THE SOCIO-ECONOMIC CONSEQUENCES OF THE IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN SOUTH AFRICA

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Most of the climate change models for South Africa predict a reduction in freshwater availability by 2050, which implies that water availability for sectoral production activities is expected to decline. This decline has an impact on sectoral output, value added and households' welfare. Using a computable general equilibrium approach, this study investigates the possible impact of global change on households' welfare. The simulation results show that water scarcity due to global change can potentially lead to a general deterioration in households' welfare. The poor households, whose incomes are adversely impacted, are the most vulnerable to the consequences of the impact of global change on water resources in South Africa. This vulnerability can only be reduced if welfare policies that maintain food consumption levels for the least and low-income households are implemented

1 INTRODUCTION

Global freshwater availability is projected to decline in the future as a result of climate change, increased industrial activities and wasteful use of the resource (Rosegrant *et al.*, 2002). In South Africa, climate change models predict an increase in temperature between 2.5^0C and 3^0C by 2050. Some models predict a catastrophic reduction of 70 percent in mean annual runoff (MAR), while others predict between 10 and 30 reduction in MAR (Turpie *et al.,* 2002). Because of the concern for environmental sustainability, 10 percent of the renewable water resources should be reserved for ecological services in South Africa (DWAF 2005). The ecological reserve requirement can change in response to changes in freshwater availability in the country. These changes can lead to a reduction in water availability for sectoral production activities, and competition among the production sectors for the use of the scarce resource.

Reduction in sectoral water availability has consequences for the production of food and non-food items in the country; hence, it has welfare implications households. The need to investigate the possible consequences of water scarcity and recommend short-run policies that can minimize those consequences in South Africa requires an analysis of both the economic and social consequences of the impact of climate change on water resources. Therefore, this study uses a computable general equilibrium approach to analyze the impact of climate change on households' welfare via its impact on water resources in South Africa. Although climate change has a direct impact on human health, water resources, livestock, agricultural productivity and the economy, this study focuses on the socio-economic consequences of the impact of climate change on water resources in South Africa.

2 DATA, THEORETICAL FRAMEWORK AND MODELLING PROCEDURE

This section discusses the data and model used in the study. Particular attention is given to the standard computable general equilibrium conditions and the specific model closures assumed for the study.

2.1 Description and sources of data

The study updates, aggregates and uses the 1998 social accounting matrix (SAM) for South by Thurlow and van Seventer (2002). The TIPS 2003 supply-use table was used to update the 1998 activities and commodities accounts (TIPS, 2004). The information on household income and expenditure patterns were extracted from Statistics South Africa 2001 census figures.

The updated SAM was aggregated to 13 activities/commodities consisting of agriculture (AGR), mining (MIN), beverages and tobacco (AGI), textiles and wearing apparel (TEX), wood, paper and printing (PPP), petroleum products (PET), chemicals (CHM), heavy manufacturing (HEV), machinery and equipment (MAC), other manufacturing (OHM), electricity (ELE), construction (CON) and services (SER). These aggregations reflect the structure of water use by these sectors or sub-sectors.

2.2 Water

As a key factor in this study, the use of water requires a detailed description of the water data sources and adjustments made to the SAM to properly account for sectoral water allocation and use in the economy. The water supply information from the municipalities' billing records grossly understates the actual water used by the different sectors, because most sectors use self-supplied water. These entries were therefore replaced by the information published in Statistics

South Africa water accounts for the nineteen water management areas (STATSSA, 2004). Using the municipal water tariff schedule the monetary value of the physical quantities of water used by each production sector was computed.

In Thurlow and van Seventer (2002), water is treated as a production sector, with the row accounts showing water used as a fixed intermediate input by each of the other production sectors and as a final good by households. It also shows payments by these sectors and institutions to the water sector. The column entries show payments by the water sector to the other sectors for the use of other intermediate inputs and factors services. A key objective in this study is to investigate the macroeconomic implications of water reallocation from the agriculture to the non-agriculture sectors on the basis of efficiency. Consequently, treating water as a fixed intermediate input (as is usually the approach in standard CGE models) is not suitable. Therefore, water enters into the production process as a third factor of production (value added function) and not as a fixed intermediate input.

As a factor of production, the row accounts represent distribution of water among the production sectors and the respective payments by these production sectors for the use of this factor. Households initially used water as a final good and made payments to the water sector for this good. These payments are removed from the water accounts and transferred to government which provides the service via its municipal water supply networks. The initial account payments from the other production sectors to the water sector are maintained in the adjusted SAM as payments for the use of this factor. Water no longer pays for factor services as well as for fixed intermediate inputs. To balance the SAM again the study assumes that all factor payments to water accrue to government which is recorded as part government receipts. This increases government revenue. In its expenditure accounts, government's net investments as well as payments to the services sector increases. This is followed by a corresponding increase in investments in water delivery infrastructure and services payments to the factors of production. The increased factor payments are finally redistributed among the various household categories. Government also pays the rest of world for the use of water from sources outside South Africa. The adjusted SAM is presented in the appendix.

The adjusted SAM has three factors of production (water, capital and labour, which comprises unskilled, medium-skilled and high-skilled labour). There are also five household accounts (the first to the fifth quintile). Each quintile represents 20 percent of the households in that category. Ranked from first to fifth, the quintiles represent the least-income, low-income, middle-income, high-income and highest-income households respectively.

Households receive income from wages and from both local sources (government and inter-personal transfers) and international transfers. Their disposable income is allocated to consumption and savings. Households' consumption is divided into food and non-food consumption. Food consumption is determined by households' expenditure on agriculture and beverages and tobacco sectors. Non-food consumption expenditures are those incurred on the other sectors, which are further divided into durables and non durables. These divisions are the basis for welfare policy investigations. Sectoral output is sold to the production sectors as intermediate input, consumed domestically, or exported. Government accounts, which were broken down into expenditure and income accounts in the original SAM are maintained.

2.2 The theoretical framework

A Computable General Equilibrium (CGE) model is used to present a counterfactual picture of the impact of efficient water allocation on households' welfare in South Africa. The study adopts the CGE framework developed by Strzepek and Carbone (2007). This framework uses the mathematical programming system for general equilibrium (MPSGE), which is a GAMS extension developed by Rutherford (1998), with the MCP GAMS solver. The model uses multi-level nested production functions to determine the level of production. Sectoral outputs are represented by a Leontief's combination of fixed intermediate consumption and value added. The model also specifies a constant elasticity of substitution (CES) function to establish the relationship between inputs and output. However, the use of capital is modelled by a Leontief's fixed proportions functions, because the short-run use of capital is fixed and sector specific. Conversely, water and the three labour categories are freely mobile across sectors except where specified. Therefore, the use of these inputs is modelled by the CES function. This allows the functioning of a competitive market to efficiently allocate the mobile factors. Therefore, these mobile factors move to sectors where factor returns are highest. The free movement of these factors of production enhances the adjustment of wages for each of the three labour categories to achieve equilibrium in the factor markets.

The model uses the constant elasticity of transformation (CET) function to formulate the imperfect substitution between domestic consumption of sectoral output and export. The constant elasticity of substitution function is also used to model the imperfect substitution between domestically produced and imported goods. The imperfect substitutability modelled above enhances the importation and exportation of the same goods.

The factor market for water is closed by assuming that the quantity of water used is fixed and that total sectoral water use is equal to the total sectoral water supply; hence there are no reserves. The capital and labour markets are closed by assuming that the demand for each of these factors is equal to their supply. These assumptions imply full employment of the factors. The saving-investment closure assumes that savings equal investment and that government income (receipts) equals government spending (payments).

2.3 The experimental simulations

The situation documented in the adjusted SAM is the base situation which reflects the current sectoral water allocation in South Africa. All input and output prices including water are normalized in this base period. This situation represents water market inefficiency because the price paid by the production sectors does not reflect the competitive market price of water. To achieve the efficient level of water allocation the study uses the sectoral marginal values of water estimated in a related as shadow prices to calibrate the SAM. Sectoral water use and output, value added at factor cost, and household consumption under the market allocation scenario are compared to the base scenario.

Water reduction scenarios: After running the market allocation scenario, the study simulates the impact of 10 percent, 20 percent and 30 percent reductions in total sectoral water availability on sectoral output, value added and households' welfare. Total sectoral water availability is reduced by the given percentages and the remaining water is allocated among the sectors by the market mechanism, using the estimated marginal values of water as shadow prices. the sectoral output, value added and household income/consumption indices are compared to the base indices.

Policy Simulations: In the water reduction scenarios, food consumption was allowed to change. To form a hedge against climate change the experiments are re-run by assuming that food consumption for the least and low-income households are maintained at base consumption levels. Two policy interventions to maintain base food consumption levels for the least and low-income households are food stamps and food aid. The food stamps in these experiments are equivalent to the loss in consumption, and are recorded as a government transfer to the targeted households. In this scenario, government's inter-departmental expenditure is reduced by an equivalent amount of the reduction in consumption expenditures of the least and low-income households. Food vouchers equivalent to the loss in consumption expenditures are distributed among the low and least-income households. Similarly, food aid is recorded as an external shock to the model. Food commodity, equivalent to the amount of reduction in least and low-income households income/consumption, and distributed among the impacted households. This paper investigates the impact of such short-run policies on general households' welfare and the importation and exportation of agricultural commodities. All the changes in output, value added and households' welfare are relative to the base indices. These changes show the impact of water scarcity on output and general households' welfare.

2.4 Welfare analysis

The study uses the concept of equivalent variation (EV) discussed in Chitiga and Mabugu (2006) to analyze the impact of climate change on households' welfare. EV compares the level of households' consumption at the given price and income in the base scenario to the levels of consumption in both the market allocation and water reduction scenarios. In principle, equivalent variation can be interpreted as the minimum amount of money that has to be given to the households to renounce a utility increasing project or the maximum amount of money that households are willing to pay to prevent a utility decreasing change. As used in this study, equivalent variation (EV) is defined as the maximum amount households are willing to pay to prevent a decline in consumption levels due to water shortages. Alternatively, it is the minimum amount they are willing to accept to forgo an increase in consumption levels such that the same level of utility is maintained after the reduction in sectoral water use.

Functionally, equivalent variation is denoted as:

$$EV = \left(\frac{P_1^0}{P_1^1}\right)^{\gamma} \left(\frac{P_2^0}{P_2^1}\right)^{1-\gamma} Y^1 - Y^0 \qquad (1)$$

Where P_1^0 is the price of good 1 in the base model,

P_1^1 is the price of good 1 after the simulation,

P_2^0 is the price of good 2 in the base model

P_2^1 is the price of good 2 after the simulation

Y^0 is the income in the base model and

Y^1 is households' income after the simulation

A positive EV implies welfare improvement, while a negative EV implies welfare deterioration (loss). An increase in households' expenditures or income implies welfare improvement, while a decrease implies welfare deterioration.

3 PRESENTATION OF SIMULATION RESULTS

This section discusses the impact of climate change on sectoral output, value added at factor cost and households welfare. It also discusses the short-run intervention polices that can minimise the adverse welfare effects of the impact of climate change on water resources. Table 1 presents these impacts. The first block presents the impact on sectoral output, while blocks two and three present the impacts on value added and households' welfare respectively, and block four presents the impact on agricultural trade.

3.1 The impact of climate change on sectoral output

Columns 2 and 3 present the base output and base indices. Column 4 shows the changes in the base indices due to market allocation of water resources among the production sectors. The results indicate that with the market allocation of water in South Africa sectoral output increases by 6.79 percent. Specifically, output in the mining sector increases by 22 percent. The results also indicate that output increases in the basic chemicals and heavy manufacturing sectors. However, market allocation of water resources can potentially lead to a significant output decline in the agriculture, beverages and tobacco, construction and services sectors.

Columns 5, 6 and 7 present the impact of water reduction on sectoral output in South Africa. The results indicate that total sectoral output declines by 4.39 percent, 7.58 percent and 16.39 percent with 10 percent, 20 percent and 30 percent respective reductions in sectoral water availability. Most of the sectors record significant declines in output as a result of reductions in sectoral water availability due to climate change. Notably, agricultural output declines by 8.43 percent, 12.37 percent and 15.96 percent when sectoral water use reduces by 10 percent, 20 percent and 30 percent respectively. A similar pattern of decline is noted for the mining, beverages and tobacco, basic chemicals and the electricity sectors. In spite of the general decline in sectoral output due to water scarcity, output in some sectors increase. These sectors are the less water-intensive sectors and include construction, pulp and paper, machinery and equipment and metal manufacturing sectors.

Table 1: Economy-wide analyses of the impact of climate change on water resources in South Africa

1 Sectoral Output

Sectors	Base Figures	Base Indices	Market Allocation	Climate Change Scenarios		
				m30	m20	m10
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Agriculture	107549.30	1.0000	-1.0478	-1.1596	-1.1237	-1.0843
Mining	186475.60	1.0000	1.2203	-1.2327	-1.1445	-1.0940
Agro-industry	238395.70	1.0000	-1.0275	-1.1738	-1.0928	-1.0372
Leather & wearing apparel	80312.64	1.0000	1.0001	-1.0179	-1.0016	-1.0009
Paper and pulp	79506.52	1.0000	-1.0136	1.0635	1.0316	1.0244
Petroleum	82195.24	1.0000	-1.0219	-1.0193	-1.0164	-1.0030
Basic chemicals	148622.50	1.0000	1.0285	-1.1046	-1.0933	-1.0017
Heavy metal manufacturing	175957.80	1.0000	1.0198	1.0976	1.0342	1.0113
Machinery & equipment	295222.10	1.0000	1.0017	1.0388	1.0202	1.0220
Other manufacturing	100214.20	1.0000	1.0044	1.0754	1.0421	1.0488
Electricity	57311.97	1.0000	1.0105	-1.1172	-1.0853	-1.0405
Construction	150434.80	1.0000	-1.0357	1.0272	1.0134	1.0048
Services	1831373.00	1.0000	-1.0249	-1.0896	-1.0796	-1.0175
Total	**3533571.37**	**1.0000**	**1.0679**	**-1.1639**	**-1.0758**	**-1.0439**

2 Primary Factors

Capital	370416.40	1.0000	1.0469	1.0627	1.0391	1.0258
Water	18218.11	1.0000	1.0893	-1.1826	-1.1265	-1.0847
Unskilled Labour	141514.50	1.0000	1.1357	-1.2305	-1.1576	-1.0982
Medium-skilled labour	169071.90	1.0000	1.1193	-1.0392	-1.0175	-1.0065
High-skilled labour	86538.55	1.0000	1.0726	1.0093	1.0078	1.0001
Total	**785759.46**	**1.0000**	**1.0973**	**-1.1658**	**-1.0947**	**-1.0393**

3 Households' Welfare

Least-income	17674.90	1.0000	1.0973	-1.1652	-1.1032	-1.0318
Low-income	33553.95	1.0000	1.0897	-1.1758	-1.1131	-1.0439
Middle-income	281996.40	1.0000	1.0418	-1.0522	-1.0743	-1.0177
High-income	146835.80	1.0000	1.0263	1.0436	1.0138	1.0097
Highest-income	114287.00	1.0000	1.0104	1.0271	1.0057	1.0009
Total	**594348.05**	**1.0000**	**1.0439**	**-1.0671**	**-1.0216**	**-1.0173**

4 Agricultural Trade

Agricultural export		1.0000	1.1329	-1.2937	-1.1721	-1.1257
Agricultural import		1.0000	1.0759	1.2193	1.0908	1.0138
Agricultural supply		1.0000	1.2842	-1.2548	-1.1023	-1.0354

3.2 Changes in value added

Changes in sectoral outputs due to water reduction under the different climate change scenarios have a direct impact on value added. While some sectors substitute water with other factors, other sectors cannot. Therefore, changes in sectoral water availability due to climate change have varying impact on factor remuneration. The second block of Table 1 presents the possible impact of water reduction on value added.

The result of the market water allocation simulation shows that value added increases by 9.73 percent. Specifically, the wages of unskilled, medium-skilled and high-skilled labourers increase by 13.57 percent, 11.95 percent and 7.26 percent respectively. Similarly, the returns on capital and water significantly increase by 4.69 percent and 8.93 percent. Details are recorded in column 4 of Table 1. These findings indicate that the market allocation of water among the production sectors enhances growth in both sectoral output and factor remuneration/value-added.

Unlike the market allocation scenario, reductions in sectoral water availability due to climate change impacts lead to a decrease in value added at factor costs. Column 5 in the second block of Table 1 shows that with a 30 percent reduction in sectoral water availability, value added decreases by 16.58 percent. There are mixed results for the individual factors. While returns on capital and the wages of high-skilled labour increase by 6.27 percent and one percent, the wages of unskilled and medium-skilled labour correspondingly decrease by 23 percent and 3.92 percent. The other climate change scenarios lead to the same pattern of changes in value added at factor cost. The possible economic reason is that reduction in sectoral water availability may increase the demand for capital by some sectors. Since capital is fixed within the short run, the price of capital increases to clear the excess demand for the factor. Hence, returns on capital increases on the average, while payments to the other factors fall. On the other hand, when agriculture and the related sectors' outputs fall, the demand for unskilled-labour correspondingly falls because agriculture is the largest employer of unskilled-labour. Therefore, to clear the excess supply of unskilled-labour wages fall until market equilibrium is again achieved.

3.3 Welfare analyses

The simulation results suggest that market allocation of sectoral water leads to an increase in both sectoral output and value-added. Conversely, both sectoral output and value added decline as a consequence of the impact of climate change on water resources. However, welfare analysis is concerned about the distribution of either the burden of climate change or the gains from the market allocation among the various households. Welfare measurements in this study consider changes in households' income/consumption expenditures. The third block of Table 1 presents the changes in households' consumption expenditures/income under the different scenarios.

The table shows that households' welfare generally improves with the market allocation of water among the production sectors. The result indicates the income or consumption of all the household categories increases. On the contrary, the experimental results indicate that water reductions due to climate lead to a general welfare deterioration. Specifically, the results indicate welfare deterioration for least, low and middle-income households and a welfare improvement of the high and highest-income households. Specific details are reported in columns 4, 5, 6 and 7 of the third block of Table 1. Generally, these results imply that while the market allocation of water resources improves the welfare of all the household categories, only the poor and middle-income households are adversely impacted by water reductions due to climate change. The possible interpretation of these results is that reductions in sectoral water use lead to a decline in output, hence, a decline in the wages of unskilled and medium-skilled labourers. This generally leads to decline in the incomes of the least, low and middle-income households, because the derive most of their income from wages.

3.4 Agricultural trade

The alterations in sectoral output and value added have consequences for agriculture supply, exports and imports of agricultural commodities. Columns 4, 5, 6 and 7 in block 4 of Table 1 illustrate the impact of market allocation of water and climate change on agricultural trade.

The results of the market allocation simulation indicate that both agricultural exports and imports increase by 13.29 percent and 7.59 percent respectively, and a 28.42 percent increase in domestic supplies of agricultural commodities. On the contrary, a 30 percent reduction in sectoral water due to climate change impacts leads to a 29.37 percent decline agricultural exports and a corresponding 21.93 percent increase in agricultural imports, while domestic supply of agricultural commodities falls by 25.48 percent. The same trend of changes in agricultural exports, imports and domestic agricultural supply is recorded for a 20 percent and a 10 percent reduction in sectoral water use.

These results indicate that while market allocation of sectoral water generally leads to an increase in domestic supply, export and import of agricultural commodities, any reduction in sectoral water availability due to climate change leads to a decline in agricultural output, which results in a decline in agricultural exports and an increase in agricultural imports.

4.0 ANALYSIS OF SHORT-RUN POLICY INTERVENTIONS TO MINIMIZE THE ADVERSE EFFECTS

This study analyses the impact of two short-run policies to minimize the adverse consequences of water scarcity due to the impact of climate change. These are food stamps and food aid.

Table 2: Welfare analysis of short-run policy interventions

Household categories	**Water reduction scenarios**					
	Food stamps			**Food aid**		
(1)	**M30 (3)**	**M20 (4)**	**M10 (5)**	**M30** (6)	**M20 (7)**	**M10 (8)**
Least-income	1.2347	1.1170	1.0681	1.1315	1.1058	1.0617
Low-income	1.2029	1.1379	1.0804	1.1073	1.0765	1.0374
Middle-income	-1.2863	-1.1083	-1.0845	1.0659	1.0318	1.0098
High-income	1.1676	1.1138	1.0962	-1.0025	-1.0009	1.0000
Highest-income	1.0773	1.0692	1.0868	-1.0010	-1.0003	1.0000
Total	1.1204	1.1057	1.0784	1.1109	1.0857	1.0037

As discussed in the simulation methods, food stamp is considered as a government transfer payment to the affected households, while food aid is an external shock into the economy. Table 2 presents the simulation results. According to the results food stamps improve the welfare of the least, low, high and highest-income households at the expense of the middle-income households. With food stamps the demand for food increases, while the short-run supply is unchanged. To clear the market food prices rise. Since the low and least-income households have food stamps they are unaffected by the increase in food prices. The middle-income households, who are not covered in the welfare programme, pay the full price. Therefore, the EV for this household group becomes negative. This implies welfare deterioration for the middle-income household.

Unlike food stamps, the distribution of food aid among the least and low-income households leads to deterioration in the welfare of the high and highest-income households, although this programme enhances general welfare improvement. Details are presented on Table 2.

5.0 SUMMARY AND CONCLUSIONS

This article uses the computable general equilibrium model to investigate the socio-economic consequences of the impact of climate change on water resources in South Africa. Gathering data from different sources and adjusting, modelling and analysing these data the simulation results indicate that water scarcity due to the impact of climate change generally leads to a decline in sectoral output, value added and households' welfare. Specifically, the output of agriculture and the related sectors declines. This leads to a decline in the wages of unskilled and medium-skilled labourers, and water tariffs, and an increase in the wages of skilled labourers and interest payments on capital, which subsequently results in welfare deterioration of the poor households. This has consequences for agricultural supplies and trade. While domestic agriculture supplies and exports decline, imports increase because domestic supplies can not match the domestic demand for agricultural products.

Usually, short-run welfare programmes target the poor households. Such programmes have consequences for the other household categories. For example, while the distribution of food stamps among the low and least-income leads to welfare deterioration of middle-income households, the distribution of food aid among the poor households leads to welfare deterioration of the rich households. However, both programmes enhance general welfare improvement. Generally, the results show that water scarcity due to the impact of climate change has adverse consequences for poor households which can be addressed in the short-run by welfare policies.

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