J Hum Ecol, 71(1-3): 8-15 (2020)
PRINT: ISSN 0970-9274 ONLINE: ISSN 2456-6608
DOI: 10.31901/24566608.2020/71.1-3.3220

The Economic Impact of Policy Interventions to Mitigate Water Use in Irrigation Agriculture in South Africa

H. Jordaan[1] and Y.T. Bahta[2*]

The University of the Free State, Department of Agricultural Economics, P.O. Box 339, Internal Box 58, Bloemfontein 9300, South Africa
Phone: [1]<+2751 401 9648>, [2]<27514019050), [1,2]Fax: +2751 401 3473

KEYWORDS Behavior. Computable General Equilibrium Model. Social Accounting Matric. Soil Water Irrigation Planning – Energy model. Water Charge. Water Restriction

ABSTRACT The recent severe drought in South Africa forced the different stakeholders to change the behavior of water users through policy interventions. This paper assesses the impact of policy intervention on irrigation agriculture using a modified IFPRI CGE, SWIP – E model and SAM. The result showed that when water restrictions were set it was more profitable to reduce the number of hectares planted and rather apply full irrigation to produce higher yields. The increase of irrigation water tariffs had a minimal impact on yield. The main challenge was the availability of the water, not the policy interventions. The study recommends that without a behavior change of farmers, the water policy interventions will not achieve the desired goal. Governments with different stakeholders should introduce a mechanism to educate farmers and enhance their understanding of the past, current and future trends of water and drought to plan and mitigate unexpected shocks.

INTRODUCTION

Water is one of the most important natural resources in the development of civilizations. The importance of water lies in the fact that it satisfies a broad group of needs, as well as its role as a basic input in agricultural and industrial production processes (Roibas et al. 2007). The demographic structure of the population, climatic factors, institutions, and macroeconomic policy determine the periodic water shortages and will continually reappear. Therefore, it gives rise to the need for policies, which limit water consumption and change consumers' behaviors towards water use (Connor et al. 2015). Alavian et al. (2009) suggested that policy interventions could significantly affect water demand and water availability.

The rapid increase in urbanization and population threatens food security, environmental sustainability, sustainable intensification of agriculture, and resource allocation (FAO 2009). The population surge has resulted in further straining resources, specifically water resources, as there are more mouths to feed, with the world's population estimated to reach over 9 billion by 2050. The sustainability of water resources is already under pressure in agriculture given that the sector consumes approximately 60 percent of South Africa's already scarce water resources. To facilitate the development and implementation of water, saving initiatives in agriculture, several stakeholders, including governments, organizations, development partners and practitioners have shown interest to participate in such initiatives (LENNTECH 2016).

Recurring droughts coupled with subsequent water restrictions have worsened the water scarcity problem in many regions, with South Africa being no exception. More often than not, drought periods are succeeded by water rationings to match supply with demand. The impact of water restriction policies on the wellbeing of households has been quantified in the literature (Roibas et al. 2007; Burdack 2011; Cooper et al. 2019).

Climate variability and the recurrent agricultural drought affects the production of South Africa agribusiness (Pereira and Ruysenaar 2012). South African consumers are not different from other countries, recently different provinces had to cut water usage (water restriction) by 15 percent, and the agricultural sector would have to reduce water use by 50 percent (Water and Sanitation Department 2017).

The applicability of the Computable General Equilibrium (CGE) model is evident in literature,

Address for correspondence:
E-mail: Bahtay@ufs.ac.za, Yonas204@yahoo.com
ORCID: Yonas T. Bahta;
http://orcid.org/0000-0002-3782-5597

as a number of water management studies have applied the model. Hertel and Liu (2019) applied a CGE model to assess the impact of water scarcity on growth. Gomez et al. (2004) applied a CGE model to investigate potential water saving scenarios in the Balearic Islands. Luckmann et al. (2014) and Fang et al. (2016) analyze water allocation problems and water shortage using a CGE model. Cazcarro et al. (2011) applied a modified IFPRI-CGE model to analyze different payment scenarios on behavioral and macroeconomic variables of agriculture and industry sectors.

Objectives

The objective of this study is to assess the impact of policy-driven water cost changes (rate) and water restrictions on output, yield, consumption, and other macroeconomic variables in irrigation agriculture[1]. The results can apply to, not only South Africa but also the Southern Africa region and globally. However, despite the increased interest in sustainable water management in food production, especially in South Africa, to the best of our knowledge, no empirical research exists to explore and integrate human behaviors into the diverse factors influencing water use in food production.

METHODOLOGY

Theoretical and Empirical Framework of (SWIP – E) Model

The SWIP – E model (Venter 2015) was used to calculate the effect of water restrictions on crop yield, the area planted and gross margin of maize and wheat. The SWIP – E programming model is based on the SAPWAT optimization (SAPWAT – OPT) (Grové 2008) model that optimizes a daily soil water budget for a single crop. The SAPWAT – OPT model was further developed to optimize water use for a crop rotation system. Detailed electricity cost calculations are included in the model to facilitate electricity management in an irrigated way.

The objective function maximizes the gross margin of a crop rotation system. Equation (1) represents the objective function used in the SWIP – E model:

$$MAX: GM = \Sigma_c PI_c - \Sigma_c YDC_c - \Sigma_c ADC_c - \Sigma_c IDC_c \quad (1)$$

GM is the total gross margin (R),

PI_c is the total production income for crop c (R),

YDC_c cis the Total yield dependent costs for crop c (R)

ADC_c is the total area dependent costs for crop c (R) and

IDC_c is the total irrigation dependent costs for crop c (R)

The first four terms of the objective function calculate the gross margin for specified crop rotation. Production income, yield, area, and irrigation dependent costs are based on the calculation procedure recommended by Venter (2015).

Production income is a function of yield, the area planted for each crop and the price of the crop. Production income is calculated by multiplying the crop yield with the crop price and area planted. The calculation of yield dependent costs is based on a cost reduction method (Grové 1997). Area-dependent costs include all input costs which will change the area planted. Irrigation Dependent Costs (IDC) include electricity, labor, repair and maintenance and water cost of the irrigation system. Total electricity costs depend on the type of electricity tariff. All tariff options include a fixed and variable cost. Fixed costs have to be paid every month irrespective of whether electricity was used or not while variable costs have to be paid for electricity consumption. Variable electricity costs are a function of management (hours pumped), electricity tariffs and irrigation system design (KiloWatt (kW)).

The calculation procedures for labor and repair and maintenance costs are based on formulas proposed by Meiring (1989). Water charges are a function of the irrigation water applied, the area planted and the water tariff charged by the water user association.

Theoretical and Empirical Framework of a CGE Model

To evaluate the impact of different policy-driven scenarios of water on the grain sub-sector (maize and wheat), a modified IFPRI CGE model was used. The model solved using GAMS calibrated to the 2009 SAM for South Africa as a database developed by IFPRI (2014). The model is initially set up to replicate the base year SAM by appropriately calibrating the parameters of the model (Lofgren et al. 2002). Most of the parameters of the model are calibrated from the SAM, however, the Armington elasticities are obtained from Gibson for some agricultural and non-agricultural products and selected agricultural products (Gibson 2003; Ogundeji et al. 2010). A mathematical summary of a CGE model available from Lofgren et al. (2002).

Adopting the work of Cazcarro et al. (2011), taxes were included in the model after calibration as follows (Equations 2 and 3):

$$TAXPAR(\text{'TX'},AC) = TAXPAR(\text{'TX'},AC) + Scenario(\text{'TX''},AC) \quad (2)$$

The tax rates defined by:

$$tAC = \frac{TAXPAR(\text{'TX'}, AC)}{SAM(AC/\text{'TOTAL'})} \quad (3)$$

Where TAXPAR is the set of tax accounts, TX incorporating consumption taxes, export taxes, and activity taxes, AC represents activities or commodities, and Scenario is the increment in payment in proposed scenarios.

A Constant Elasticity Substitution (CES) production technology was used for irrigated farming (Equations 4 and 5):

$$QA_a = a^a_a(\delta^a_a \,.\, QVA_a{}^{-Pa}{}_a + (1-\delta^a_a).\, QINTA_a{}^{-Pa}{}_a)^{\frac{-1}{P^a_a}} \quad (4)$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a}\;\frac{\delta^a_a}{1-\delta^a_a}\right)^{\frac{1}{1+p^a_a}} \quad (5)$$

α^a_a is used to change the level of agricultural productivity. The production technology of the rest of activity is a Leontief technology expressed as (Equations 6 and 7):

$$QVA_a = iva_a \cdot QA_a \quad (6)$$

$$QINT_a = ivt^a_a \,.\, QA_a \quad (7)$$

The water-saving of the model was estimated as (Equations 8 and 9):

$$water\ saving\ via\ export_c = \lambda^1.QE.L_c\text{-}\lambda^0.\ QEC_c \quad (8)$$

$$water\ saving\ via\ households_{c,h} = \lambda^1.QH.L_{c,h}\text{-}\lambda^0.\ QHC_{c,h} \quad (9)$$

Where QEC_c exports in calibration scenario, $QE.L_c$ exports in the final scenario, $QH.C_{c,h}$ household consumption calibration scenario, $QH.L_{c,h}$ household consumption in the final scenario, λ^0 vector of water value in calibration scenario, λ^1 vector of water value in calibration in the final scenario.

The consumer price index (CPI) was fixed and functions as numeraire were used in the model (Equation 10):

$$CPI = \Sigma_{c\varepsilon C}\, PQ_c - cwts_c \quad (10)$$

Where $cwts_c$ weight of commodity 'c' in the consumer price index and PQ_c is the price of composite good 'c'.

The production elasticities were set at 1.2 and 0.6. Household expenditure aggregated into 14 income classes up to three broad categories of poor household, encompassing the bottom 40 percent of the income-earning households; a middle class, covering the 40–80 percent of the income-earning households; and the rich households class above 81 percent income-earning households. Rich household income elasticities were set at 0.5 for agricultural products, 0.7 for mining products, 0.8 for industry sectors and 1.3 other service sectors. Middle-class households' income elasticities were set at 0.6 for agricultural products, 0.8 for mining products, 0.85 for industry sectors and 1.4 for other service sectors. Poor household income elasticities were set at 0.7 for agricultural products, 0.9 for mining products, 0.9 for industry sectors and 1.5 for other service sectors. The general trend is consistent with Philippides et al. (2011), they argue that poor households exhibit higher income elasticities than richer households, reflecting the larger consumption share of subsistence expenditure. Export demand elasticities were set at 0.9 and 2. The Frisch parameter, which allows for the determination of a subsistence floor in household expenditure, was set to a constant across all household deciles at a value of 2.

The original SAM provided a detailed representation of the South African economy with 49 activities and 85 commodities; labor was disaggregated by education level and households by per-capita expenditure deciles (Rob and Thurlow 2013).

The South African SAM does not include specific accounting for the grain sector (maize and wheat). The grain sector was included in the "Agriculture" account. To conduct an analysis, the grain sector was separated from the aggregated 'Agricultural' account. The grain sector was disaggregated using a different source of data. For the share of gross output to total agricultural output, data from the Department of Agriculture, Forestry, and Fisheries were used (DAFF 2014). The share of maize and wheat gross output (gross value of output) in 2009 was 11.51 percent and 2.43 percent to total agricultural output respectively. The share of export and import to total agricultural export and import used information from the International Trade Centre (ITC 2014) and National Agricultural Marketing Cooperation (NAMC 2014). The share of maize and wheat export in 2009 was 8.18 percent and 0.50 percent to total agricultural export respectively, and the share of maize and wheat import in 2009 was 0.51 percent and 6.58 percent to total agricultural import respectively. Furthermore, the maize and wheat sectors were disaggregated into irrigated and non- irrigated farming. Based on Statistics South Africa (2012) in 2009, about 19 percent of maize production and 30 percent of wheat production were based on irrigated land. Information on import tariff and household expenditure was obtained from ITC and Income and Expenditure (IES) respectively (Statistics South Africa 2015). As a result of all the data discrepancies, the SAM was unbalanced and the Cross-Entropy (CE) method was used to balance the SAM. Balancing SAM using CE is explained in detail (Shannon 1948; Kullback-Leibler 1951; Zellner 1962; Theil 1967; Robinson et al. 2000; Bahta et al. 2014; Lee and Su 2014).

Description of Scenarios

Policy scenarios regarding the increase of water tariffs and water restrictions affecting direct users (farmers), indirect users (agri-food industry) and end-users (households) were used for analyses. These policies were included to examine user responsibility and macroeconomic effects on agriculture and other industries. It is believed that supply cut (water restriction measures) and pricing policies, (an increase of water tariff) can be seen as a water conservation strategy.

The reasoning behind the selection of the particular scenarios used for the analyses was as follows: the worst drought in South African history since 1982 and climate change triggered the government to try to reduce water usage by 15 percent (Department of Water and Sanitation, 2016) with water restriction tariffs (an increase of water tariff) and punitive measures. The restriction tariffs are imposed in a stepped manner: 10 percent extra on consumption between 20000 liters and 30000 liters/month, 20 percent on consumption between 30000 and 40000 liters/month, and 30 percent on consumption above 40000 liters/month. Based on the Water and Sanitation Department (2017) the average, South African irrigation water tariff stood at 14.91cents/m.

A steep fall (15%) of water usage and an increase of 30 percent for water tariffs were chosen to calculate the effect of water restrictions on crop yield, the area planted and gross margin of maize and wheat using the CGE and SWIP – E models. Also considered were the potential implications of such events to direct users, yield, indirect users and end-users to examine user responsibility and macroeconomic effect on agriculture and other industries.

RESULTS

The SWIP – E Model

The analyses included a full water allocation and a water restriction scenario for a small and large center pivot where the hectares were either fixed or variable. A water restriction of 15 percent was used, thus the full water allocation of 1000 mm/ha/year was reduced to 850mm/ha/year. Table 1 illustrates the results for fixed and variable hectare scenarios with full water allocation and water restrictions. When the hectares were fixed, crop yield was close to potential yield for maize (18 ton/ha) and wheat (8 ton/ha) under a full water allocation for both center pivot sizes. However, when water restrictions were introduced, crop yield decreased to 13.98 ton/ha and 7.10 ton/ha of maize and wheat, respectively. The decrease in yield resulted in a decrease in gross margin for both center pivot sizes. Gross margin decreased with ZAR 157 475 and ZAR 248 513 for the small center pivot (30.1 ha) and large center pivot (47.7ha), respectively.

CGE Model

The increase of tariffs for irrigation farming had a multiplier effect on the industry and household expenditure. As a result, household con-

Table 1: Results for a fixed and variable hectare scenario for full water allocation and water restriction

		Fixed hectares Water allocation (mm/ha)				*Variable hectare Water allocation (mm/ha)*			
		1000		*850*		*1000*		*850*	
		Maximum pivot size (ha)		*Maximum pivot size (ha)*		*Maximum pivot size (ha)*		*Maximum pivot size (ha)*	
		30.1	47.7	30.1	47.7	30.1	47.7	30.1	47.7
Yield (ton/ha)	Maize	17.53	17.53	13.98	13.98	17.95	17.95	17.95	17.95
	Wheat	7.45	7.45	7.10	7.10	7.50	7.95	7.50	7.95
Hectare (ha)	Maize	30.1	47.7	30.1	47.7	29.1	40.8	21.1	28.2
	Wheat	30.1	47.7	30.1	47.7	30.1	47.7	30.1	47.7
Applied water (mm/ha)	Maize	553	553	429	429	568	568	568	568
	Wheat	447	447	421	421	452	514	452	514
Irrigation dependent costs (ZAR)	Maize	30700	52240	24477	41563	30467	45932	22134	31753
	Wheat	27292	47037	25672	44246	27548	54054	27548	54054
Gross Margin (ZAR)		899210	1425825	741735	1177312	900884	1403664	769121	1195831

Source: Authors' calculations

sumption expenditure on all commodities of the poor household categories was the most affected compared to the middle class and rich households categories and reduced by ZAR[2] 37 093. At a commodity level, the consumption of irrigated and non-irrigated maize had the highest increase for poor household categories (ZAR 132 360) compared to the middle (ZAR 118 163) and rich household categories (ZAR 87 652).

For irrigated wheat again, poor households spent more (ZAR 3407) compared to middle-income households (ZAR 3041) and rich households (ZAR 2256). A similar trend was observed for non-irrigated maize and wheat consumption expenditure. The results indicated that poor households most affected with the lowest welfare (EV) gain observed in their categories.

Regarding factor activity, economy wage (rent) for activity factor, price of a factor for activity and factor income for all commodities and specific commodities decrease. All labor categories of workers (with different levels of school) decreased except workers with tertiary school levels.

The result of selected macro-variable indicators suggests that import and export decreased with tariff hikes. An increase in GDP, consumption and net income was observed, however, the increase is insignificant. At the industry level, the increase in irrigation water tariffs did not have an impact on the GDP of the industry.

Aggregate marketed commodity output for irrigated and non-irrigated wheat and maize decreased, as a result, it influences the relative prices of agricultural products directly, but insignificantly. The result indicated that a decrease in irrigated maize (ZAR 4619), non-irrigated maize (ZAR 975), irrigated wheat (ZAR 1244) and non-irrigated wheat (ZAR 30 742).

The price of value-added is the amount and the weighted average price that every industry pays for all the factors of production. It is therefore influenced by the wage rates of labor, the rate of returns and capital. The result indicated that the price of value-added of the grain sector (irrigated and non- irrigated maize and wheat) decreased insignificantly. The highest decrease was observed for irrigated maize (ZAR 2 478).

The results showed an increase in the price of intermediate inputs for agriculture and grain (wheat and maize) sectors, because of increases in purchase prices. The result showed that an increased price of intermediate inputs for irrigated maize (ZAR 21 510), non- irrigated maize (ZAR 67 568), irrigated wheat (ZAR 1 560) and non-irrigated wheat (ZAR 1 250).

The industry average output price is the weighted average of the price of intermediate inputs and the price of value-added. The result indicated that when export quantity and prices of grain (maize and wheat) and the agriculture sector decreased, the average output price decreased at a minimal rate. However, the quantity of maize and wheat imported increased insignificantly. The quantity of maize and wheat for domestic sales increased at a minimal rate.

DISCUSSION

The SWIP – E Model

The decrease in gross margin was mainly from the decrease in production income. Area-dependent costs remained constant, but irrigation and yield dependent costs decreased due to the decrease in water application and crop yield. However, the effect of the decrease in production income was more than the decrease in irrigation and yield dependent costs, therefore, resulting in a decrease in the gross margin.

When the hectares were variable the crop yield for maize and wheat remained constant with a full water application as well as with a water restriction scenario. However, the planted maize (in hectares) reduced. The main reason for the reduction was that full irrigation produced higher yield and the income received from higher yield was more than the cost to produce more hectares. This resulted in higher gross margins. The gross margin for the small and large center pivot increased with R 27 386 and R 18 519, respectively under a water restriction scenario. Burdack (2011) indicated that water restriction has a significant impact on yield.

CGE Model

Regarding the household consumption expenditure on grain, poor households spent more than middle- class and rich household categories. This also highlighted by Deya-Toretlla et al. (2016) the increase in water tariff has a significant impact on consumption.

The effect on the household welfare measured by Equivalent Variation (EV), implies that the money equivalent to whether households are better or worse off, because of the simulation. The poor household categories gaining lower welfare compared to the rich household categories. This study concurred with the finding of Burdack (2011) who highlighted that the welfare effect of policy intervention.

Aggregate marketed commodity output for irrigated and non-irrigated wheat and maize decreased. A possible reason could be that Rand slump led to increasing costs of imports such as oil and fertilizer. While shipping costs were also paid in dollars and linked to the dollar-based oil price, these should not outweigh the benefits of exporting on a weaker rand.

A price of intermediate inputs is the share of maize and wheat industries to the aggregate intermediate product. The majority of intermediate inputs such as fertilizer and fuel were imported. Based on different studies, for every one-cent increase in the diesel price, fuel spent in the agricultural sector increased by R10 million/annum.

CONCLUSION

The conclusion is that when water restrictions are set it is more profitable to reduce the number of hectares planted and apply full irrigation to produce higher yields. However, various factors will influence the decision of the irrigator, such as crop prices, water, and electricity costs. Therefore, it is significant to assess the current economic environment to make the best decision when water restrictions are set.

From the result of the CGE model, it can be concluded that the increase in irrigation water tariffs has an impact to some extent, but the impact is minimal. The main challenge is the availability of a scarce resource (water), not the incremental water tariff.

RECOMMENDATIONS

The study recommends that without the behavioral change in farmers, the application of policy interventions will not achieve the desired result. The government with different stakeholders should introduce a mechanism to educate farmers and enhance their understanding of the past, current and future trends of water scarcity and drought to plan for and mitigate unexpected future shocks.

ACKNOWLEDGMENTS

The paper is based on research that was conducted as part of a research project, “determining the water footprints of selected field and forage crops towards sustainable use of freshwater (K5/2397//4)", which was initiated, managed, and funded by the WRC. Financial and other assistance by the WRC is gratefully acknowledged. Financial assistance by the University of the Free State through the Interdisciplinary Research Grant is also gratefully acknowledged. We acknowledge also Liesl van Der Westhuizen (chief officer; Science Writer) for language editing of this manuscript.

ABBREVIATIONS

The following abbreviation is used in this manuscript:

CE: Cross-Entropy
CES: Constant Elasticity Substitution
CGE: Commutable General Equilibrium model
DAFF: Department of Agriculture, Forestry and Fisheries
EV: Equivalent Variation
GAMS: General Algebraic Modelling System
FAO: Food and Agricultural Organization
IDC: Irrigated Dependent Costs
IFPRI CGE: International Food Policy Research Institute Commutable General Equilibrium model
ITC: International Trade Center
KW: Kilo Watt
NAMC: National Agricultural Marketing Cooperation
SAM: Social Accounting Matrix
SARB: South African Reserve Bank
SWIP – E: Soil Water Irrigation Planning – Energy model
WRC: Water Research Commission
ZAR: South African currency (Rand)

NOTES

1. This paper is part of the big project: Determining the water footprints of selected field and forage crops, and derived products in South Africa.
2. ZAR is the South African currency Rand - (1US$= Rand 8.44 - 2009- Exchange Rate), Source: SARB (2018).

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Paper received for publication in February, 2020
Paper accepted for publication in March, 2020