Macro-micro feedback links of water management in South Africa: CGE analyses of selected policy regimes

ABSTRACT

The pressure on an already stressed water situation in SA is predicted to increase significantly under climate change, plans for large industrial expansion, observed rapid urbanization, and government programs to provide access to water to millions of previously excluded populations. The present study employed a general equilibrium approach to examine the economy-wide impacts of selected macro and water related policy reforms on water use and allocation, rural livelihoods and economy at large. The analyses reveal that implicit crop-level water quotas reduce the amount of irrigated land allocated to higher-value horticultural crops and create higher shadow rents for production of lower-value water-intensive field crops, such as sugarcane and fodder. Accordingly, liberalizing local water allocation within irrigation agriculture was found to work in favor of higher-value crops, and expand agricultural production and exports and farm employment. Allowing for water trade between irrigation and non-agricultural uses fuelled by higher competition for water from industrial expansion and urbanization leads to greater water shadow prices for irrigation water with reduced income and employment benefits to rural households and higher gains for non-agricultural households. The analyses show difficult tradeoffs between general economic gains and higher water prices which place serious questions on subsidizing water supply to irrigated agriculture, i.e. making irrigation subsidies much harder to justify.

1. Introduction

Agriculture consumes over 60% of South Africa's (SA) available water supply, most of which is used in irrigation. While the dominance of agriculture in water use is typical for most countries, this disproportionate allocation has special significance for SA where water is scarce and the country is rapidly approaching a water stress situation. At the same time, contribution of agriculture to the country's total gross domestic product (GDP) is small and continues to decline falling to an estimated share of less than 3% by 2007 (StatSa, 2008). The same applies to the sectors' employment capacity which fell to less than 9% of total formal employment by 2002. This transition is typical of countries which have been successful in diversifying economic structure away from primary production (resource extraction and farming) toward manufacturing and services' provision activities. However, agriculture remains an important economic activity in terms of its economy-wide multiplier effects and its contribution to food security in general and the livelihoods of the rural poor in particular.

The SA agricultural economy enjoyed high protection in the past for food security and other political reasons. The sector received a direct price subsidy on water use as well as non-price protection (i.e. water quota system) that remains largely in place today. More over, previous water allocation regimes were biased in favor of large scale white farmers seriously disadvantaging other segments of the rural population of mostly small holder black farming families. Previous water management regimes and policies also paid little attention to ecological needs and protection of the health of freshwater ecosystems.

Since 1994 however, the SA economy at large and the agriculture and water sectors in particular have witnessed radical policy reforms, many of which are still under implementation. Major macroeconomic reforms have been introduced to correct the grave socio-economic injustices of the past particularly in terms of provision of basic services (e.g. water and sanitation, housing, health and education) and income and employment opportunities to millions of previously service-deprived communities. These shifts in public policy and investment priorities have major implications for water use and allocation within the economy, and the need to reform water policy commensurate with these new policy initiatives.

A new National Water Policy (NWP) was adopted in 1997 marking a radical shift in the strategic objectives and principles of water management in SA (DWAF, 1998). Implementation of the new NWP and subsequent National Water Act (NWA) has already changed and expected to have further long-term effects on the way water resources are developed, allocated and managed in SA. As many of the said policy changes may have unintended and undesirable consequences for other non-target activities and may be serving conflicting goals, their net effect on the economic and social wellbeing of the people of SA are unknown. This is particularly true when impacts of different sets of policy interventions are analyzed and evaluated at a sectoral and sub-regional level irrespective of their implications for the rest of the economy.

This study analyzed the potential effects of ongoing and intended macro and water sector level policy changes on the economy of SA from an economy-wide perspective. It takes into account structural inter-sector linkages and macro-micro feedback mechanisms. The study adapts and extends an analytical framework developed and applied to the case of irrigation water management in Morocco (Roe et al. 2005) to build an economy-wide model to conduct the intended analyses. A water social accounting matrix (SAM) is constructed to support computable general equilibrium (CGE) analyses of the implications of selected macroeconomic and water policy regimes for SA. The analysis is expected to inform scheduled efforts for revising the current water resource management strategy in 2009 for the 5 years period to follow (DWAF, 2008).

The next section provides an overview of the structure of the water economy and policy in SA. Section three gives a brief review of relevant CGE applications to water management and develops the SA water SAM and CGE model. Macro & macro economic and water policy scenarios are developed and simulated in section four. Section five presents the conclusions and implications of the study findings.

2. Water resources management and the SA economy

SA receives about 450 mm of rainfall per annum (compared to world average of 860 mm) and is expected to approach the limits of potentially available water supplies by 2025 (DWAF, 2004). Not only natural availability of freshwater is spatially very diverse in SA but also major economic activities, populations and development centers concentrate in certain urban and peri-urban pockets that are often not within areas of water abundance. To match supply with demand for water at these centers, the country had to make huge investments in developing sophisticated water supply and delivery infrastructures that allowed transfers of water from surplus to deficit areas (e.g. inter-basin transfers) and between seasons (storage dams). This gave the country great flexibility in control and management of water resources as one giant interlinked system of supply.

Only 60% of the annual runoff (19.5 billion m^3) is available as surface water yield about half of which is kept in stream as ecological reserve, and the rest (9.6 billion m^3) constitutes the bulk water supply resources managed and distributed by the Department of Water Affairs and Forestry (DWAF) to the economic system for domestic consumption and production purposes (DWAF, 2004). The country has massive water storage infrastructure with total dams' capacity of 32.4 billion m^3 amounting to about 66% of total mean annual runoff (DWAF, 2004).

DWAF distributes available bulk water to the economy through a complex network of water management and supply institutions. In 2000, irrigation agriculture received most (63%) of available yield as bulk raw water through Irrigation Boards (IBs) and the rest was supplied to other economic activities (33%) either directly or through Water Boards (WBs) and as undistributed surplus back to the environment (Hassan and Crafford, 2006). WBs redistribute water supplied by DWAF to domestic and industrial users either directly to some major mining, power generation and industrial operations or through municipalities. SA relies primarily on surface water with groundwater resources currently account for only 10% of total water supply and is utilized in localized areas[1].

SA has been divided into 19 water management areas (WMA) where a catchment management agency (CMA) are being established in each to directly manage water resources' development and utilization in the designated WMA. The national water resources strategy (NWRS) (DWAF, 2004) provides the needed quantitative information about current and future water requirements and availability and interventions required for reconciling supply and demand in the 19 WMAs. In developing such strategic plans the NWRS is to be guided by the NWA priorities for allocation of water which accords highest priority to the following: (1) the "Reserve" ensuring the right to sufficient supplies to meet basic human and ecological needs, (2) international agreements and obligations, (3) social needs such as eradication of poverty and inequity, (4) use of strategic importance such as power generation. After satisfying the requirements to meet these 4 priority objectives water is to be provided to economic use (which includes commercial irrigation, mining and industrial use) on basis of economic efficiency, i.e. to achieve greatest total economic benefits to the country (DWAF, 2004).

One key intervention instrument to balance resource availability and priority needs is the transfer of water from surplus to deficit WMAs. Accordingly, the NWRS establishes plans for inter-regional water transfers based on estimated strategic requirements and available water supplies within each WMA, i.e. water transfers between WMAs are currently not guided by market incentives but exogenously determined. Allocation of available water resources between competing economic uses within each WMA is also currently based on estimates of water requirements given current use and predicted potential future developments. The NWRS however, aspires to promote economic efficiency in water allocation for economic use through market-based mechanisms, which would require relaxing current quantitative (quota) restrictions (between WMAs and between economic activities within WMAs) at least partially in the future. These

[1] For more details about water supply and allocation in SA see Hassan, et al. (2008).

represent key water policy changes the economy-wide impacts of which require careful assessment.

On the other hand some key macroeconomic reforms are being introduced that are expected to have important influences on water use and allocation and overall economic wellbeing. Those include strategic plans aiming at higher rates of economic growth over the next decade through the Accelerated and Shared Growth Initiative for SA (Asgisa) and the rapid rural-urban migration. These have major implications for increased competition for water between agriculture and non-agricultural activities (particularly domestic and industrial). Moreover, important global phenomena such as climate change (CC) is predicted to have significant impacts on water availability (Schultze, 2005) whereas the world energy crisis is already inducing major land use changes, especially towards production of biofuels with important implications for water and food security.

The impact of these policy changes on the productivity of irrigated agriculture, rural poverty and food security in SA need to be carefully studied. The fact that goals of a number of these policy changes are often conflicting (i.e. equity versus efficiency) and sometimes work in opposite directions it is hard to predict net outcomes unless their impacts are evaluated within a general equilibrium framework.

3. Modeling irrigation water management in the economy of SA

To overcome limitations of partial equilibrium approaches in incorporating important inter-sector and inter-market linkages and endogenous prices, recent efforts attempted to develop economy-wide modeling frameworks for analyzing economic and policy aspects of water management. Examples of early work employing CGE framework include Seung et al. (2000) and Goodman (2000). Further modeling complications were then added to these early efforts to allow for larger sector and regional dis-aggregations (Peterson et al., 2004; Dywer et al., 2005; Smajgl et al., 2005; Tirado et al., 2006; Velazquez, 2007), analyze implications on trade (Beritella et al., 2006; Kohn, 2003), evaluate equity and distributional effects (Bocanfuso et al., 2005; Letsoalo et al., 2005) and address environmental impacts (Finoff, 2004; Letsoalo et al., 2005).

While CGE models better handle economy-wide effects they suffer from high aggregation of economic activities into key sectors which limits their ability to investigate feedback effects from micro or sector changes and interventions to the macro-economy and vise versa. Recent attempts have been made to develop CGE models that can handle such feedback linkages (Roe et al., 2005). The Roe et al. (2005) work allows for tracing micro effects of macro level policy changes, e.g. trade, as well as feedback effects on macro-economic aggregates of micro-level policy changes, e.g. farm level water allocation and trading regimes. This however is implemented sequentially in a two-step analytical structure with a micro farm model component separate from the macro CGE model. The Water CGE model developed for SA described below attempts to overcome this limitation of the Roe et al. (2005) model by directly incorporating highly disaggregated structure of water and agricultural activities as integral components of the CGE model. This enables obtaining solutions with both macro and micro effects and adjustments simultaneously occurring, i.e. not sequential. Most previous work on modeling economics and policy of water resource management in SA falls under the partial equilibrium tradition with few attempts to capture multi-sector linkages but employing relatively simpler model structures (Hassan, 2003; Letsoalo et al., 2005; Matete and Hassan, 2007; Juana, 2008).

3.1 The SA Water SAM and CGE model structure

A new agriculture and water-focused South African SAM and CGE model were constructed for this study to examine the economy-wide impacts of selected macro and micro (water related) policies. Apart from its treatment of water, the model contains detailed information on production, trade and consumption, which are discussed below. Full description of the SA SAM and CGE model is documented in Hassan et al. (2008) and Thurlow (2008).

3.1.1 Production and employment

The model contains 40 sectors/commodities, including 17 agricultural and 15 industrial sectors (see Table 1). Agricultural production is divided into field crops (summer cereals; winter cereals; oil crops and legumes; fodder crops; cotton and tobacco; and sugarcane), horticultural crops (vegetables; fruits-citrus, subtropical, deciduous; viticulture; and other horticulture), livestock (livestock sales; dairy; poultry; and other livestock products) and fishing and forestry.[2] Field crops are further separated into irrigated and rainfed whereas all horticultural production is assumed irrigated. Together, these agricultural sub-sectors account for 4.3% of the national GDP – making agriculture a relatively small part of the economy (Table 1). By contrast, the industrial sectors comprise one-third of national GDP, ranging from the more capital-intensive mining, metals and energy sectors, to the more labor-intensive food processing, textiles and construction.

One key new and unique feature of the developed SA Water SAM (SAWSAM) is modeling production and consumption activities by WMA. This is of crucial relevance to water resources management and policy institutions such as DWAF and the newly established catchment management agencies (CMAs) as all their current and future allocation plans and strategies are drawn based on WMAs as the principal geographic units of management. Agricultural and nonagricultural production in the SAWSAM model is therefore disaggregated across each of SA's 19 WMAs[3]. The characteristics of these WMAs vary considerably. For example, Appendix 1 shows that agriculture is only one percent of the Upper Vaal's GDP (i.e., Gauteng Province), but more than a third of Breede's GDP (i.e., the grape growing regions surrounding Cape Town). The largest agricultural area in terms of GDP is Mvoti-Umzimkulu (i.e., the sugarcane growing region outside of Durban), but in terms of land area it is the Middle Vaal (i.e., the maize growing region in Free State province). Thus, while the regional dis-aggregation of the

[2] Agriculture is disaggregated across sub-sectors using the 2002 Census of Commercial Agriculture (StatSA, 2002) and the 2006 Abstract of Agricultural Statistics (NDA, 2007).

[3] Sectoral production in the Water-SAM was disaggregated across WMAs using municipal-district-level information (for details on dis-aggregation of production sector (see Hassan et al. (2008)). In total there are 874 representative producers in the model (each of the 19 WMAs contain 40 sectors, with the 6 field crops further disaggregated into irrigated and rainfed).

model is motivated by WMAs, it also captures the varying importance of agriculture and other sectors in different parts of the country.

To capture differences in production technologies, the model identifies six factors of production: three types of labor (unskilled, skilled and highly-skilled), agricultural land, irrigation water, and capital. Higher-skilled labor and capital are assumed to be fully employed with flexible real wages.[4] Conversely, and to reflect SA's high levels of unemployment, we assume the supply of unskilled labor is perfectly elastic at a fixed nominal wage (see Appendix 2 for further discussions of modeling details). Regional labor markets allow workers to migrate across sectors within each WMA, i.e. not across WMAs. Land and irrigation water are also assumed to be freely allocable across agricultural activities within each WMA, but their supplies are fixed at the level observed in each WMA in the base year. Finally, capital is fully-employed and mobile across all sectors and WMAs. Producers in the model employ these factors so as to maximize profits under constant returns to scale, with the choice between factors governed by a constant elasticity of substitution (CES) function.

Composite factors are combined with fixed-share intermediates under a Leontief specification. Intermediate demands for crops and livestock are derived from the 2002 Census of Commercial Agriculture (StaSA, 2002). Agricultural production technologies are thus unique to each sub-sector/activity and region (i.e. WMA). By contrast, nonagricultural production technologies are taken from the national supply-use table (StatSA, 2004) and are thus the same across WMAs.

3.1.2 Domestic and international trade

Producers in each region[5] supply their output to a national commodity market, where they are exported, sold domestically, and/or combined with imported goods. Substitution possibilities exist between production for domestic and foreign markets based on a

[4] Labor employment data is taken from the 2004 Labor Force Survey (September) (StatSA, 2005).
[5] Note that "region" and "WMA" are interchangeably used throughout this paper to mean the same thing.

constant elasticity of transformation (CET) function. Profit maximization drives producers to sell in those markets where they can achieve the highest returns.

Substitution possibilities also exist between imported and domestic goods under a CES Armington specification. [6] The final ratio of imports to domestic goods is determined by the cost minimizing decision-making of domestic demanders based on the relative prices of imports and domestic goods (both of which include relevant taxes). Under the small-country assumption, SA faces perfectly elastic world demand/supply at fixed world prices. There are, therefore, four endogenous commodity prices in the model: a single national supply price reflecting region-specific producer prices; an export and an import price based on world prices and the exchange rate; and a composite market price. The final market price is the same in all regions and includes transaction costs and indirect taxes.

The CGE model contains a measure of the exchange rate, which adjusts to ensure that SA's current account balance remains fixed in foreign currency. However, in the CGE model, the real exchange rate depreciates in order to raise the export prices received by domestic producers, while also raising import prices for domestic consumers. This stimulates an increase in exports needed to pay for additional imports, thereby maintaining the current account balance at its original level.

3.1.3 Household incomes and demographic structure

The model distinguishes between various institutions, mainly government and a number of representative household groups. Households in each WMA are disaggregated across rural/urban areas and national expenditure quintiles[7]. Households receive income in payment for producers' use of their factors of production[8] and pay direct taxes to

[6] Trade elasticities are taken from the Global Trade Analysis Project (Dimaranan, 2006).
[7] There are 190 representative households (five expenditure rural and urban quintiles in each WMA)
[8] Note that the SAWSAM does not have an "enterprise" account and hence capital payments are paid directly to households. Land and irrigation water rents are similarly distributed across households.

government (based on fixed tax rates)[9], save (based on marginal propensities to save), and make transfers to the rest of the world. Households use their income to consume commodities under a linear expenditure system (LES) of demand.

The final institution in the model is the government, which receives revenues from imposing activity, sales and direct taxes and import tariffs, and then makes transfers to households, enterprises and the rest of the world. The government also purchases commodities in the form of government consumption expenditure, and the remaining income of government is (dis)saved.

3.1.4 Model closure

The model includes three broad macroeconomic accounts: the government balance, the current account, and the savings and investment account. In order to bring about balance between the various macro accounts, it is necessary to specify a set of 'macroclosure' rules, which provide a mechanism through which macroeconomic balance is achieved. We assume a 'balanced closure' such that nominal changes in total absorption are evenly distributed across private and public consumption spending and investment demand. Government recurrent spending is financed through proportional changes in direct tax rates, and domestic institutions' savings propensities are adjusted proportionally to ensure equality of savings and investment in equilibrium[10]. For the current account it was assumed that a measure of the real exchange rate (i.e. a price index of tradables to non-tradables) adjusts in order to maintain a fixed level of foreign savings (i.e. the external balance is held fixed in foreign currency.

3.1.5 Agricultural water use and shadow prices

[9] Since the SAWSAM does not have a separate enterprise account, corporate taxes are taken directly from capital to the government direct tax account. Similarly, it was assumed that all industrial and domestic water value-added is paid to the government at a 100% tax rate.
[10] This follows Nell (2003) who found that investment in SA is at least partly savings driven.

As mentioned earlier, the model disaggregates agriculture across a number of crops and WMAs. It also separates field crops into irrigated and rainfed production. Since almost all horticultural production takes place under irrigation, around one-fifth of SA's agricultural land is irrigated. Amongst field crops, irrigation is most prevalent for higher-value crops, such as cotton, tobacco, sugarcane and fodder, and lowest for maize and oil crops. Irrigated land also produces substantially higher yields, with average irrigated maize yields twice those of rainfed maize (Hassan et al., 2008). The model is calibrated to capture these differences in production levels and yields across crops and regions.

In order to incorporate irrigation water into the model, it is necessary to identify the productivity effects of water on crop yields. This study extended the approach and results of Hassan and Mungatana (2006) to include additional crops modeled in the SAWSAM and updated their estimates of the value of marginal product (VMP) of water using 2002 market output prices (see Hassan et al.; 2008 for more discussion on modeling agriculture and non-agriculture water use). Irrigated water therefore appears as a factor of production in the CGE model and is used exclusively by irrigated agricultural sectors. The returns to the irrigated water factor (i.e., the shadow price) are distributed to higher-income rural households according to their ownership of the returns to commercial agricultural land. The government also charges a fixed raw water tariff that varies by WMA depending on what supply schemes are providing water.

3.1.6 Nonagricultural water use and distribution system

Although the model pays particular attention to agriculture and irrigated water, it also captures industrial and domestic water use. Unlike irrigated water, the provision of nonagricultural water takes place via the water distribution system. In other words, it is treated as an intermediate input and not as factor of production (as was the case with irrigation water). Moreover, the water distribution system charges different tariff rates to different sectors or users, including rural and urban households, industrial users, and the mining and energy sectors (DWAF, 2002-07). However, to simplify the system, the CGE model only distinguishes between two groups: (i) heavy industry and (ii) light industry and households. This is because water tariffs charged to heavy industries (e.g. mining and energy) are substantially below those charged to households and light industries.

Industrial water expenditures are reported in SA's supply-use tables. Given the value of these expenditures and the total amount of water used by these industries (reported in StatSA, 2006), we estimate the implied price per unit of water supplied to heavy industry. We then subtracted the cost of supplying this water via the distribution system (Hassan et al., 2008) in order to arrive at the residual ('profit') earned by water in the heavy industrial sectors. This was used as a measure of the value-added of a new water factor that used exclusively by the heavy industry water distribution sector.
A similar process was used to estimate the value-added of domestic and light industrial water use.

In summary, water is incorporated into the SAM and CGE model by (i) separating agriculture in irrigated and rainfed production; (ii) disaggregating all production, labor markets and households across water management areas; (iii) estimating the shadow value of irrigation water for different crops; and (iv) distinguishing between the industrial and domestic water distribution systems.

4. Results of scenario analyses of key water related macro-micro policy linkages

4.1 The selected policy scenarios

As seen from the discussion in section 2 above water allocation between WMA's and between competing economic uses within WMAs remains governed by a number of quantitative restrictions and non-market factors. The developed Water CGE model will be useful for evaluating the net impacts of potential shifts in water policy towards more market-based allocation regimes which the NWRS aspires to promote. The SA Water CGE model is accordingly employed in this section to examine a number of water-related issues in SA. The economy-wide (micro and macro) impacts of the following policy scenarios have been evaluated:

4.1.1 Scenario I: Liberalizing regional irrigation markets

This scenario examined the impact of liberalizing local water allocation among crops, i.e. *intraregional irrigated-water-market liberalization* to equalize the SP of irrigation water across crops within each WMA based on crop-specific water demands (VMP). The experiment does not change total water use at the WMA-level (i.e. no change in current inter-region water transfers) and also does not change allocation of available water between irrigation and other uses (e.g. industry and domestic users). This scenario leads to estimation of general equilibrium SPs for irrigated water for the various WMAs.

4.1.2 Scenario II: Liberalizing national irrigation markets

In this scenario we allow for changes in *inter-regional transfers of water* for irrigation use based on existing water transfer schemes in addition to liberalizing regional (within WMA) irrigation water markets (*Scenario I*). Although water allocation between irrigation and non-agricultural use remain unchanged in this scenario, it leads to equalizing irrigation water SPs both within and between all WMA's and thus establishes a national general equilibrium SP for irrigation water.

4.1.3 Scenario III: Water-Restricted -Urbanization

Urban residents consume substantially more water resources than rural residents implying that urbanization and industrial expansions will greatly increase the competition for water between urban users and agriculture increasing the opportunity cost of subsidizing irrigation water, and may warrant a reallocation of water resources out of irrigation agriculture. We therefore increase competition for water from predicted expansions in non-agricultural uses and rapid urbanization through rural-urban migration in this scenario without liberalizing water markets, i.e. does not allow transfer of or trade in water between irrigation and non-agricultural uses. Current inter-basin water transfers are also maintained in this scenario. This will establish the potential gain from liberalizing water markets to allow water trade between irrigation and non-agriculture sectors under current regional quotas.

4.1.4 Scenario IV: Water-Liberalized Urbanization

This scenario liberalizes water markets allowing for market-based water transfers out of irrigation to meet the growth in demand for domestic and industrial use introduced under *Scenario III*. It is expected that this will lead to declines in agricultural GDP, rural employment and incomes with offsetting gains from expansions in urban-based non-agricultural sectors' income and employment.

4.2 Results of the policy scenario analyses

4.2.1 Micro impacts of the Regional (Scenario I) and National (Scenario II) irrigation water market liberalization

As shown in Table 2, the shift from a crop-specific to a uniform market-based regional irrigation water price under scenario I has different effects on average SPs across WMAs, with some regions' prices rising and others falling, depending on initial crop patterns and water SPs. For instance, as expected initial water SPs are lowest in major water exporting regions surplus WMAs such as the Upper Orange, Usutu-Mhlatuze and Thukela, compared to water importing regions such as the Berge, Olifants, Crocodile and Fish WMAs where SPs are relatively higher reflecting scarcity.

In addition to the water stress factor, current pattern of cropping also have important influences on average base SPs. For example, WMAs cultivating high shares of their land to high value crops (e.g. horticulture in Luvulvhu-Letaba, Olifants/Dom and Breede and oil seed in Limpopo - see Appendix 1) show relatively higher SPs, in contrast with the case of water importing WMAs such as Middle and Lower Vaal where most of the land are planted to lower value field crops (e.g. summer and winter cereals).

Table 2 shows that crops with low initial SPs experience the largest declines in production, such as fodder crops, summer cereals and sugarcane. Irrigated land allocated to these crops declines substantially such that all fodder production and most of cereals and sugar cane go under rainfed systems. By contrast, irrigated production of most horticultural crops expands significantly (especially citrus fruits and vegetables) after liberalizing local irrigated water markets. While there is a general shift in irrigated land from field crops to horticulture, some field crops do benefit under water market liberalization (e.g. irrigation of higher-value cotton and tobacco increases but their dry-land production decreases) leading to substantial increase in total cotton and tobacco production due to the higher yields achieved under irrigation.

The production of summer cereals (i.e. maize) declines and water resources are reallocated towards winter cereals (i.e. wheat), which have a slightly higher SP[11]. As summer cereals are more water-intensive than winter cereals, their reduction creates an excess supply of irrigation water, thus driving down the regional price of water in the Vaal WMAs with the exception of the Lower Vaal, where the market-based irrigation water price rises as a result of producing higher-value deciduous fruits and viticulture.

The final ranking of irrigated water market prices follows expectations with upstream WMAs, where water is relatively abundant (i.e. Upper Vaal) having lower prices than downstream WMAs (Middle and Lower Vaal's). This pattern is similar for the Upper and Lower Orange WMAs. The highest prices are estimated for the higher-value fruit-producing Western Cape (i.e., Berg, Breede and Olifants/Doorn) and lowest for the cereals-producing Vaal WMAs. Results from this scenario indicate that, while the largest SP differences are indeed at the crop-level, there are also substantial differences *between* WMAs. This indicates possible gains from *interregional* liberalization allowing changes in current inter-basin water transfers as simulated in *Scenario II* below.

[11] This model predicted shift toward increased irrigated wheat has already happened as actual field observations from the Douglas/Vaal/Orange Riet and Modderrivier irrigation areas confirm this trend on the ground.

In the previous scenario we assumed that the infrastructure required to equalize crop-level SPs already exists within each WMA. However, to equalize regional SPs requires more extensive interregional infrastructure. SA already has three major water transfer schemes designed for this purpose, as well as a number of natural flows along rivers connecting WMAs (Appendix 3).

Given existing infrastructure and natural river-based flows, the second scenario (*National Irrigation Market* liberalization) focuses on equalizing SPs for irrigated water both *within* all WMAs and also *across* two of the main water transfer schemes. First, the previous scenario indicated that liberalizing regional irrigation water markets widens the gap in irrigation water prices between the Fish-Tsitsikamma and Orange WMAs (Table 2). In the second (*National Irrigation)* scenario we increase exogenously water transfers to the Fish-Tsitsikamma WMA in order to equalize SPs with the Upper and Lower Orange WMAs. Second, the previous scenario also indicates that intraregional liberalization would raise the Thukela WMA's irrigation water price above that of the Vaal WMAs. Thus, while existing crop-based water quotas create incentives to transfer water under the Thukela-Vaal scheme, removing these quotas would justify reducing these transfers in order to equate SPs across the two regions. Accordingly, in the second scenario we decrease water transfers from the Thukela WMA in order to equalize SPs with the Upper, Middle and Lower Vaal WMAs. We expect that the increase in irrigation water will lower the price of irrigated water in the recipient regions thus favoring more irrigated-water-intensive crops.

According to Appendix 4, 348 million m^3 of the 431 million m^3 currently transferred under Thukela-Vaal scheme would need to be reversed in order to equalize SPs with the Vaal River WMAs at a price R0.46 per $1000m^3$ and would double the amount irrigation water available in the Thukela WMA. Similarly, an additional 476 million m^3 of irrigation water would have to be transferred to the Fish-Tsitsikamma WMA in order to equate SPs with the Orange River WMAs (i.e., at R0.68 per $1000m^3$).

As expected, the increase in irrigated water supply causes a shift out of dry-land production in the Thukela WMA, especially for sugarcane and summer cereals, which occupy most of the available dry-lands (Appendix 4). While some of the newly irrigated lands are used to replace the decline in dry-land production, there is an overall decline in production of most field crops. This is because expanding irrigated land allows farmers in the Thukela WMA to increase production of higher-value vegetables and citrus fruits. By contrast, the reduction in irrigated water supply in the Vaal WMAs encourages a shift out of irrigated cereals and into dry-land production.

There are similar effects from increasing irrigated water supply to the Fish-Tsitsikamma WMA. With the increased availability and falling price of irrigation water, farmers in the recipient WMA shift production from dryland fodder crops to more water-intensive citrus fruit. This is consistent with the current situation where farmers in the Eastern Cape use transferred water to grow citrus. By contrast, farmers in the two Orange River WMAs respond to falling irrigated water supply and rising water prices by increasing dryland production of cereals and fodder crops and reducing irrigated vegetable production. Since yields are significantly lower on drylands, there is an overall decline in field crop production, especially for winter cereals. These results are in line with the regional liberalization effects of *Scenario I.*

4.2.2 Macro impacts of the Regional (Scenario I) and National (Scenario II) irrigation water market liberalization

With regional and national liberalization of irrigation water markets imported cereals increase in order to replace falling domestic cereals production (caused by the shift to low-yield rainfed production). The decline in cereals exports is more than offset by increased horticultural exports, such that overall agricultural exports rise under both scenarios. This causes a slight decline in the relative price of tradables to non-tradables driven by lower demand for internationally-traded commodities.

Ultimately, agricultural GDP increases by 4.5% under *Regional* market liberalization, driven almost entirely by increased horticultural production and exports. Adjusting water transfers under *National* liberalization (*Scenario II*) also affects WMAs outside of the two transfer schemes (i.e. economy-wide impacts from WMA level policies). For instance, falling cereals and vegetables production in the Vaal and Orange River WMAs drive up the national price of these commodities (Table 3), which encourages other WMAs to increase production. Conversely, increased citrus fruit production in the transfer recipient WMAs lowers prices and encourages other regions to reduce citrus production. Overall, agricultural GDP levels further improve gaining an additional percentage point (i.e. achieving 5.4% compared to 4.5% increase) under *Scenario II*, again driven by shifting land from lower-value dry-land field crops into higher-value horticulture.

Non-agricultural GDP declines slightly due to increased competition for productive resources, such as capital and labor, and due to the falling domestic price of internationally-traded commodities, which reduces, at the margin, the competitiveness of export-competing goods and non-agricultural exports in particular. Overall, there is little change in total economy-wide GDP, in part due to agriculture's relatively small share as noted above. Irrigation water market liberalization also causes the consumer price index to increase slightly due to the rising price of cereals (in spite of substantial declines in horticultural prices). This causes a shift in agricultural production away from consumer-intensive commodities, such as cereals, towards more export-intensive horticultural products. SA therefore becomes a larger net importer of cereals (i.e. maize and wheat).

Increased agricultural production also creates additional employment for lower-skilled workers that is more than double the number of displaced workers from the contracting non-agricultural sectors under *Scenario I* (Table 4). Employment gains for lower-skilled workers are higher under *Scenario II*. As agricultural production is less skill- and capital-intensive, and its wages are about two-thirds of average non-agricultural wage, the shift into agricultural employment causes a slight decline in economy-wide wages for the three labor skill groups and in returns to capital. On the other hand, this shift raises the demand for agricultural land, whose returns rise as a result of the scarcity of this agriculture-specific factor. Together this increases incomes and per capita expenditures amongst lower-income households. By contrast, demand for high-skilled labor and capital declines with the shift out of non-agriculture causing these factors' returns to decline.

Interestingly, rural households are the main beneficiaries from irrigation water market liberalization (Appendix 5). These households benefit from higher agricultural production, increased employment in the agricultural sector, and rising returns to agricultural land. By contrast, urban households' per capita consumption declines slightly due to falling non-agricultural production, declining higher-skilled workers' wages, and rising agricultural commodity prices. This suggests that liberalization of irrigation water markets leads to both efficiency and equity gains. Finally, the regions whose rural households benefit overall are generally those whose water SPs rose as a result of liberalization (e.g., Usutu-Mhlatuze, Tukela, Lower Vaal, Fish-Tsitsikamma, and Gouritz). Of the WMAs outside of the transfer schemes benefiting under the *National* liberalization scenario are those that were initially more focused on field crop rather than horticulture production, since field crops' prices rise relative to horticultural prices.

4.2.3 Macro and micro economic implications of competition under Water-Restricted (Scenario III) and Water-Liberalized Urbanization (Scenario IV)

Agricultural GDP grew at 0.4% per year during 1994-2007, while industry and services grew at 2.6 and 4.3%, respectively (StatSA, 2008). These transitional forces pulled labor from agriculture as per capita incomes grew, and reflects SA's accelerating shift away from primary sector production (including mining) towards greater industrialization and a more prominent role for services. These structural changes have been partly facilitated by removal of subsidies and trade protection from many agricultural products, and by greater openness of the economy, which has fostered capital deepening contributing to real wages and nonagricultural export growth (Hérault and Thurlow, 2009).

The sectoral pattern of growth and the lifting of restrictions on internal migration, has also favored urban centers, which in turn has prompted rapid out-migration from rural areas. There was a rapid divergence in population growth, with rural and urban populations growing at 0.9% and 3.0%, respectively during 1985-2005. As a result, urban population share rose by 9.9% between 1985-05 such that by 2005 about 60% of the population lives in urban centers, compared to 49.4% in 1985. As poorer urban households consume more water per capita than their rural counterparts migration of lower-income households from rural to urban centers is expected to dramatically increase the demand for water pressure on providing municipalities.

In this section we present two scenarios reflecting the current structural and demographic changes taking place in SA. The first (*Scenario III*) examines the impact of rural-to-urban migration on urban household water demand and the additional pressures that this places on water resources under current water allocations (the *Water-Restricted Urbanization* scenario). The second (*Scenario IV*) implements *Scenario III* under liberalized regional water markets allowing for market-based transfers of water between irrigation agriculture and non-agriculture within WMA's (*Water-Liberalized Urbanization*) while maintaining current inter-basin transfers (between WMA's) unchanged.

Scenario III is implemented in the model by exogenously increasing urban demand through an urbanization mechanism (i.e. rural-urban migration). To capture the rapid pace of rural-to-urban migration in SA, we model an out-migration of half of the remaining rural population living in the lowest three expenditure quintiles (i.e., the rural population shares fall to around 20%). We assume that migrants move from rural quintiles to equivalent urban quintiles, thereby increasing labor endowment of this representative household in the model and hence its share of labor incomes earned within their WMA-specific labor market. Moreover, new migrants and their families adopt urban consumption patterns, allowing us to capture increased demand for water resources caused by urbanization.

Migration from rural to urban areas shifts overall composition of household demand towards urban consumption patterns, which are considerably more water-intensive causing a 3% increase in the price of domestic water under the *Water-Restricted Urbanization* scenario (Table 5). Urban consumers also spend a larger share of their incomes on processed foods and other nonagricultural goods. Thus the shift in demand composition caused by urbanization increases nonagricultural GDP, but reduces demand for less-processed agricultural goods. Agricultural employment declines as a result by 59,000 jobs (equivalent to 8.4% of current agricultural workforce - Table 6). While new nonagricultural jobs are created for migrant workers, they are insufficient to offset the decline in agricultural employment. These results indicate how the lower labor-intensity of industry vis-à-vis agriculture may increase national unemployment in SA as urbanization proceeds. The decline in labor-intensive agricultural production reduces the overall level of employment in the country under *Water-Restricted Urbanization* causing slight declines in household worker populations for these higher-income households.

As discussed above, urbanization reduces demand for agricultural goods, which causes a decline in agricultural production and employment. While rural expenditures per worker for the lower quintiles decline with urbanization, higher-income rural households benefit from larger returns to high-skilled labor and capital. Given their larger incomes per worker, the impact is sufficient to raise average rural incomes. Conversely, the shift in consumer demand towards nonagricultural goods and the increase in nonagricultural GDP increases expenditures per worker in urban areas. However, the inflow of lower-paid migrants into urban areas causes average urban expenditures to decline (Appendix 6).

In *Scenario III* we assumed no change in the supply of urban/industrial water resources, which coupled with rising domestic water demand, caused domestic water prices to rise by 3.1% (Table 5). In the *Water-Liberalized Urbanization* (*Scenario IV*) we allow for transfer of irrigation water to urban/industrial use, to maintain the national urban/industrial water price unchanged. In order to neutralize rising water prices, 7.1% of irrigation water at the national level must be transferred to domestic use. This causes agricultural production and GDP to decline further under liberalization (Table 5). Production expands substantially for the domestic water distribution sector, which lowers the national domestic water price. However, the small size of water charges relative to sectors' GDP implies that reducing water price does not greatly reduce the overall cost of production and hence leads to small changes in other nonagricultural sectors' GDP.

The decline in irrigation water and a consequent increase in its SP cause a substantial drop in agricultural production, primarily for irrigation-intensive crops such as fruits. This reduces agricultural employment by one percent of total agricultural workforce, causing rural expenditures per worker to decline for all expenditure quintiles. While urban households benefit more than rural households from lower water prices, the overall effect of the domestic transfer on urban consumption per worker is small.

The above results suggest that liberalizing water trade involves difficult trade-offs in allocating water resources between alternative uses. While industrialization and urbanization create additional nonagricultural jobs and raise household incomes in urban areas, these processes also cause substantial increases in water prices. These two outcomes apparently justify increased transfers away from subsidized irrigation use. On the other hand, transferring water from irrigation to domestic use leads to substantial declines in agricultural production, which raise agricultural and food prices and lowers per capita incomes in the SA's poorer rural areas. There are thus trade-offs between SA's industrialization strategy and urbanization process, and its social objectives of raising employment, reducing poverty, and improving service delivery.

5. Conclusions, policy implications and future research agenda

Pressure on existing water resources in SA is predicted to worsen with planned growth strategies, observed recent demographic changes and unfavorable global climatic and economic conditions. The implications are expected to be particularly severe for irrigation agriculture which currently uses more than 60% of water resources in the country. The country is also undergoing radical water sector reforms which aim to correct for previous social injustices and economic inefficiencies in water use and allocation with again serious implications for irrigation agriculture.

The fact that many of these changes and policy reforms serve conflicting objectives and often work in opposite directions necessitates adoption of an economy-wide approach to properly evaluate their net impacts on rural livelihoods and economy at large. The present study attempted to develop such comprehensive analytical framework within a general equilibrium framework to account for inter-sector linkages and micro-macro feedbacks. Accordingly a new social accounting matrix and CGE model were constructed to examine the economy-wide impacts of selected macro and water related policies on water use and allocation and national economy. The CGE model incorporates agricultural and nonagricultural water use and contains detailed information on production, trade and consumption.

Currently water resources' management within the SA economy is based on some strategic allocation regimes that determine the distribution of managed total water supplies between regions (WMAs) and economic sectors at set (not market determined) water charges. Sectoral and economy-wide impacts of four policy change scenarios have been evaluated. The four policy scenarios experimented with relaxing such non-price restrictions on water distribution to allow for market based allocations under current water productivity levels and predicted urbanization and industrialization trends. In the first policy scenario (*Regional Irrigation* water market liberalization) current regional shares of water supplies were allocated between competing irrigated agricultural activities (i.e. different crops) on basis of economic efficiency (i.e. market based) to equalize water shadow prices (SP) across all crops within the same WMA. Implicit crop-level water quotas were found to reduce the amount of irrigated land allocated to higher-value horticultural crops, while creating higher shadow rents for farmers producing lower-value and water-intensive field crops, such as sugarcane and fodders. Liberalizing regional irrigation water markets would therefore improve the efficiency of water allocation within WMAs leading to expansions in agricultural production and exports, and create additional jobs for farm laborers. These jobs are especially important for lower-income rural households. Regional water market liberalization would also increase the price of cereals, hurting urban consumers. Accordingly, liberalizing local water allocation within irrigation agriculture was found to work in favor (increased area and production) of high value crops such as horticulture, expand agricultural production and exports and farm employment.

The second policy experiment simulated implications of liberalizing interregional water markets to equalize water SPs within irrigated agriculture across all WMAs (i.e. allowing for market-based transfers between some WMAs in addition to among crops). Again such policy change favors production of higher value crops and regions with positive macroeconomic impacts and improves employment and income levels for low-income households. Using existing transfer schemes to equalize interregional SPs increases agricultural GDP favoring greater production of high-value crops (citrus fruits) at the expense of cereals and other field crops. This raises the price of these crops, which reduces real expenditures for higher-income households, especially in urban areas. By contrast, real per capita expenditures increase for lower-income households in water receiving regions due to increased agricultural employment and rising returns to agricultural land. Finally, amending existing water transfer schemes has economy-wide implications, with some regions able to respond to rising cereals prices by increasing production and, thereby, raising rural incomes.

The third policy scenario introduced competition for water from non-agriculture urban uses with irrigation agriculture. This leads to higher water SPs for irrigation water with reduced income and employment benefits to rural households and higher gains for non-agricultural households. Like *Scenario III*, the final policy experiment (*Scenario IV*) considered competition from industrial expansion and urbanization but transferred water from irrigated agriculture to domestic use to maintain the national water price unchanged. This has major negative consequences on the agricultural economy. The above experiments reveal difficult tradeoffs between general economic gains and higher water prices which place serious questions on subsidizing water supply to irrigated agriculture, i.e. making irrigation subsidies much harder to justify.

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Table 1: Structure of the South African economy (2002)

	Share of total (%)				Export intensity	Import intensity
	GDP	Employment	Exports	Imports		
Total GDP	100.00	100.00	100.00	100.00	13.48	13.31
Agriculture	4.32	7.87	3.65	2.17	15.05	9.27
Field crops	1.79	2.93	0.59	1.46	5.93	13.53
Summer cereals	0.43	0.89	0.31	0.40	11.09	13.55
Winter cereals	0.17	0.33	0.01	0.26	1.00	18.97
Oils & legumes	0.18	0.34	0.18	0.48	15.62	34.07
Fodder crops	0.03	0.06	0.00	0.00	2.61	0.00
Sugarcane	0.84	0.99	0.00	0.00	0.00	0.00
Cotton & tobacco	0.14	0.32	0.09	0.32	11.02	30.69
Horticultural crops	1.00	1.85	2.16	0.23	42.05	7.08
Vegetables	0.22	0.55	0.07	0.00	5.60	0.00
Citrus fruits	0.15	0.24	0.53	0.02	67.91	6.76
Subtropical fruits	0.08	0.11	0.07	0.00	16.52	0.00
Deciduous fruits	0.45	0.65	1.30	0.00	62.57	0.00
Other horticulture	0.10	0.30	0.19	0.22	34.26	35.71
Livestock	1.28	2.80	0.85	0.27	10.88	3.46
Other agriculture	0.26	0.29	0.05	0.21	3.89	13.53
Industry	33.38	29.27	75.84	83.46	22.17	21.96
Mining	8.72	4.96	33.72	10.28	71.10	43.45
Manufacturing	19.90	17.65	42.12	73.18	16.87	23.30
Food processing	3.03	2.51	3.03	2.98	7.77	5.98
Textiles & clothing	0.92	1.93	1.44	4.43	11.61	21.01
Wood & paper	1.96	2.78	2.20	2.71	11.04	12.53
Chemicals	4.73	2.74	8.85	14.42	14.47	19.96
Nonmetallic minerals	0.68	0.87	0.60	1.31	8.98	17.47
Metals & machinery	3.98	2.88	14.87	13.58	29.63	26.66
Electrical machinery	0.85	0.85	1.75	13.02	15.82	53.55
Scientific equipment	0.10	0.08	0.27	3.23	22.01	59.07
Transport equipment	1.91	1.73	6.65	15.69	19.37	34.67
Other manufacturing	1.74	1.30	2.48	1.81	18.00	11.44
Electricity generation	2.03	0.98	0.00	0.00	0.00	0.00
Water distribution	0.45	0.17	0.00	0.00	0.00	0.00
Construction	2.27	5.50	0.00	0.00	0.00	0.00
Services	62.30	62.86	20.51	14.37	5.46	4.13

Source: South Africa 2002 Water-SAM. Import intensity is the share of imports in total domestic demand. Export intensity is the share of exports in total domestic output.

Table 2. Micro impacts of the *Regional Irrigation* water liberalization scenario

Change in water shadow prices

	Average base value (R/1000 m3)	Percent change
National	0.57	-2.9
Limpopo	0.76	-28.8
Luvulvhu-Letaba	0.90	-21.2
Crocodile-Marico	0.53	0.7
Olifants	0.67	-5
Inkomati	0.47	-11.1
Usutu-Mhlatuze	0.38	10.3
Thukela	0.41	13.4
Upper Vaal	0.54	-16.5
Middle Vaal	0.46	-4.3
Lower Vaal	0.36	6.7
Mvoti-Umzimkulu	0.42	-2.9
Mzimvubu-Keiskamma	0.69	-17.8
Upper Orange	0.35	6.2
Lower Orange	0.41	9.7
Fish-Tsitsikamma	0.59	20
Gouritz	0.37	21
Olifants/Doorn	0.87	-11.4
Breede	0.79	-10.5
Berg	0.82	-13.5

Changes in production, land areas and water use

	Production quantity (1000 mt)		Agricultural land area (1000 ha)		Irrigation water use (mil m^3)	
	Base quantity	Percent change	Base land area	Percent change	Base water use	Percent change
All crops	48,801	-	6,992	-1	7,274	0
Summer cereals	10,377	0.7	3,356	-1	1,242	-77
Winter cereals	2,689	-1.4	1,047	-7	593	-15
Oils & legumes	1,422	-5.9	1,103	-13	190	-15
Fodder crops	2,943	5.8	956	19	655	-100
Sugarcane	21,157	-3.9	470	-10	1,386	-39
Cotton & tobacco	150	62.1	59	12	91	282
Vegetables	4,482	35.3	187	31	796	57
Citrus fruits	1,472	173.4	63	129	451	281
Subtropical fruits	602	-2.6	51	-24	375	13
Deciduous fruits	3,339	12.6	249	0	1,293	31
Other horticulture	171	-32.2	87	-36	203	-79
Irrigated field crops	21,204	-	924	-59	-	-
Summer cereals	1,759	-75.7	302	-76	-	-
Winter cereals	770	-13.9	163	-25	-	-
Oils & legumes	125	-12.5	59	-17	-	-
Fodder crops	1,147	-100	236	-100	-	-
Sugarcane	7,239	-36.2	133	-41	-	-
Cotton & tobacco	98	129	32	84	-	-
Rainfed field crops	27,598	-	6,068	7	-	-
Summer cereals	8,617	16.3	3,055	7	-	-
Winter cereals	1,919	3.6	884	-4	-	-
Oils & legumes	1,296	-5.3	1,044	-12	-	-
Fodder crops	1,796	73.4	720	58	-	-
Sugarcane	13,918	12.8	337	3	-	-
Cotton & tobacco	52	-64.8	28	-68	-	-

Table 3. Macroeconomic and consumer price effects of liberalizing regional and national irrigation water markets

	Base value	Regional irrigation scenario	National irrigation scenario
		Percentage change (%)	
GDP factor cost	100.00	0.03	0.01
Agriculture	4.32	4.48	5.43
Field crops	1.79	-3.82	-4.56
Horticulture	1.00	26.41	31.84
Livestock	1.28	-0.08	-0.05
Other	0.26	-0.23	-0.28
Non-agriculture	95.68	-0.18	-0.24
Consumption	62.77	-0.04	-0.08
Investment	15.32	0.02	0.03
Government	18.43	-0.06	-0.09
Exports	32.43	0.31	0.36
Agriculture	3.65	31.73	38.43
Field crops	0.59	-8.81	-10.41
Horticulture	2.16	55.38	66.98
Non-agriculture	96.35	-0.88	-1.08
Processed foods	3.03	-1.14	-1.43
Imports	-28.95	0.35	0.40
Agriculture	2.17	3.90	4.76
Field crops	1.46	5.45	6.63
Horticulture	0.23	1.80	2.30
Non-agriculture	97.83	0.27	0.30
Processed foods	2.98	0.41	0.54
		Final value	
Exchange rate	1.000	0.997	0.996
Consumer prices (CPI)	1.000	1.001	1.002
Summer cereals	1.000	1.038	1.044
Winter cereals	1.000	1.026	1.034
Oils & legumes	1.000	1.026	1.030
Fodder crops	1.000	1.054	1.060
Sugarcane	1.000	1.053	1.061
Cotton & tobacco	1.000	0.995	1.001
Vegetables	1.000	0.862	0.871
Citrus fruits	1.000	0.678	0.637
Subtropical fruits	1.000	1.021	1.028
Deciduous fruits	1.000	0.982	0.995
Other horticulture	1.000	1.046	1.052

Source: Results from the South Africa 2002 Water-CGE model.

Table 4. Factor market impacts of liberalizing regional and national irrigation water markets

	All sectors			Agriculture only		
	Base value	Regional irrigation	National irrigation	Base value	Regional irrigation	National irrigation
Factor employment		Change (absolute)			Change (absolute)	
Labor (1000s)	8,239	13.7	17.9	648	32.0	42.8
High-skilled	1,300	0.0	0.0	44	2.0	2.7
Skilled	3,275	-4.8	-6.8	27	1.3	1.7
Unskilled	3,664	18.4	24.7	577	28.6	38.4
Capital (index)	506	0.0	0.0	21	0.5	0.6
Land (1000 ha)	-	-	-	7,629	0.0	0.0
Irrigation water (mil m^3)	-	-	-	7,274	0.0	0.0
Factor returns		Change (%)			Change (%)	
Labor (R1000)	63,176	-0.20	-0.28	16,554	0.0	0.1
High-skilled	147,505	-0.26	-0.37	36,225	0.1	0.3
Skilled	61,982	-0.02	-0.03	46,529	0.8	1.2
Unskilled	34,330	-0.20	-0.26	13,647	0.0	0.0
Capital (index)	100	-0.32	-0.46	100	-0.3	-0.5
Land (index)	-	-	-	100	133.4	160.5
Irrigation water (R/m^3)	-	-	-	0.57	-2.9	-1.2

Source: Results from the South Africa 2002 Water-CGE model.

Table 5. Macroeconomic results of the *Water-Restricted* (III) and *Water-Liberalized Urbanization* (IV) scenarios

	Base value	Water-restricted urbanization	Water-liberalized urbanization
		Change from base (%)	
GDP factor cost	100.00	0.13	0.12
Agriculture	4.32	-5.66	-6.37
Mining	8.72	-0.06	0.02
Manufacturing	19.90	0.59	0.61
Food processing	3.03	3.33	3.26
Electricity	2.03	1.63	1.67
Water	0.45	3.12	5.13
Construction	2.27	0.15	0.14
Services	62.30	0.33	0.34
Consumption	62.77	0.21	0.20
Investment	15.32	0.07	0.06
Government	18.43	0.14	0.15
Exports	32.43	-0.04	-0.06
Agriculture	3.65	-3.54	-6.21
Non-agriculture	96.35	0.09	0.17
Imports	-28.95	-0.05	-0.07
Agriculture	2.17	-13.57	-13.32
Non-agriculture	97.83	0.26	0.23
Exchange rate	1.000	1.002	1.002
Consumer prices (CPI)	1.000	0.998	0.998
Agriculture		0.980	0.982
Processed foods	1.000	0.999	1.000
Other goods/services	1.000	1.003	1.002
Electricity	1.000	1.003	1.003
Distributed water	1.000	1.031	1.000

Source: Results from the South Africa 2002 Water-CGE model.

Table 6. Factor market results of the *Water-Restricted* (III) and *Water-Liberalized Urbanization* (IV) scenarios

	All sectors			Agriculture only		
	Base value	Water-restricted urbanization	Water-liberalized urbanization	Base value	Water-restricted urbanization	Water-restricted urbanization
Factor employment		Change (absolute)			Change (absolute)	
Labor (1000s)	8,239	-20.0	-26.0	648	-59.0	-65.9
High-skilled	1,300	0.0	0.0	44	-4.2	-4.8
Skilled	3,275	13.0	12.7	27	-2.5	-2.9
Unskilled	3,664	-33.1	-38.8	577	-52.3	-58.2
Capital (index)	506	0.0	0.0	21	-1.6	-1.6
Land (1000 ha)	-	-	-	7,629	0.0	0.0
Irrigation water (mil m^3)	-	-	-	7,274	0.0	-51.4
Factor returns		Change (%)			Change (%)	
Labor (R1000)	63,176	-59.0	-65.9	16,554	0.97	1.71
High-skilled	147,505	-4.2	-4.8	36,225	0.98	1.74
Skilled	61,982	-2.5	-2.9	46,529	0.90	2.03
Unskilled	34,330	-52.3	-58.2	13,647	1.07	1.80
Capital (index)	100	-1.6	-1.6	100	0.38	0.41
Land (index)	-		-	100	-11.22	-10.72
Irrigation water (R/m^3)	-		-	0.57	-9.43	-5.32

Source: Results from the South Africa 2002 Water-CGE model.

Appendix 1: Summary characteristics of Water Management Areas

	Population		GDP per capita	Share of national GDP (%)			Share of region GDP (%)	
	Total (1000s)	Rural (%)	(R)	Total	Agric.	Industry	Agric.	Industry
National	44,770	43.70	23,282	100.00	100.00	100.00	4.31	24.66
Limpopo	868	76.56	16,344	1.36	2.24	0.59	7.09	10.77
Luvulvhu-Letaba	2,330	95.17	13,113	2.93	4.12	1.01	6.06	8.53
Crocodile-Marico	3,830	35.47	35,913	13.20	4.29	9.88	1.40	18.46
Olifants	2,934	70.02	22,629	6.37	4.20	5.95	2.84	23.03
Inkomati	1,177	77.48	16,041	1.81	4.82	1.54	11.46	20.91
Usutu-Mhlatuze	2,153	83.44	10,554	2.18	7.13	2.10	14.10	23.78
Thukela	1,747	71.05	9,042	1.52	4.59	1.97	13.06	32.09
Upper Vaal	8,354	13.22	33,620	26.94	7.67	34.21	1.23	31.31
Middle Vaal	1,647	19.54	20,592	3.25	8.96	1.43	11.87	10.85
Lower Vaal	1,721	57.51	13,768	2.27	4.86	0.80	9.22	8.73
Mvoti-Umzimkulu	6,091	42.45	22,797	13.32	17.68	16.96	5.72	31.39
Mzimvubu-Keiskamma	4,202	76.23	8,142	3.28	1.25	2.38	1.65	17.87
Upper Orange	1,013	21.67	21,930	2.13	2.13	1.30	4.32	15.03
Lower Orange	429	20.58	25,932	1.07	4.18	0.23	16.89	5.30
Fish-Tsitsikamma	1,798	19.36	25,789	4.45	3.35	4.96	3.25	27.51
Gouritz	435	16.78	19,171	0.80	1.71	0.88	9.24	27.14
Olifants/Doorn	239	44.73	18,497	0.42	3.22	0.33	32.65	18.98
Breede	437	33.44	20,418	0.86	7.19	0.63	36.19	18.07
Berg	3,367	3.93	36,639	11.83	6.39	12.85	2.33	26.77

Source: South Africa 2002 Water-SAM and CGE model. ‘Industry’ includes manufacturing, energy and construction, but excludes the mining sector.

Appendix 2: Specification of the South African Water-CGE model

This appendix presents more details on the SA Water-CGE model. Production activities in the Water-CGE model are governed by a constant elasticity of substitution (CES) production function. Composite factors are combined with fixed-share intermediates under a Leontief specification. Activities also receive producer subsidies and pay activity taxes, including a water tariff for their use of irrigation water. While the model disaggregates production across WMAs, these regions are treated as different activities producing the same commodity for sale in the national commodity market. The aggregation of different WMAs' output into a composite commodity is also governed by a CES aggregation function. This allows substitution between different WMAs' based on their relative producer prices to minimize the marketed supply price of a commodity.

Marketed supply from domestic producers is either exported or sold in domestic markets based on a constant elasticity of transformation (CET) function. Profit maximization drives producers to sell in those markets where they can achieve the highest returns based on relative domestic and export prices. Export prices include any transaction costs incurred in transporting the commodity from the border to the final sales market. Commodities that are not exported are supplied to domestic markets and also incur transaction costs. Demanders then decide whether to consume domestically produced and supplied commodities or whether to consume imported commodities. Thus, substitution possibilities also exist between imported and domestic goods under a CES Armington specification. The final ratio of imports to domestic goods is determined by the cost minimization based on the relative prices of imports and domestic goods, with the latter including import tariffs and import transaction costs. Under a small-country assumption, world import and export prices are fixed in foreign currency.

Total factor incomes are determined by activities' collective demand for each factor of production. Total factor supply is fixed for relatively scarce factors (i.e., agricultural land, water resources, capital and highly skilled labor) and flexible for more abundant underemployed factors (i.e., skilled and unskilled labor). The former are fully employed earnings flexible nominal returns, while the latter earn a fixed nominal wage with perfectly elastic supply. After paying factor taxes, the remaining factor incomes are paid to households depending on their share of total factor endowments adjusted for a fixed household wage distortion term. Factor taxes include corporate taxes and the returns to domestic and industrial water resources. Households also receive income from government and inter-household transfers. Households then save and pay taxes, and the remaining disposable income is used for consumption expenditures. Commodity consumption expenditure is derived from maximizing a Stone-Geary utility function, which results in a linear expenditure system (LES) of demand. Households in each WMA are disaggregated across rural/urban areas and national expenditure quintiles[12]. Each representative household is an aggregation of the individual households captured in the

[12] There are 190 representative households (five expenditure rural and urban quintiles in each WMA)

2001 Population Census and the 2000 Income and Expenditure Survey (reconciled with inflation and national accounts) (StatSA, 2002 and 2001)[13].

Commodity demands from other components of domestic absorption are assumed to be proportional to base-year demand quantities. The value of total investment demand is equal to total available savings, which includes government savings (or dis-savings), household savings, and foreign savings or capital inflows. Since household savings rates are fixed, the Water-CGE model assumes a savings-driven investment closure.[14] The version of the Water-CGE model documented in this paper is comparative static, so the level of investment does not influence the level of capital stocks. Tax rates are fixed. So government savings, which includes the fiscal deficit and public investments, is determined endogenously such that total revenues equals total expenditures in equilibrium. Finally, the level of foreign savings is fixed in foreign currency, and the exchange rate adjusts to balance the current account, which is dominated by trade with the rest of the world. Together the total amount of commodities demanded must be equal to total composite supply in equilibrium. This includes commodity demand generated by transaction costs. The Water-CGE model is coded using GAMS.

[13] Since the household survey is not representative at the WMA level, per capita income/expenditure patterns were identified at the provincial level for rural and urban areas, and then multiplied by the number of rural and urban inhabitants reported by the population census. Household incomes from various income sources were manually adjusted proportionately to match the expenditure levels reported in the survey.

[14] Nell (2003) finds that this is an appropriate closure for South Africa.

Appendix 3: Existing natural and manmade interregional water transfers

	Total water transferred (mil. m^3)	Share of transfer in… (%)	
		Sending region	Receiving region
Total interregional water transfers	5,528	-	-
Water transfer schemes	1,415	-	-
Orange River Project			
From Upper Orange to Fish-Tsitsikamma	714	17.4	50.8
Thukela-Vaal transfer schemes			
From Thukela to Upper Vaal	431	49.7	34.8
Lesotho Highlands Water Project			
From Lesotho to Upper Vaal	270	n/a	10.8
Major river-based transfers	3,962	-	-
Vaal river			
From Upper Vaal to Middle Vaal	799	32.1	73.7
From Middle Vaal to Lower Vaal	603	55.6	49.2
Orange river			
From Upper Orange to Lower Orange	2,360	57.6	90.0
Breede river			
From Breede to Berg	200	26.7	18.3

Source: Own calculations using StatSA (2006).

Appendix 4. Regional agricultural land allocation under the *National Irrigation* water liberalization scenario

	Absolute change in crop land allocation compared to the *Regional Irrigation water liberalization* scenario (1000ha)								
	All Regions	Thukela-Vaal scheme				Orange River Project			Other regions
		Thukela	Upper Vaal	Middle Vaal	Lower Vaal	Upper Orange	Lower Orange	Fish-Tsitsikamma	
Irrigation water demand									
Base (mil. m^3)	7,274	312	254	371	552	271	407	371	4736
New transfers (mil. m^3)	0.0	348	-140	-100	-108	-243	-233	476	0.0
<u>All crops</u>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Summer cereals	0.4	-8.8	2.1	-9.6	8.3	4.8	8.9	-1.6	-3.8
Winter cereals	46.7	3.3	-1.2	19.0	-6.6	-5.6	5.1	-0.6	33.4
Oils & legumes	-6.9	-1.6	-3.1	-4.5	-1.9	3.8	0.4	0.0	0.0
Fodder crops	-24.5	-5.5	6.0	1.5	3.4	11.3	20.3	-33.3	-28.1
Sugarcane	-9.1	-9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Cotton & tobacco	-4.2	0.3	-0.4	-3.0	0.1	-4.2	0.8	0.4	1.9
Vegetables	-12.1	11.4	-2.4	-2.9	0.3	-9.7	-37.1	0.6	27.7
Citrus fruits	27.0	10.2	-0.1	-0.1	-0.1	0.0	-0.1	32.3	-15.1
Subtropical fruits	-1.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.6	-1.6
Deciduous fruits	-14.5	0.0	-0.8	-0.4	-3.6	-0.3	0.7	1.9	-12.0
Other horticulture	-1.9	0.0	0.0	0.0	0.0	0.0	1.1	-0.2	-2.6
<u>Irrigated field crops</u>	-92.3	10.5	-28.1	-16.5	-17.2	-40.9	-5.0	0.6	4.3
Summer cereals	-33.0	1.9	-15.0	-5.6	-4.0	-9.9	-2.0	0.0	1.6
Winter cereals	-45.3	3.5	-8.8	-4.6	-8.9	-24.8	-3.3	0.1	1.4
Oils & legumes	-12.2	1.5	-3.9	-3.2	-4.2	-2.0	-0.4	0.0	0.0
Fodder crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane	2.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	-0.4
Cotton & tobacco	-4.6	0.4	-0.4	-3.1	0.0	-4.3	0.6	0.5	1.7
<u>Rainfed field crops</u>	94.8	-32.1	31.4	19.9	20.5	50.9	40.5	-35.7	-0.6
Summer cereals	33.4	-10.7	17.1	-4.0	12.3	14.7	10.9	-1.7	-5.3
Winter cereals	92.1	-0.2	7.6	23.6	2.3	19.1	8.4	-0.7	32.0
Oils & legumes	5.3	-3.1	0.8	-1.3	2.3	5.7	0.8	0.0	0.0
Fodder crops	-24.4	-5.5	6.0	1.5	3.4	11.3	20.3	-33.3	-28.1
Sugarcane	-11.8	-12.4	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Cotton & tobacco	0.3	-0.1	0.0	0.1	0.1	0.0	0.1	-0.1	0.2

Source: Results from the South Africa 2002 Water-CGE model.

Appendix 5. Changes in real per worker consumption spending

	Rural and urban households			Rural households			Urban households		
	Base value (R)	Change from base (%)		Base value (R)	Change from base (%)		Base value (R)	Change from base (%)	
		Regional irrigation	National irrigation		Regional irrigation	National irrigation		Regional irrigation	National irrigation
All regions (national)	90,903	-0.06	-0.09	59,001	0.22	0.23	101,860	-0.11	-0.15
Limpopo	63,579	-0.32	-0.29	49,559	-0.69	-0.62	77,891	-0.07	-0.07
Luvulvhu-Letaba	65,905	-0.34	-0.49	67,742	-0.54	-0.77	63,146	-0.01	-0.06
Crocodile-Marico	103,839	-0.19	-0.25	50,317	-0.22	-0.30	130,635	-0.18	-0.25
Olifants	73,989	-0.14	-0.22	55,365	-0.03	-0.15	89,711	-0.20	-0.25
Inkomati	60,393	-1.70	-2.06	47,809	-3.28	-4.01	71,305	-0.78	-0.93
Usutu-Mhlatuze	90,445	0.68	0.78	67,928	1.64	1.92	110,571	0.15	0.16
Thukela	79,984	1.01	1.95	58,554	2.97	5.71	94,264	0.20	0.39
Upper Vaal	107,955	-0.17	-0.23	78,138	-0.31	-0.68	113,155	-0.15	-0.18
Middle Vaal	53,151	0.80	0.70	44,726	3.75	3.46	55,888	0.04	-0.02
Lower Vaal	66,170	0.68	0.50	58,544	1.65	1.25	71,211	0.15	0.09
Mvoti-Umzimkulu	85,468	0.25	0.27	47,388	2.55	2.91	96,051	-0.06	-0.10
Mzimvubu-Keiskamma	107,827	-0.11	-0.19	78,615	-0.50	-0.69	127,987	0.05	0.02
Upper Orange	75,902	0.18	-0.45	40,132	1.48	-1.81	102,790	-0.20	-0.06
Lower Orange	56,653	-0.31	-2.22	56,073	-0.66	-7.31	56,828	-0.21	-0.71
Fish-Tsitsikamma	86,579	0.13	0.94	51,180	2.39	11.99	94,113	-0.13	-0.33
Gouritz	78,418	0.50	0.47	60,456	2.60	2.65	82,978	0.11	0.07
Olifants/Doorn	47,368	-0.85	-0.67	47,159	-2.87	-2.46	47,473	0.14	0.22
Breede	58,412	-1.78	-1.99	82,210	-5.53	-6.04	53,723	-0.66	-0.77
Berg	103,566	-0.13	-0.18	60,703	-1.66	-1.99	106,913	-0.06	-0.10
Quintile 1 (low)	26,973	0.26	0.28	59,001	0.22	0.23	30,306	0.10	0.16
Quintile 2	38,539	0.21	0.24	21,804	0.60	0.54	43,599	0.07	0.14
Quintile 3	49,048	0.07	0.08	28,853	0.61	0.55	52,934	-0.01	0.02
Quintile 4	62,189	0.09	0.13	38,224	0.39	0.29	61,713	-0.08	-0.08
Quintile 5 (high)	149,918	-0.14	-0.20	63,370	0.51	0.66	161,047	-0.14	-0.21

Source: Results from the South Africa 2002 Water-CGE model.

Appendix 6. Household worker populations and consumption effects of the *Water-Restricted* (III) and *Water-Liberalized Urbanization* (IV) scenarios

	Base labor population (1000 workers)	% Change under Water-restricted urbanization	Total consumption per worker (Rands)	Percentage change (%)	
				Water-restricted urbanization	Water-liberalized urbanization
All households	8,239	-0.24	89,021	0.21	0.20
Quintile 1 (low)	727	-0.29	22,786	12.06	12.03
Quintile 2	994	-0.32	32,291	13.94	13.92
Quintile 3	1,281	-0.40	44,171	5.98	5.98
Quintile 4	1,789	-0.40	62,189	-2.14	-2.17
Quintile 5 (high)	3,448	-0.07	149,918	-1.15	-1.15
Urban households	5,168	18.40	112,262	-10.84	-10.82
Quintile 1 (low)	157	180.69	26,353	8.52	8.54
Quintile 2	312	108.62	39,814	4.51	4.53
Quintile 3	604	55.36	50,834	-1.26	-1.24
Quintile 4	1,275	-0.39	61,713	-1.76	-1.74
Quintile 5 (high)	2,821	-0.03	161,047	-1.05	-1.04
Rural households	3,071	-31.62	49,909	15.23	15.08
Quintile 1 (low)	570	-50.11	21,804	-4.68	-4.81
Quintile 2	682	-50.11	28,853	-4.44	-4.56
Quintile 3	677	-50.17	38,224	-2.14	-2.25
Quintile 4	514	-0.43	63,370	-3.06	-3.21
Quintile 5 (high)	628	-0.28	99,904	-1.81	-1.94

Source: Results from the South Africa 2002 Water-CGE model.