(0.185)
High Summer Rainfall	-2.501***	-0.329***	-0.273*	-0.537***
	(0.00928)	(0.107)	(0.139)	(0.193)
High Average Farm Size	0.168***	0.216**	-0.930***	0.464*
	(0.0265)	(0.0968)	(0.117)	(0.256)
Soil Fertility Interactions				
$\ln(w_{it})$	0.0543***	-0.0285***	0.636***	0.665***
	(0.00206)	(0.00830)	(0.0183)	(0.0171)
$\frac{\ln(w_{it})^2}{2}$	0.103***	-0.0428***	-0.0735***	0.223***
	(0.000645)	(0.00123)	(0.00413)	(0.00302)
$\ln(c_{it})$	9.652***	-2.263***	1.977***	-4.249***
	(0.212)	(0.0354)	(0.213)	(0.119)
$\frac{\ln(c_{it})^2}{2}$	14.68***	0.0594***	0.866**	1.370***
	(0.451)	(0.0108)	(0.352)	(0.153)
$\ln(w_{it})\ln(c_{it})$	0.651***	-0.0163***	-0.347***	-0.248***
	(0.0181)	(0.00210)	(0.0224)	(0.0103)
Log-Likelihood	47.02	18.36	20.27	-3.28
AIC	-80.05	-12.72	-14.55	32.56
BIC	-66.95	9.73	9.78	56.89
Observations	48	48	48	48

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Input and Price Variables

Overall the parameter estimates are statistically significant at conventional levels of significance. For all crops the irrigation water terms are statistically significant at the 1% level. The coefficients on the composite input terms are similarly significant. This accords with the expectation that irrigation water and the composite input are important determinants of output and revenue for irrigated crops in the Berg WMA. Furthermore, the majority of the coefficients on the average crop price terms are statistically significant at conventional levels, suggesting that irrigation water is a quasi-fixed input in the region and that production is therefore joint for irrigated agriculture.

The sign and magnitude of the coefficients on the input and price variables are difficult to relate to theoretical expectations. There is only one theoretical property of the revenue function related to input endowments: that the revenue function should be non-decreasing in an output (Chambers, 1988, p.263). Due to the inclusion of non-linear and interaction terms, this property does not provide any guidance on the expected signs on any of the coefficients on the input variables. However, it should be expected that coefficients combine such that the marginal effect with respect to each input is non-negative - given the levels of irrigation water, composite input and output prices (i.e. irrigation water shadow price estimates should be non-negative). Similarly, the inclusion of interaction and non-linear price terms implies that there are no theoretical expectations placed on the individual parameter estimates.

Heterogeneity Controls

The soil and climatic control variables function differently in a multicrop model with a fixed, allocable input. Because crops compete for resources, the coefficients on these variables should be interpreted as a measure of the comparative advantage of the variable in producing a particular crop, as opposed to its absolute advantage (Moore & Negri, 1992, p.35). For instance, the negative coefficients on high fertility soil estimated for lucerne and potatoes implies that less production is less extensive in high productivity soil for these two crops, which are *comparatively* more profitable in low productivity soil. It does not imply that high productivity soil will result in lower potato or lucerne revenues than low productivity soil will.

The coefficients on the high average slope, erosion, summer rainfall, summer aridity and farm size should be interpreted similarly. Overall these coefficients are highly statistically significant and accord with agroeconomic expectations. For instance, the results suggest that lucerne has a comparative advantage on marginal land with relatively low productivity soil, steep slope and high levels of erosion. On the other hand, potatoes have a comparative advantage in areas with below average slope, which receive above average summer rainfall as a percentage of winter rainfall and have relatively larger average farm sizes (a proxy for lower intensity agriculture).

The interaction terms between the high soil fertility dummy and the irrigation water and composite input variables are statistically significant overall. [14] This suggests that differences in soil fertility result in significant differences in the relationship between crop revenues and levels of irrigation water and composite inputs.

Tests of Assumptions

The normality and heteroscedasticity test results can be found in *Table A.2* of the appendix. The results from the Conditional Moments, show that the null hypothesis of normally distributed residuals is not rejected at conventional levels of significance for all crops. Similarly, the Lagrange Multiplier test for heteroskedastic errors is not rejected for any of the crops at conventional levels of significance. Thus, one can conclude that the Tobit model assumptions are met and the estimators are consistent.

Marginal Value Estimates

Using the parameter estimates presented in *Table A1* and the mean levels of irrigation water input, composite input and prices the marginal value of irrigation water is estimated for each magisterial district in the Berg WMA for 16 crops according to equation (5). The full set of estimates can be found in *Table A2* of the Appendix. In addition to the point estimates, the standard error of each prediction is reported as well as a Wald test of the null hypothesis that the prediction is equal to zero against a two-sided alternative is conducted to test the significance of each estimate, according to the method proposed by Park and Phillips (1988).

For the majority of crops the marginal value estimates for all magisterial districts are statistically significant from zero at the 10%-level or below. Additionally, only three estimates are negative, but these are not statistically different from zero. On the other hand, 13 out of 15 of the estimates for wine grapes are insignificant and a number of the estimates for table grapes and tomatoes were also insignificant. This is likely an indication that, either the model did not accurately describe irrigation practices for these crops, or that there were too few observations to generate accurate estimates. However, on balance the model appears to generate significant and plausible shadow price estimates.

Overall Mean Estimates

The overall mean shadow price estimates for the irrigated crops in the Berg WMA are reported in *Table 6,* and ranked according to the shadow price estimates. *Table 7* reports the mean average water productivity as well as the mean estimated revenue-water elasticity for each crop. The range of estimates is similar to those obtained by Louw (2001) of 0 – 5.99 2015 rand per m^3 and appear plausible. Notably, average water productivity differs significantly from the marginal value for all crops. This is the result of estimated elasticities that are significantly different from one. The result highlights the importance that water policy decisions are made on the basis of marginal value estimates rather than average value estimates. Average values are inherently 'historic',

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[14] It is notable that the percentage of statistically significant parameter estimates increased from 83% to 95% for the model including soil fertility dummy interactions and the other control dummies compared to the basic translog model.

illustrating how much output-value was achieved for a given level of irrigation water application. Furthermore, an average value takes the production decisions taken by farmers as given and fixed. On the other hand, the marginal value figures are inherently forward looking and estimate how output value will change if the level of irrigation water application changes, while further allowing certain dimensions of farmers production decisions to change in response to changes in the availability of irrigation water supply.

Table 7: **Overall Mean Estimates for Berg WMA**

Crop	*Marginal Value* (R/m^3)	$\frac{R_i}{w_i}$	$\varepsilon_{Rw,i}$
Peaches	4.84	14.61	0.33
Tomatoes	4.78	13.97	0.34
Table Grapes	4.36	16.90	0.26
Potatoes	3.10	9.02	0.34
Wine Grapes	2.99	24.67	0.12
Apples	2.69	11.48	0.23
Cabbage	2.27	6.82	0.33
Lemons	2.20	2.63	0.84
Naartjies	1.92	4.74	0.40
Oranges	1.90	2.30	0.83
Onions	1.82	6.22	0.29
Carrots	1.74	7.75	0.22
Pears	1.45	5.48	0.26
Pumpkins	1.10	4.09	0.27
Lucerne	0.64	0.44	1.44
Wheat	0.14	1.12	0.12

Mean Estimates by Local Municipality

Table 8 presents a summary of the crop marginal value estimates, reporting the mean estimates for the seven local municipalities in the Berg WMA. Notably, there is significant variation in the mean shadow price estimates across crops within the same local municipality. Assuming that farmers are making rational water application decisions, this suggests a limitation in the empirical application, since the optimal farm-level allocation of the water occurs when its marginal value is equal across crops grown. This limitation may be the result of the use of aggregate data, or because the assumption of cropland representing a composite input does not hold for all crops. However, it is likely to (at least in part) be the result of unobserved heterogeneity which has not been accounted for.

***Table 8:* Mean Marginal Values by Local Municipality (R/m^3)**

Local Municipality	*Wheat*	*Lucerne*	*Oranges*	*Lemons*	*Naartjies*	*Peaches*	*Pears*	*Apples*
Bergrivier	0.02	1.73	2.47	2.29	0.81	3.74	0.73	2.80
City of Cape Town	-	0.16	2.44	1.89	3.13	4.06	1.15	2.08
Drakenstein	0.66	0.03	1.80	2.84	1.64	2.93	0.96	2.05
Saldanha	0.03	0.85	-	-	-	-	-	-
Stellenbosch	-	0.59	1.57	2.24	1.60	9.51	2.59	5.10
Swartland	0.07	0.46	1.55	1.89	1.92	3.00	1.55	2.63
Witzenberg	0.04	0.67	1.60	2.07	2.41	5.80	1.72	1.45

***Table 8* Continued**

Local Municipality	*Table Grapes*	*Wine Grapes*	*Potatoes*	*Tomatoes*	*Onions*	*Pumpkins*	*Carrots*	*Cabbage*
Bergrivier	3.56	1.16	2.25	1.84	1.54	1.03	-	0.54
City of Cape Town	4.59	6.81	5.80	4.30	2.41	1.13	1.67	1.69
Drakenstein	5.96	2.25	2.25	4.04	1.28	1.00	0.93	2.91
Saldanha	0.11	3.11	1.35	-	-	-	-	-
Stellenbosch	7.56	7.03	2.82	9.71	1.06	1.24	1.70	2.92
Swartland	6.66	0.45	3.92	6.14	1.70	1.07	2.25	3.78
Witzenberg	2.07	0.15	3.32	2.67	2.93	1.12	2.14	1.76

Overall Mean Estimates by Soil Fertility

In *Table 9* the overall mean shadow prices are reported for areas with high- and low-fertility soil separately. The results highlight the significant effect of soil fertility on the marginal value of irrigation water for all crops, except cabbage. Notably, soil fertility raises the marginal value of irrigation water for the majority of crops but lowers the marginal value for a significant proportion as well. Indeed, while the most efficient irrigated crop in high fertility soil is table grapes, this is not the case in low fertility soil where peaches are the most efficient. Thus, the overall mean shadow prices presented in *Table 7* mask significant variation in the shadow price estimates which result simply from differences in soil fertility.

***Table 9:* Overall Mean Marginal Values by Soil Fertility**

Crop	*High Fertility Soil*	*Low Fertility Soil*	*Overall Mean*
Peaches	4.70	4.98	4.84
Tomatoes	5.31	4.25	4.78
Table Grapes	5.76	2.96	4.36
Potatoes	3.71	2.49	3.10
Wine Grapes	3.07	2.91	2.99
Apples	2.37	3.01	2.69
Cabbages	2.30	2.24	2.27
Lemons	2.01	2.39	2.20
Naartjies	2.09	1.75	1.92
Oranges	1.72	2.08	1.90
Onions	2.20	1.44	1.82
Carrots	2.07	1.41	1.74
Pears	1.90	1.00	1.45
Pumpkins	1.10	1.10	1.10
Lucerne	0.50	0.78	0.64
Wheat	0.05	0.23	0.14

Discussion and Conclusion

This study set out three objectives. First, the study aimed to establish reliable estimates of the marginal benefit of commercial irrigation water in the Berg WMA. The crop-level estimates generated by the study are broadly in line with previous estimates obtained for commercial irrigation in the Berg region, and suggest that agriculture is likely to generate the lowest marginal benefit from irrigation water when compared to industrial and municipal users in the Berg WMA. The methodology also highlights the significant effect that on-farm conditions, such as soil fertility, has on the marginal benefit of water in irrigated agriculture. Thus, while crop-choice has a significant effect on the overall efficiency of water use in the commercial agricultural sector, the study shows that the marginal benefit of agricultural water is heterogeneous, nuanced and likely to be affected by a variety of factors.

However, the study focuses on the economic value of agricultural water and does not evaluate other dimensions of value, such as environmental or social value. These are important dimensions of value, but are left for other studies to evaluate. In addition, the study estimates short-run marginal values for commercial irrigation water. Short-run marginal values of irrigation water provide an indication of how the value of irrigated production would change in response to a change in the quantum of water available agricultural producers within a growing season, with land allocation and crop-choice decisions having already been made by the farmer. Longer-run marginal value estimates, on the other hand, will likely be lower than the short-run estimates. In response to a decrease in available irrigation water in the long-run, farmers would be able adapt land allocation and cropping patterns, as well as invest in water-saving technologies (such as more efficient irrigation infrastructure) in order to mitigate the effect on production value of the change in available irrigation water supply. Thus, the estimates from this study are likely to overstate the long-run values on which water policy ought to be formulated. In addition, the study models the marginal value of irrigation water to perennial and annual crops in the identically. This ignores the fact that the marginal revenues for perennial crops may be thought of as not only the marginal revenues in the current year, rather are the discounted present values of revenues if the crops are watered and thus maintained for production in future years.

The second objective of the study was to develop an econometric basis for estimating the marginal value of agricultural irrigation water, which can be easily adapted for application in other constrained catchments in South Africa. The model developed in this study is estimable using data readily available across South Africa, and is based on profit maximizing behaviour of farmers. The model also incorporates the multi-output nature of irrigated agriculture and the institutional setting that characterises irrigation water allocation. However, the model methodology does contain limitations resulting from data limitations. First, the model makes a relatively strong assumption that cropland represents a composite input. If this assumption fails, the estimates will be biased in an indeterminate direction. Second, the methodology employs a farm-level model of agricultural production but is estimated using data for a representative farm obtained from aggregate data. This too may result in biased estimates. The methodology can, however, easily address these deficiencies if more comprehensive, farm-level data becomes available. In particular, a greater number of observations would allow the econometric model to be extended to a more flexible double-hurdle model or a Heckman selection model. The model could also be extended to include a full-set of interaction terms in the translog functional form, and allow for more controls for on-farm conditions to be included. Farm-level data would also improve the quality of the heterogeneity control variables, and might facilitate the use of actual water use data rather than an estimate thereof.

The final aim of this study was to advance and facilitate public policy that efficiently allocates scarce water resources and minimises the constraint on economic development imposed by limited water resources. Indeed, the findings from this study suggest that intersectoral reallocation of water supplies presents an opportunity for increasing the economic efficiency of the allocation of water in the Berg WMA. Reallocation of water away from the agricultural sector, towards industrial uses such as the Saldanha Bay IDZ would make a significant contribution towards minimizing the constraint placed on economic development by limited water resources.

Furthermore, the study highlights the importance that policymakers make use of forward looking marginal value estimates. The study also highlights areas in which more reliable and accurate estimates could be obtained by extending the methodology of this study to a more comprehensive dataset. Policymakers should consider the need for a comprehensive, publicly available, farm-level survey of irrigated agriculture. Such a survey would greatly enhance the effectiveness of policymaking with respect to both water allocation and economic development.

Lastly, the findings of this study also imply that policymakers must adopt an approach to intersectoral reallocation that acknowledges the nuance inherent in irrigated agriculture. In particular, such an approach to intersectoral reallocation that focuses on the agricultural sector should recognise that several factors are likely to affect the marginal benefit generated by irrigation water. Data and methodological limitations restrict the extent to which a policymaker is able to observe and account for this heterogeneity. However, farmers are incentivised to make rational production decisions and have significantly more information on the productivity of irrigation water for their farm than a policymaker does. Thus, if policymakers wish to reallocate water away from irrigated agriculture efficiently they should avoid prescribing any particular area or crop-type from which to reallocate the water. Instead, policymakers should reallocate water away from farmers and allow them to rationally allocate their remaining quota. In the short- to intermediate run farmers will continue to allocate water efficiently between the irrigated crops grown, while in the long-run they will change their crop-choice so as generate the maximum benefit from the irrigation water quota available to them.

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Appendix

Table A.1: Full Regression Results (Conditional Marginal Effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Parameter	Wheat	Lucerne	Lemons	Oranges	Naartjies	Apples	Peaches	Pears	Table Grapes	Wine Grapes	Potatoes	Tomatoes	Onions	Pumpkins	Carrots	Cabbage
Water																
β_w	0.0936***	0.154***	0.391***	0.157***	0.224***	0.293***	0.328***	0.382***	0.182***	0.945***	0.241***	1.559***	0.929***	0.741***	0.181***	0.0518***
	(0.000319)	(0.00143)	(4.52e-06)	(0.00257)	(0.00101)	(0.00160)	(0.00337)	(0.00169)	(0.00937)	(0.0288)	(0.0205)	(0.0315)	(0.00715)	(0.0220)	(0.0127)	(0.00763)
β_{ww}	0.0114***	0.0496***	0.0365***	0.0440***	0.0348***	-0.00709***	0.00801***	-0.0178***	-0.0980***	-0.112***	0.0475***	-0.180***	0.0223***	-0.0675***	-0.0764***	-0.0655***
	(5.05e-05)	(0.000472)	(1.22e-06)	(0.000481)	(0.000236)	(0.000296)	(0.000519)	(0.000261)	(0.00202)	(0.00518)	(0.00362)	(0.00733)	(0.00122)	(0.00461)	(0.00227)	(0.00139)
Composite Input																
β_c	0.436***	-15.62***	-4.110***	1.115***	3.481***	1.223***	0.435***	0.490***	1.218***	3.227***	7.474***	-43.40***	2.000***	7.442***	-1.255***	-2.036***
	(0.00160)	(0.203)	(0.000557)	(0.0377)	(0.0848)	(0.00998)	(0.0106)	(0.00587)	(0.0368)	(0.0920)	(0.148)	(0.828)	(0.0199)	(0.274)	(0.0941)	(0.0556)
β_{cc}	-0.0642***	-4.739***	134.9***	-4.259***	-106.2***	-1.090***	-0.117***	-0.638***	-1.227***	-0.650***	2.111***	316.8***	-0.0265	-2.692***	4.929***	1.204***
	(0.000846)	(0.450)	(0.00383)	(0.0544)	(0.293)	(0.00898)	(0.00528)	(0.00324)	(0.0295)	(0.0444)	(0.162)	(3.368)	(0.0305)	(0.504)	(0.116)	(0.0730)
β_{wc}	0.0227***	-1.304***	-1.534***	0.101***	0.111***	0.0490***	0.0750***	-0.0460***	-0.0210***	-0.128***	-0.132***	2.708***	0.0625***	-0.472***	-0.358***	-0.571***
	(0.000114)	(0.0175)	(5.62e-05)	(0.00294)	(0.00743)	(0.000818)	(0.000762)	(0.000453)	(0.00396)	(0.00806)	(0.0124)	(0.0853)	(0.00128)	(0.0263)	(0.00839)	(0.00469)
Own Output Prices																
β_p	0.251***	-0.0358***	0.387***	0.158***	0.129***	0.0713***	0.338***	0.266***	0.200***	-0.905***	-0.173***	0.680***	0.263***	0.178***	1.007***	0.631***
	(0.000489)	(0.00243)	(4.58e-06)	(0.00322)	(0.00111)	(0.00211)	(0.00478)	(0.00258)	(0.00932)	(0.0371)	(0.0289)	(0.0298)	(0.00933)	(0.0287)	(0.0182)	(0.0109)
β_{pp}	0.0641***	-0.00918***	0.0626***	0.0721***	0.0293***	0.0131***	0.0566***	0.0444***	0.0559***	-0.231***	0.223***	-0.142***	-0.0417***	0.0651***	0.220***	0.213***
	(0.000123)	(0.00108)	(1.29e-06)	(0.000794)	(0.000269)	(0.000500)	(0.00108)	(0.000651)	(0.00216)	(0.00873)	(0.00740)	(0.00708)	(0.00241)	(0.00779)	(0.00471)	(0.00307)
β_{wp}	0.0111***	0.0534***	0.0298***	0.0286***	0.0290***	0.0275***	0.0237***	0.0510***	0.0422***	0.149***	0.0346***	0.0589***	0.0687***	-0.0728***	0.0287***	0.0529***
	(4.01e-05)	(0.000108)	(6.19e-07)	(0.000315)	(0.000124)	(0.000194)	(0.000380)	(0.000212)	(0.00108)	(0.00341)	(0.00264)	(0.00386)	(0.000934)	(0.00310)	(0.00164)	(0.00109)
β_{cp}	0.0495***	-0.209***	-1.893***	0.122***	1.764***	0.0763***	-0.0237***	0.130***	0.191***	0.133***	-0.759***	-9.128***	-0.137***	0.237***	0.559***	0.705***
	(0.000202)	(0.0265)	(7.41e-05)	(0.00458)	(0.0103)	(0.00126)	(0.00124)	(0.000705)	(0.00423)	(0.0105)	(0.0192)	(0.102)	(0.00271)	(0.0368)	(0.0120)	(0.00807)
Average Other Crop Prices																
β_1	-0.140***	-0.218***	0.221***	-0.159***	-0.116***	-0.0711***	-0.128***	1.210***	0.496***	-0.157**	0.916***	-0.0483	0.655***	0.148***	0.720***	-0.669***
	(0.000828)	(0.00854)	(4.21e-06)	(0.00326)	(0.00129)	(0.00571)	(0.0117)	(0.00436)	(0.0152)	(0.0787)	(0.0466)	(0.0435)	(0.0104)	(0.0396)	(0.0574)	(0.0134)
β_{11}	-0.00361***	-0.126***	0.0667***	-0.0560***	-0.0729***	0.0181***	0.116***	-0.113***	-0.128***	0.113***	0.159***	0.221***	0.325***	-0.0116	0.104***	-0.0614***
	(0.000206)	(0.00187)	(1.15e-06)	(0.000791)	(0.000378)	(0.00153)	(0.00317)	(0.00120)	(0.00424)	(0.0218)	(0.0128)	(0.0111)	(0.00282)	(0.0102)	(0.0156)	(0.00348)
β_2	0.118***	0.000716	-0.141***	-0.288***	-0.0779***	0.0282***	0.115***	0.0385***	0.311***	1.263***	-1.136***	-0.447***	0.637***	-0.615***	-0.779***	0.211***
	(0.000709)	(0.00356)	(4.20e-06)	(0.00292)	(0.00123)	(0.00233)	(0.00494)	(0.00247)	(0.00901)	(0.0341)	(0.0372)	(0.0302)	(0.0101)	(0.0318)	(0.0253)	(0.00781)
β_{22}	-0.0613***	-0.000601	-0.168***	0.0335***	-0.0676***	-0.00234***	0.0225***	0.0136***	-0.187***	-0.0665***	-0.0705***	-0.0147*	-0.0961***	0.0927***	-0.0252***	-0.190***
	(0.000181)	(0.000905)	(1.10e-06)	(0.000745)	(0.000342)	(0.000590)	(0.00115)	(0.000597)	(0.00214)	(0.00845)	(0.00969)	(0.00790)	(0.00266)	(0.00819)	(0.00707)	(0.00206)
β_3	0.107***	0.0553***	0.639***	-0.246***	-0.109***	0.0716***	-1.959***	0.713***	0.837***	-0.679***	1.370***	0.414***	0.956***	-0.631***	0.360***	-0.673***
	(0.000519)	(0.00183)	(6.06e-06)	(0.00495)	(0.00319)	(0.00679)	(0.0161)	(0.00776)	(0.0203)	(0.0773)	(0.0413)	(0.0640)	(0.0143)	(0.0471)	(0.0825)	(0.0201)
β_{33}	0.0436***	-0.218***	0.0510***	0.0706***	0.0329***	0.0404***	0.120***	-0.0358***	-0.133***	0.0771***	-0.159***	-0.310***	-0.205***	0.263***	-0.321***	0.261***
	(0.000141)	(0.000868)	(1.82e-06)	(0.00153)	(0.000941)	(0.00194)	(0.00471)	(0.00214)	(0.00578)	(0.0226)	(0.0115)	(0.0180)	(0.00426)	(0.0139)	(0.0252)	(0.00599)
β_4	-0.0276***	-0.139***	0.206***	0.0269***	0.0437***	0.0117***	-0.289***	-0.173***	0.0150	1.576***	-0.318***	-0.154***	-0.306***	-0.0172	0.0661***	0.0630***
	(0.000571)	(0.00221)	(3.62e-06)	(0.00315)	(0.00109)	(0.00228)	(0.00474)	(0.00223)	(0.00932)	(0.0329)	(0.0304)	(0.0312)	(0.00717)	(0.0257)	(0.0203)	(0.00967)
β_{44}	0.0222***	-0.0443***	0.0795***	0.0405***	0.00816***	0.000307	-0.0788***	-0.00482***	0.0772***	0.0539***	0.192***	0.0188**	0.0420***	0.0791***	0.135***	0.0160***
	(0.000137)	(0.000601)	(8.68e-07)	(0.000761)	(0.000258)	(0.000560)	(0.00107)	(0.000501)	(0.00214)	(0.00824)	(0.00771)	(0.00769)	(0.00174)	(0.00647)	(0.00541)	(0.00241)
β_5	0.0218***	-0.146***	-0.466***	0.0611***	0.118***	0.0277***	0.776***	0.470***	0.00250	-0.699***	0.520***	0.383***	-0.610***	-0.0125	-0.0370	0.0919***
	(0.000583)	(0.00218)	(3.33e-06)	(0.00397)	(0.00157)	(0.00395)	(0.0118)	(0.00455)	(0.0148)	(0.0468)	(0.0319)	(0.0328)	(0.00775)	(0.0271)	(0.0226)	(0.00957)
β_{55}	0.0379***	0.0249***	-0.297***	0.0806***	0.0287***	-0.0149***	-0.119***	-0.477***	0.0152***	-0.00829	-0.168***	-0.0161*	-0.188***	-0.113***	-0.209***	0.0849***
	(0.000166)	(0.00120)	(7.63e-07)	(0.00117)	(0.000557)	(0.00136)	(0.00309)	(0.00120)	(0.00397)	(0.0136)	(0.00853)	(0.00849)	(0.00203)	(0.00720)	(0.00648)	(0.00237)
β_{w1}	0.0100***	0.0528***	0.0542***	0.00464***	0.0117***	-0.0275***	-0.0604***	-0.0303***	0.00490**	-0.0392***	-0.138***	-0.109***	-0.244***	-0.0404***	-0.129***	0.0320***
	(7.85e-05)	(0.000866)	(6.16e-07)	(0.000311)	(0.000123)	(0.000543)	(0.00116)	(0.000430)	(0.00191)	(0.00700)	(0.00421)	(0.00563)	(0.00139)	(0.00438)	(0.00805)	(0.00155)
β_{w2}	0.0160***	0.0189***	-0.000659***	-0.0101***	0.0119***	0.0316***	0.0371***	0.0321***	0.0538***	-0.0958***	0.112***	-0.0982***	-0.0175***	0.0151***	0.0381***	0.0575***
	(7.01e-05)	(0.000445)	(5.84e-07)	(0.000287)	(0.000122)	(0.000206)	(0.000393)	(0.000204)	(0.00102)	(0.00393)	(0.00323)	(0.00387)	(0.00122)	(0.00358)	(0.00228)	(0.000732)
β_{w3}	0.0123***	0.157***	-0.00262***	-0.00980***	-0.0120***	-0.0124***	0.141***	-0.0546***	-0.0322***	0.0424***	-0.0684***	0.228***	0.00135	0.00271	0.0415***	-0.000477
	(4.20e-05)	(0.000146)	(8.72e-07)	(0.000484)	(0.000284)	(0.000628)	(0.00135)	(0.000743)	(0.00235)	(0.00694)	(0.00370)	(0.00751)	(0.00138)	(0.00509)	(0.00924)	(0.00226)
β_{w4}	0.00360***	0.0433***	0.0581***	0.0259***	0.0245***	0.0321***	0.0100***	0.0402***	0.0669***	-0.00457	-0.0262***	0.0935***	0.0397***	0.120***	0.0738***	0.0140***
	(4.76e-05)	(0.000268)	(5.39e-07)	(0.000310)	(0.000116)	(0.000197)	(0.000378)	(0.000190)	(0.00107)	(0.00360)	(0.00272)	(0.00398)	(0.000873)	(0.00282)	(0.00172)	(0.000969)
β_{w5}	0.0174***	0.0316***	-0.0153***	0.0300***	0.0417***	0.0269***	0.0179***	0.0411***	-0.0107***	0.0575***	-0.00735***	0.0635***	0.0697***	0.0113***	-0.0203***	0.0281***
	(4.78e-05)	(0.000295)	(5.23e-07)	(0.000392)	(0.000135)	(0.000367)	(0.00122)	(0.000435)	(0.00188)	(0.00454)	(0.00284)	(0.00408)	(0.000940)	(0.00295)	(0.00191)	(0.000925)

Table A.1: Continued

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Parameter	Wheat	Lucerne	Lemons	Oranges	Naartjies	Apples	Peaches	Pears	Table Grapes	Wine Grapes	Potatoes	Tomatoes	Onions	Pumpkins	Carrots	Cabbage
Year Dummies																
2002	0.446***	1.869***	-0.0612***	0.0416	1.868***	0.861***	2.137***	0.450***	0.437**	-0.0663	1.583***	3.877***	-0.560***	-0.340	1.873***	-1.278***
	(0.0105)	(0.332)	(0.000157)	(0.0974)	(0.0515)	(0.0597)	(0.101)	(0.0576)	(0.175)	(0.513)	(0.319)	(0.248)	(0.0844)	(0.241)	(0.352)	(0.182)
2007	1.303***	2.735***	-0.419***	0.533***	2.209***	0.904***	2.408***	-1.504***	0.340***	0.131	0.364	0.877**	-7.473***	-0.663***	-1.145***	1.109***
	(0.0120)	(0.292)	(0.000313)	(0.101)	(0.0408)	(0.0227)	(0.0418)	(0.0316)	(0.116)	(0.274)	(0.340)	(0.440)	(0.542)	(0.135)	(0.175)	(0.222)
Soil Fertility Dummies																
High Fertility Soil Dummy	-1.393***	-6.900***	2.054***	-1.612***	-0.0563***	-0.585***	5.204***	-4.525***	-2.708***	4.433***	-13.62***	-0.122	-6.653***	1.103***	-0.485**	-2.334***
	(0.00491)	(0.0142)	(4.34e-05)	(0.0370)	(0.0140)	(0.0439)	(0.0944)	(0.0619)	(0.143)	(0.372)	(0.189)	(0.343)	(0.0842)	(0.195)	(0.203)	(0.0924)
Soil Fertility Interactions																
2002 Dummy	-0.595***	-1.170***	-0.935***	1.399***	-0.347***	-0.527***	-1.648***	0.926***	-0.706**	0.323	-0.165	-3.740***	1.511***	0.712***	-0.155	0.204
	(0.0242)	(0.334)	(0.000195)	(0.109)	(0.106)	(0.117)	(0.235)	(0.0948)	(0.297)	(0.686)	(0.454)	(0.293)	(0.171)	(0.271)	(0.572)	(0.223)
2007 Dummy	-0.888***	-1.054***	-0.0552***	2.032***	-1.073***	-0.0878	-0.801***	3.032***	0.135	0.160	-0.391	-0.641	7.488***	1.024***	1.872***	-0.241
	(0.0190)	(0.326)	(0.000344)	(0.105)	(0.103)	(0.0965)	(0.119)	(0.0989)	(0.395)	(0.368)	(0.378)	(0.419)	(0.542)	(0.172)	(0.515)	(0.377)
Water	0.0751***	0.0543***	0.0971***	0.0628***	0.107***	0.472***	-0.0285***	0.334***	0.636***	-0.0260	0.665***	-0.0402	0.985***	0.118***	0.481***	0.208***
	(0.000438)	(0.00206)	(5.70e-06)	(0.00392)	(0.00113)	(0.00379)	(0.00830)	(0.00568)	(0.0183)	(0.0343)	(0.0171)	(0.0391)	(0.00826)	(0.0212)	(0.0171)	(0.00860)
Water squared	0.0143***	0.103***	-0.0434***	0.0316***	0.0108***	-0.0575***	-0.0428***	-0.0210***	-0.0735***	-0.0131**	0.223***	-0.0500***	-0.0561***	-0.0392***	-0.0115***	0.0316***
	(7.94e-05)	(0.000645)	(1.46e-06)	(0.000770)	(0.000196)	(0.000580)	(0.00123)	(0.000930)	(0.00413)	(0.00611)	(0.00302)	(0.00849)	(0.00134)	(0.00444)	(0.00271)	(0.00154)
Composite Input	0.283***	9.652***	-17.93***	-3.403***	-5.294***	-1.108***	-2.263***	5.048***	1.977***	-1.359***	-4.249***	-4.377***	-2.273***	0.223	4.501***	0.860***
	(0.00376)	(0.212)	(0.000682)	(0.0594)	(0.0263)	(0.0154)	(0.0354)	(0.0332)	(0.213)	(0.106)	(0.119)	(0.892)	(0.0235)	(0.267)	(0.0544)	(0.0672)
Composite Input Squared	-0.784***	14.68***	290.7***	6.472***	-6.193***	0.594***	0.0594***	-2.456***	0.866**	0.579***	1.370***	-69.79***	0.00871	7.341***	-7.750***	1.678***
	(0.00313)	(0.451)	(0.00730)	(0.0723)	(0.125)	(0.00807)	(0.0108)	(0.0186)	(0.352)	(0.0613)	(0.153)	(3.988)	(0.0314)	(0.501)	(0.101)	(0.0918)
Water-Composite Input	-	0.651***	-1.804***	-0.111***	-	-0.0104***	-0.0163***	-0.0853***	-0.347***	-0.0469***	-0.248***	5.989***	-	-0.500***	-0.218***	-0.0642***
		(0.0181)	(7.07e-05)	(0.00460)		(0.00100)	(0.00210)	(0.00231)	(0.0224)	(0.00964)	(0.0103)	(0.0910)		(0.0258)	(0.00516)	(0.00585)
Other Control Dummies																
High Slope	-0.629***	0.412***	-0.342***	-0.502***	1.089***	-0.194***	1.444***	0.0326**	-0.594***	-0.944***	-1.021***	-1.100***	1.314***	1.314***	2.216***	-0.282***
	(0.00978)	(0.0393)	(7.43e-05)	(0.0126)	(0.00845)	(0.0126)	(0.0249)	(0.0156)	(0.0693)	(0.262)	(0.294)	(0.266)	(0.0567)	(0.222)	(0.171)	(0.0947)
High Erosion	-0.560***	3.276***	0.510***	0.517***	0.0715	0.0851***	0.270***	-2.743***	-0.259***	0.291	-0.407**	-0.584***	-0.814***	0.842***	-6.482***	1.717***
	(0.00489)	(0.0180)	(6.16e-05)	(0.0406)	(0.0636)	(0.0164)	(0.0308)	(0.0163)	(0.0641)	(0.219)	(0.165)	(0.181)	(0.0433)	(0.142)	(0.115)	(0.0643)
High Summer Rainfall Sea	1.934***	-4.332***	2.245***	-2.163***	-0.801***	-1.038***	-1.808***	5.067***	-0.539***	0.0923	2.498***	0.872***	5.105***	1.838***	0.465***	-1.877***
	(0.0124)	(0.0267)	(3.41e-05)	(0.0259)	(0.0150)	(0.0164)	(0.0311)	(0.0165)	(0.0687)	(0.242)	(0.185)	(0.173)	(0.0461)	(0.160)	(0.131)	(0.0648)
High Summer Rainfall	-0.295***	-2.501***	-1.275***	-2.985***	0.599***	-2.165***	-0.329***	1.034***	-0.273*	-0.960***	-0.537***	-4.406***	4.109***	0.366*	2.403***	-2.566***
	(0.00393)	(0.00928)	(3.72e-05)	(0.0384)	(0.0183)	(0.0456)	(0.107)	(0.0555)	(0.139)	(0.312)	(0.193)	(0.338)	(0.0880)	(0.209)	(0.190)	(0.0809)
High Average Farm Size	-0.776***	0.168***	-0.841***	-0.118***	-	0.594***	0.216**	4.498***	-0.930***	-0.591**	0.464*	0.792**	2.028***	0.723***	-5.877***	-1.023***
	(0.00528)	(0.0265)	(4.88e-05)	(0.0300)		(0.0507)	(0.0968)	(0.0412)	(0.117)	(0.297)	(0.256)	(0.324)	(0.113)	(0.208)	(0.496)	(0.141)
Constant	-4.185***	-5.113***	-2.368***	-2.692***	-4.439***	-1.018***	-3.220***	-5.410***	-2.455***	-6.066***	-4.564***	-3.147***	-8.401***	-4.805***	-3.475***	-3.627***
	(0.00400)	(0.0120)	(3.00e-05)	(0.0260)	(0.00917)	(0.0180)	(0.0419)	(0.0197)	(0.0805)	(0.255)	(0.229)	(0.250)	(0.0586)	(0.202)	(0.150)	(0.0772)
Sigma	0.00127***	0.00797***	4.60e-06***	0.00280***	0.00276***	0.00702***	0.00966***	0.00604***	0.0109***	0.0223***	0.0224***	0.0144***	0.00957***	0.00957***	0.0203***	0.0118***
	(3.81e-06)	(2.37e-06)	(1.03e-07)	(6.09e-07)	(8.77e-07)	(0.000297)	(0.000132)	(0.000103)	(4.43e-05)	(0.000808)	(0.000880)	(0.000435)	(0.000202)	(0.000222)	(0.000963)	(6.56e-06)
Log-Likelihood	47.02296	20.10015	146.1234	44.82197	28.55698	24.33469	18.36155	25.91195	20.27358	1.062379	-3.28089	6.530787	14.66743	20.44522	0.889112	13.46514
AIC[A]	-80.0459	-22.2003	-274.247	-69.6439	-41.114	-22.6694	-12.7231	-31.8239	-14.5472	27.87524	32.56177	10.93843	-5.33485	-16.8905	18.22178	-4.93029
BIC [B]	-66.9475	-5.3595	-257.406	-50.9319	-26.1444	1.656237	9.731304	-13.1119	9.778461	55.94326	56.88739	33.39284	17.11956	5.563964	36.93379	15.65292
Observations	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Estimates presented are conditional partial effects. See Wooldridge (2002, p.527).

[A] Alkaike Information Criterion

[B] Bayesian Information Criterion

Table A.2: Normality and Heteroskedasticity Tests

	Wheat	Lucerne	Lemons	Oranges	Naartjies	Apples	Peaches	Pears	Table Grapes	Wine Grapes	Potatoes	Tomatoes	Onions	Pumpkins	Carrots	Cabbage
Conditional Moments test for Normality^A																
Test Statistic	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	2.000	1.000	1.000	0.000	1.000	1.000	0.000
p-value	1.000	1.000	1.000	1.000	1.000	1.000	0.607	1.000	1.000	0.368	0.607	0.607	1.000	0.607	0.607	1.000
Lagrange Multiplier Test for Heteroskedasticity^B																
Test Statistic	18.000	25.000	18.000	25.000	16.000	23.000	27.000	23.000	33.000	39.897	36.000	26.000	23.000	29.000	23.000	28.000
p-value	0.998	0.960	0.998	0.960	1.000	0.981	0.927	0.981	0.739	0.430	0.607	0.945	0.981	0.879	0.981	0.905

^{A} Conditional moments test of the null hypothesis test that the residuals are normally distributed. Distributed as a Chi-Squared (1) variable. See Pagan and Vella (1989).

^{B} Lagrange multiplier test of the null hypothesis that the residuals are homoskedastic. Distributed as a Chi-squared (40) variable. See Greene (2003, p.769)

Table A.3: Marginal Value Estimates by Magesterial District for the Berg WMA

Magesterial District	Wheat	Lucerne	Oranges	Lemons	Naartjies	Peaches	Pears	Apples	Table Grapes	Wine Grapes	Potatoes	Tomatoes	Onions	Pumpkins	Carrots	Cabbages
Bellville	-	0.16 ***	2.44 ***	1.89 ***	-	1.07 *	1.93 ***	0.93 ***	13.40 ***	11.48	-	5.28 **	1.82 ***	1.12 **	2.35 **	1.10 ***
		(0.01)	(0.93)	(0.42)		(0.65)	(0.15)	(0.17)	(3.32)	(7.78)		(2.22)	(0.58)	(0.56)	(1.06)	(0.17)
Ceres	0.05 ***	0.63 ***	1.42 *	1.68 ***	1.20 ***	6.62 ***	2.40 ***	1.94 ***	0.75	0.54	4.98 ***	3.08	3.91 ***	1.15 **	2.14 *	2.30 ***
	(0.01)	(0.07)	(0.79)	(0.43)	(0.07)	(0.54)	(0.41)	(0.34)	(1.00)	(0.70)	(1.21)	(2.62)	(0.70)	(0.58)	(1.11)	(0.41)
Hopefield	0.03 ***	0.85 ***	-	-	-	-	-	-	0.11	-	1.35 ***	-	-	-	-	-
	(0.01)	(0.06)							(0.69)		(0.42)					
Kuilsriver	-	-	-	-	-	-	-	-	1.91	1.78	4.97 ***	4.54 ***	3.24 ***	0.93 **	1.88 ***	2.49 ***
									(2.79)	(0.45)	(1.19)	(1.70)	(0.19)	(0.38)	(0.47)	(0.86)
Malmesbury	0.09 ***	0.54 ***	1.65 **	1.67 ***	1.92 ***	2.38 ***	1.55 ***	3.40 ***	6.71 **	0.37	4.48 **	5.82	1.74 ***	1.02 *	2.25 *	3.78 ***
	(0.03)	(0.05)	(0.84)	(0.43)	(0.10)	(0.38)	(0.14)	(0.47)	(3.28)	(6.53)	(1.80)	(3.88)	(0.61)	(0.57)	(1.18)	(0.60)
Moorreesburg	0.04 ***	0.38 ***	1.44 *	2.11 ***	-	3.62 ***	-	1.87 ***	6.61 *	0.52	3.36 **	6.46	1.67 ***	1.12 **	-	-
	(0.01)	(0.03)	(0.79)	(0.47)		(0.49)		(0.35)	(3.92)	(0.70)	(1.50)	(1.93)	(0.58)	(0.57)		
Paarl	0.66 ***	0.03 ***	2.04 **	2.96 ***	1.92 ***	2.59 ***	0.94 ***	2.75 ***	4.37 ***	1.15	1.31	3.71	1.20 **	1.04 *	2.17 *	3.46 ***
	(0.23)	(0.00)	(0.90)	(0.52)	(0.13)	(0.52)	(0.20)	(0.24)	(0.66)	(0.96)	(2.05)	(2.78)	(0.57)	(0.58)	(1.18)	(0.59)
Piketberg	0.02 **	1.73 ***	2.47 ***	2.29 ***	0.81 ***	3.74 ***	0.73 ***	2.80 ***	3.56 ***	1.16	2.25	1.84	1.54 ***	1.03 *	-	0.54 ***
	(0.01)	(0.15)	(0.96)	(0.48)	(0.06)	(0.70)	(0.19)	(0.23)	(0.40)	(0.89)	(1.81)	(1.63)	(0.44)	(0.56)		(0.09)
Simon's Town	-	-	-	-	-	-	-	0.99 ***	-	12.12 *	-	-	-	-	1.66 ***	-
								(0.11)		(6.26)					(0.46)	
Somerset West	-	-	-	-	3.13 ***	8.05 ***	0.55 ***	4.32 ***	6.69 ***	6.81	4.10 *	3.24	1.69 ***	0.94 *	0.94	1.79 ***
					(0.16)	(1.71)	(0.15)	(0.23)	(1.45)	(6.07)	(2.51)	(1.64)	(0.54)	(0.48)	(0.48)	(0.17)
Stellenbosch	-	0.59 ***	1.57 *	2.24 ***	1.60 ***	9.51 ***	2.59 ***	5.10 ***	7.56 **	7.03	2.82 *	9.71	1.06 *	1.24 *	1.70	2.92 ***
		(0.05)	(0.81)	(0.46)	(0.08)	(1.10)	(0.30)	(0.64)	(2.47)	(9.61)	(1.47)	(6.16)	(0.55)	(0.66)	(1.11)	(0.45)
Strand	-	-	-	-	-	1.73 ***	0.96 ***	1.12 ***	-0.22	1.99	-	-	1.73 ***	-	-	-
						(0.52)	(0.33)	(0.10)	(0.44)	(0.30)			(0.20)			
Tulbagh	0.04 ***	0.70 ***	1.77 **	2.45 ***	3.63 ***	4.97 ***	1.03 ***	0.96 ***	3.39 ***	-0.24	1.65 ***	2.26	1.95 ***	1.09 *	-	1.21 ***
	(0.01)	(0.06)	(0.86)	(0.50)	(0.19)	(0.43)	(0.15)	(0.21)	(0.97)	(1.41)	(0.62)	(1.81)	(0.62)	(0.58)		(0.20)
Vredenburg	-	-	-	-	-	-	-	-	-	3.11 ***	-	-	-	-	-	-
										(1.09)						
Wellington	-	-	1.55 **	2.72 ***	1.36 ***	3.27 ***	0.98 ***	1.35 ***	7.54 ***	3.36	3.19	4.38 ***	1.36 ***	0.95 **	-0.31	2.36 ***
			(0.77)	(0.39)	(0.23)	(0.80)	(0.16)	(0.15)	(1.63)	(2.89)	(2.27)	(1.32)	(0.35)	(0.49)	(0.62)	(0.24)
Wynberg	-	-	-	-	-	5.39 ***	-	3.05 ***	1.20	6.65	8.34 ***	4.16 **	3.58 ***	1.53 ***	1.54 ***	1.39 ***
						(1.23)		(0.12)	(0.94)	(9.94)	(2.73)	(2.12)	(0.49)	(0.25)	(0.52)	(0.42)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

A dash indicates no estimate available because no data on irrigated production of that crop was available in that magisterial district