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CGE Analyses of Selected Policy Regimes

R. Hassan
J. Thurlow
T. Roe
X. Diao
S. Chumi
Y. Tsur

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Development Research Group
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Abstract

The pressure on an already stressed water situation in South Africa 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 people. 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 the 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 in irrigation agriculture is 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 fueled 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, making irrigation subsidies difficult to justify.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on role of water resources in the economy. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at The authors may be contacted at rhassan@postino.up.ac.za, j.thurlow@cgiar.org, troe@umn.edu, x.diao@cgiar.org, singochumi@yahoo.com, tsur@agri.huji.ac.il.

Macro-Micro Feedback Links of Water Management in South Africa: CGE Analyses of Selected Policy Regimes

R. Hassan[1], J. Thurlow[2], T. Roe[3], X. Diao[2], S. Chumi[1], and Y. Tsur[4]

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[1] CEEPA, University of Pretoria, South Africa, [2]IFPRI Washington DC, [3]University of Minnesota, Saint Paul USA, [4]Hebrew University of Jerusalem, Israel

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. Nevertheless, the 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, its multi-sector linkages and its contribution to food security in general and the livelihoods of the rural poor in particular.

Other important water related features of the SA agricultural economy include the high protection the sector enjoyed in the past for reasons of food security and other political concerns. Agriculture received a direct price subsidy on water use and on investment in irrigation infrastructure 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.

Land reform, liberalization of agricultural trade and removal of protection from agriculture are other important policy changes that have major consequences on water use and allocation in SA. 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.

Moreover, important recent developments in the international scene such as the energy shortage, surging food prices, growing interest in biofuels, and climate change are expected to have additional impacts on competition on the availability of water resources in general with important implications for water allocation and use in SA (DWAF, 2008).

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 intends to analyze the potential effects of such 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

Although SA has not yet reached full utilization of its available fresh water resources, the country is not endowed with abundant water and is expected to approach the limits of potentially available water supplies by 2025 (DWAF, 2004). An indicator of water scarcity in SA is the average annual rainfall of about 450 mm received, which is almost half the world average of 860 mm. More over, only an estimated 20% of the country's groundwater resources are found in economically exploitable geological formations (DWAF, 2004). There is however, large spatial variation in rainfall and availability of surface and ground water across the country ranging from dry semi-desert conditions on the western parts to wetter sub-humid climates on eastern coastal areas.

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). While this gave the country great flexibility in control and management of water resources as one giant interlinked system of supply, freshwater flow regimes have been altered significantly in many river basins in SA.

2.1 Current water supply, use and allocation within the SA economy

The natural environment supplies 49 billion m^3 of freshwater to mean annual runoff in SA (about 8% of annual rainfall reaching rivers in 2000). Only 60% of the runoff (19.5 billion m^3) is available as surface water yield while the rest is retained within the environment (base-flow support). About half of the surface water yield is kept in stream as ecological reserve and directly abstracted by forest plantations. 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 of available yield managed by DWAF (63%) 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. The above water management institutional set up is undergoing major structural changes as a result of implementing the provisions of the new NWP and NWA which are outlined in the next section.

SA has relied primarily on its surface water supplies with little emphasis on and investment in developing groundwater resources which currently account for only 10% of total water supply. Currently groundwater is utilized at limited scale in localized areas where it represents a key source of water supply especially in rural semi-arid areas mainly for irrigation and domestic use. However, recent assessment efforts indicate a much larger potential for development and use of groundwater resources as a major supply source at larger scales than currently exploited (DWAF, 2005; Woodford et al., 2006).

If one considers rainfed agriculture use of soil water (including cultivated forest), Table 1 shows that agriculture used 94% of total water in SA in 2000. Excluding the direct use of soil water by rainfed agriculture, the sector's share drops to 67%. Domestic use was the second largest water user consuming 15% compared to shares of 7%, 5% and 3% of total water used by services, manufacturing and mining, respectively in 2000. Table 1 also shows that agriculture generated the lowest shares of direct economic benefits in terms of its contribution to GDP (2.7%) and employment (0.13 jobs/000 m^3) in 2000 (Hassan and Crafford, 2006).

Water use by and contributions of economic activities to GDP and employment however vary significantly by geographic region. SA has been divided into 19 water management areas (WMA) where a catchment management agency (CMA) will be established in each to directly manage water resources development and utilization in the designated WMA (see Figure 1 for a map of boundaries of WMAs). Assessments' of the national water resources strategy (NWRS) (DWAF, 2004) indicate that 10 out of the 19 WMAs showed deficit water conditions in 2000 (Table 2), mainly those located in the dry north and western parts of the country while the country still has a surplus water balance overall. The deficit has been partially addressed by drawing water from the ecological reserve, and thereby placing environmental stress on a number of WMAs in spite of the extensive inter-basin water transfer network through which all WMAs are linked to others[2].

Establishment of a NWRS is required by the NWA to set out strategies, objectives and planning guidelines, procedures and the institutions required for managing national water resources. Accordingly the NWRS 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. However, the NWRS suggests demand

[2] Note the only WMA not linked to any other is the Mzimvubu to Keiskamma (Table 2)

management and conservation measures which promote reallocation between competing economic uses within the WMA on efficiency grounds as the main reconciling mechanism for satisfying local needs for economic use. 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 represent key water policy changes the economy-wide impacts of which require careful assessment.

2.2 Key water management and economic policy challenges and macro-micro policy linkages

Over the past few years SA agriculture has seen major structural adjustments in response to a number of critical macro and sector level policy changes. Broad macroeconomic reforms that led to major changes in managing the foreign exchange and capital markets coupled with wide liberalization of agricultural marketing and trade regimes have exposed the agricultural sector to shifts in relative world commodity and factor prices (international terms of trade). Particularly, the competitiveness of the country's agricultural exports has been affected with the removal of various forms of protection, interest rate and export subsidies and substantial currency devaluations (Vink et al., 2002, Poonyth et al., 2000 and 2001). At the same time, a number of other reforms in domestic policies governing the distribution of and access to key resources such as land and water among others have been introduced to address the social and economic inequities of the past. Although the agricultural sector has already undergone significant changes as a result, adjustment is far from complete and the effects of many of these reforms, some of which have just been implemented, will be felt for many more years to come.

As mentioned in the previous section key water sector (micro) policy changes stemming mainly from implementation of the NWA are expected to have important direct and indirect implications for future water use and allocation and associated macroeconomic consequences. Among the changes introduced in the NWA are measures correcting for past biases and promoting future equity in access to water resources[3], and promotion of efficiency in water use and allocation among competing activities such as irrigation, mining, manufacturing and services. One immediate adjustment in response to the initial move towards economic efficiency which increased charges on water was the rapid switch of land and water out of low value field crops such as maize to high value horticultural products for export and shifts to use more efficient irrigation technologies (Hassan, 1998 and 2003). The NWA also promotes trade in water leading to efficiency gains in water use in some areas (Louw, 2002). Protecting ecological demand and basic human need for water is a central objective of the NWA which directly affects water availability for economic activities

Some of the main macroeconomic changes that are expected to have important influences on water use and allocation and overall economic wellbeing include:

- Strategic plans underway aiming at higher rates of economic growth over the next decade and completion of the process of provision of basic needs of which access to clean water for large segments of the population is a top priority (i.e. Accelerated and Shared Growth Initiative for SA –Asgisa). Increased competition for water between agriculture and non-agricultural activities (domestic and industrial) is a sure consequence of this major future macroeconomic drive.
- Rapid urbanization fostered by recent major shifts away from primary production activities such as agriculture to industrial and services sectors and lifting restrictions on internal migration. This fast rural-urban migration has major implications for competition for water particularly between domestic and other uses.
- Policy changes with implications for the performance of agricultural exports mainly produced under irrigation include: further adjustments in the rate of foreign exchange;

[3] The equity objectives of the new NWA provide for allocation of larger shares of water at subsidized prices to small holder farmers and basic human need (i.e. provision of access to water and sanitation to previously excluded communities).

trade protocols with SA's main trade partner, the European Union (EU), which receives more than 50% of the country's total exports (Jooste et al. 2003); direction of future regional economic cooperation within the Southern African Development Community (SADC) as well as other African countries supplying more than 30% of the total imports and receiving about 15% of the total exports of the country (Jooste et a., 2003).

In addition to the above, important global phenomena such as climate change (CC) and the world energy crisis are expected to have impacts on water resources and the economy. For example, CC is predicted to have significant impacts on water availability (Schultze, 2005) whereas the energy crisis is already inducing major land use changes, especially towards biofuels production 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 and deeply studied. However, given the new global environment and 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.

The above represents a wide range of potential policy scenarios that would shape future water resources' management in SA, a comprehensive evaluation of which may not be possible to undertake within one study. We therefore have chosen to analyze the impacts of a selected set of main policy scenarios[4] briefly identified below with their full details described later in respective sections of the report.

1. As argued above, while SA is on its way to the complete removal of price distortions (subsidies and taxes) in the water and agricultural sectors, major non-price restrictions remain in place that constrain reallocation of water between activities, sectors and regions on basis of economic efficiency. Investigating the implications of removing such non-price constraints on water allocation between competing activities, sectors and

[4] These were arrived at through extensive consultations with key stakeholders (e.g. DWAF, farmers' associations, etc.) and experts conducting research on water management and policy in SA.

geographical regions is therefore an important policy shift to consider. One such new and important policy initiative, and one with which the country has had virtually no previous experience, is allowing trade in water among various users (i.e. allocation of water on economic efficiency basis through the water-like market), in the new NWA. This type of initiative is analyzed in scenarios where non-price restrictions on the allocation of water between competing farming activities and regions within irrigated agriculture throughout the country are implemented

2. The above scenarios are extended to analyze the consequences of relaxing quota systems (i.e. non-price restrictions) to accommodate expected increased competition between irrigated agriculture and non-agricultural sectors through the market under the planned industrial growth strategies and rapid urbanization and consequences on performance of irrigation agriculture and rural income and employment.

3. Modeling irrigation water management in the economy of SA

This section starts with a concise review of recent approaches to model economic aspects and analyze policy interventions for managing water resources with special emphasis on research addressing economy-wide linkages and impacts of various policy options. The specific structural features of the model developed for SA and its important unique attributes are then described in detail.

3.1 Quantitative models for analyzing the economics and policy of water management

Economic policy research on water has focused mainly on efficiency in use and allocation between competing economic activities and regions and evaluated implications of alternative economic policy instruments and allocation regimes. The majority of empirical studies have investigated impacts of shifting management regimes from command and control measures such as quota systems to introduction of market-based options, particularly economic pricing and trade in water. While economic efficiency was the objective evaluation criteria (typically measuring gains in economic benefits and welfare) for most of the studies, few attempts have been made to evaluate social impacts such as poverty but with little efforts so far assessing environmental outcomes.

Building on the well established farm management economics in the 1970s most early analyses were based on developing normative farm (optimization) models that allocate water among competing farming activities, e.g. crops, etc. within a representative farm to maximize profits. These efforts have then been extended to build agricultural optimization sector and regional programming models. Naturally early efforts employed single market or sector models (e.g. agriculture or water). With big advances in computational capabilities and empirical modeling, previous efforts have been further extended to developing multi-sector (i.e. adding competition from non-agriculture uses), multi-region and multi-model components (i.e. adding hydrological and bio-economic components). All mentioned studies however remained within the partial equilibrium framework that does not account for important linkages to other segments of the economy and assumes independence of markets and exogeneity of prices (find comprehensive reviews of this literature in Johansson 2002 and 2005). Recent efforts by the Bureau for Food and Agricultural Policy Research (BFAP) to build multi-market models for agricultural commodities in SA made attempts to establish linkages with nominal macroeconomic sectors such as exchange rate and general price level and endogenized prices of agricultural commodities (Meyer, 2006). This multi-market system of agricultural commodity while building powerful substitution possibilities on the demand and supply side, it focused mainly on agricultural trade aspects and lacked a water factor component in their supply response and demand structures.

To overcome the 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; Diao 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)[5].

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 the micro effects (i.e. at sector and regional scales) 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 in the following section 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, 1998 and 2003; Letsoalo et al., 2005; Matete and Hassan, 2007; Juana, 2008).

3.2 The SA Water SAM and CGE model structure

A new agriculture and water-focused South African social accounting matrix (SAM) and computable general equilibrium (CGE) model were constructed for this study to examine the economy-wide impacts of selected macro and micro (water related) policies on water use and allocation and national economy.[6] Apart from its treatment of water, the model contains detailed information on production, trade and consumption. These are discussed below before describing how agricultural and nonagricultural water use is incorporated in the model. A full description of the CGE model is given in Appendix A2.

[5] Find more comprehensive review of this and other relevant literature in Dudu and Sinqobile (2008).

[6] The Thurlow and van Seventer (2002) South African SAM form the basis for modeling non-agricultural activities for this study. New data provided the basis for modeling a new structure for highly disaggregated agricultural sector activities. The SA Water-SAM and CGE model are documented in Thurlow (2008).

3.2.1 Production and employment

The model contains 40 sectors/commodities, including 17 agricultural and 15 industrial sectors.[7] 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; citrus fruit; subtropical fruit; deciduous fruit and viticulture; and other horticulture), livestock (livestock sales; dairy; poultry; and other livestock products) and fishing and forestry.[8] 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 percent of national gross domestic product (GDP) – making agriculture a relatively small part of the South African economy (see Table 3). 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 this 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[9]. The characteristics of these WMAs vary considerably (see Tables 4 and 5). For example, agriculture is only one percent of the Upper Vaal's GDP (i.e., Gauteng Province), but more than a third of

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[7] Appendix A1 lists sectors and Appendix Tables A2.1 and A2.2 report model's variables and equations.

[8] Agriculture is disaggregated across sub-sectors using the 2002 Census of Commercial Agriculture (StatsSA, 2002) and the 2006 Abstract of Agricultural Statistics (DOA, 2007). Commercial agriculture comprised 45, 818 active farming units in 2002 (StatSA, 2002), occupying 87% of total agricultural land and produces 95% of marketed agricultural output (Vink and Kirsten, 2003). The remaining agricultural land is cultivated by 'emergent' or subsistence farmers, the actual number of whom is not well established with estimates ranging between 300,000 to a million (Johann Kirsten personal communications).

[9] See Figure 1 for a map showing the 19 WMAs. Sectoral production in the Water-SAM was disaggregated across WMAs using municipal-district-level information from the regional version of the South African Standard Industrial database (Quantec, 2007). Aggregate agricultural production was further disaggregated across WMAs using magisterial-district-level information from the 2002 Census of Commercial Agriculture (StatsSA, 2002). Districts were mapped to WMAs if a majority of their land area fell within the area's boundary. 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).

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

While agriculture contributed only 4.3 percent of national GDP in 2002, it is far more labor-intensive than other sectors, accounting for 8.7 percent of total employment (see Table 4). By contrast, the industrial sectors are more capital-intensive, mainly as a result of the heavier metals and energy sectors. 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.[10] 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.[11] 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, which asked farmers in different regions to report expenditures on a range of inputs, such as seeds, fertilizer and veterinary services. Agricultural production technologies are thus unique to each sub-sector/activity and

[10] Labor employment data is taken from the 2004 Labor Force Survey (September) (StatsSA, 2005).

[11] South Africa's unemployment rate was 31.6 percent in 2003 under the strict definition and 42.8 percent if the non-searching unemployed are included in the workforce (Casale et al., 2004). Unemployment rates are much higher for unskilled workers than for either skilled or high-skilled labor.

region (i.e. WMA). By contrast, nonagricultural production technologies are taken from the national supply-use table (StatsSA, 2004) and are thus the same across WMAs.

3.2.2 Domestic and international trade

Producers in each region[12] 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 constant elasticity of transformation (CET) function. Profit maximization drives producers to sell in those markets where they can achieve the highest returns. These returns are based on domestic and export prices (where the latter is determined by the world price multiplied by a flexible exchange rate and adjusted for any taxes). According to the 2002 SAM, relatively little of SA's agricultural production is exported, with the exception of horticultural products (see Table 3). Rather it is mining and metals that generated almost half of total export earnings.

Substitution possibilities also exist between imported and domestic goods under a CES Armington specification. [13] 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). Most of SA's imported goods are chemicals, machinery and equipment. Agricultural imports are considerably smaller and are mainly for food crops, such as maize and wheat (shown as summer and winter crops in Table 3).

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. While observed prices do vary across SA, the assumption of a national commodity market avoids having to model physical trade flows between WMAs (for which there is no data). This implies that consumers can purchase commodities produced

[12] Note that "region" and "WMA" are interchangeably used throughout this paper to mean the same thing.
[13] Trade elasticities are taken from the Global Trade Analysis Project (Dimaranan, 2006).

in any WMA, but it is not possible to identify from which WMA a specific consumer good originates. However, this assumption is reasonable given SA's relatively small and well-connected economy.

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. The model's exchange rate is an index capturing the relative price of tradables to non-tradables (i.e., the real exchange rate). Thus, for example, if total import demand rises in response to shifting consumer demand, this would, all else being equal, increase the country's current account deficit. 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.

3.2.3 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[14]. Each representative household is an aggregation of the individual households captured in the 2001 Population Census and the 2000 Income and Expenditure Survey (reconciled with inflation and national accounts) (StatsSA, 2002 and 2001)[15]. Households receive income in payment for producers' use of their factors of production[16]. Households pay direct taxes to government (based on fixed tax rates)[17], 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.

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

[15] 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.

[16] 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.

[17] 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.

Per capita expenditures vary considerably across rural and urban areas and WMAs (see Table 6). The lowest per capita expenditures are reported for WMA's where rural populations are largest (see Table 4) and agriculture is more subsistence-oriented (Luvuvhu-Letaba, Limpopo, Thukela, Mzimvubu-Keiskamma). By contrast, rural per capita expenditures are similar or exceed urban expenditures in WMAs that are close to major urban centers or where there are larger commercial farmers, such as in the Berg and Middle Vaal. The regional structure of the model thus highlights the divide that exists between SA's rural and urban areas, and between large-scale commercial farmers and small-scale subsistence-oriented farmers.

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. All savings from households, enterprises, government and the rest of the world (foreign savings) are collected in a savings pool from which investment is financed. Since the model is static, changing the level of investment does not influence the accumulation of capital stocks.

3.2.4 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[18]. For the current account it was assumed that a measure of the real exchange rate (i.e. a price index of tradables to non-

[18] This follows Nell (2003) who found that investment in SA is at least partly savings driven.

tradables) adjusts in order to maintain a fixed level of foreign savings (i.e. the external balance is held fixed in foreign currency.

3.2.5 Agricultural water use and shadow prices

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 (see Table 6). 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. The model is calibrated to capture these differences in production levels and yields across crops and regions (i.e. WMAs).

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. This approach used experimental research trials' data from SA's Agricultural Research Council (ARC, 2000) which measure the amount of water needed to achieve different yield levels for a variety of crops to estimate the following quadratic form water-yield response function:

$$Y_i = \beta_{0i} + \beta_{1i} W_i + \beta_{2i} W_i^2$$

Where Y_i is output of crop *i* per hectare of land (in kilograms) and W_i is the amount of water used to produce this level of output (in millimeters)[19].

All regressions used Ordinary Least Squares and a number of the production functions produced statistically significant results, some of which are reported in Table 7. These coefficients were then applied to the average yields reported in the 2002 Census of

[19] The ARC data represent national average results obtained under optimal irrigated crop management conditions. Hence these estimates of the effects of water on yield do not reflect variations of climatic, soil and other production conditions in different WMA's.

Commercial Agriculture in order to estimate current water use, which in turn were used to calculate the VMP for water using the following formula:

$$VMP_i = P_i \cdot (\partial Y_i / \partial W_i) = P_i \cdot (\beta_{1i} + 2\beta_{2i} W_i)$$

Where P_i is the price of crop *i*. This is shown in the final columns of Table 7, where the VMP is measured in 2002 prices. Amongst the highest VMP were those for high-value field crops, such as cotton and tobacco, and fruits, such as peaches and pears. The crop-water production functions can also be used to derive water demand curves for different crops (see Figure 2 which constructs water demand curves for selected crops at their 2002 prices). Demand curves are inelastic for lower-value and less water-intensive crops, such as lucerne and sorghum, and more elastic for water-intensive crops, such as sugarcane and sunflowers. Moreover, farmers in more water-abundant WMAs grow more water-intensive crops (e.g. sugarcane in Mvoti-Umzimkulu). The current VMP for each crop is indicated on each curve, which shows the sensitivity of some VMP estimates to average yield and water demand estimates. Although the proper measure of the marginal contribution of water to production value (VMP) should be derived from a response function that controls for the effect of other production inputs, which was not possible here for lack of data, these empirical estimates of water demand seem to provide at least reasonable ordering of elasticities across crops[20].

Finally, subtracting non-water irrigation costs from the VMPs shown in Table 7 provides an estimate of the shadow price of water for different crops. According to Hassan and Matlanyani (2004) average irrigation costs incurred by farmers in 2002 were R0.19/m^3 for water tariffs and R1.65/m^3 for non-tariff expenditures (e.g. energy, labor and repairs and maintenance). Subtracting these costs (R1.84/m3) from VMP produces a residual between farmers' willingness to pay for water (as shown by water demand curves) and the actual payments made by farmers. These water 'shadow prices' are shown in Figure 3

[20] These elasticity results are consistent with results of a similar study in Morocco (Roe et al. 2005) which found that farmers chose less water intensive crops in areas where water was relatively scarce.

for selected crops. The shadow price is negative for lucerne because the sales price (and hence VMP) for this fodder crop is insufficient to recoup the costs of irrigation[21].

We matched the estimated crop-water use coefficients and shadow values to the crop categories in the CGE model – using similar crops in cases where the regression results were unavailable or insignificant. For example, the shadow prices of potatoes and wheat were applied to all vegetables and winter crops, respectively. Furthermore, since only national experimental data was available, the same coefficients were applied in all WMAs. However, region-specific yields for each crop were used to estimate water demand. This was multiplied by the shadow price, which is measured per hectare of land, in order to calculate the total shadow value of production for different crops in each region. This was subtracted from the capital value-added for each crop reported in national accounts and the 2002 Census of Commercial Agriculture. 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 vary by WMA depending on what supply schemes are providing water (Figure 3 used the 2002 average charge of R0.02/m^3 reported in Hassan and Matlanyani (2004)).

3.2.6 *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

[21] There may be a risk premium associated with ensuring minimum levels of supply. This may explain why farmers are willing irrigate lucerne despite its negative VMP (i.e., irrigation provides a low-cost form of insurance against rainfall variability).

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 StatsSA, 2000), 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 (see Hassan and Matlanyani, 2004) 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. The demand for water by heavy industry in each region is shown in Table 6. Industrial demand is heavily concentrated within a few WMAs, particularly Upper Vaal (Johannesburg), Mvoti-Umzimkulu (Durban), and Crocodile-Marico (Pretoria).

A similar process was used to estimate the value-added of domestic and light industrial water use. Again, water expenditures for domestic and industrial use are reported in the supply-use table. More detailed information on household water expenditures (by rural/urban areas and expenditure quintiles) was taken from the 2000 Income and Expenditure Survey. These expenditures were divided by the total quantity of water demanded by these users (StatsSA, 2000) to arrive at an average price for water. Supply costs were subtracted and the residual was treated as water value-added in the domestic and light industrial water distribution sectors.

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

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:

Scenario I simulated intraregional irrigated-water-market liberalization to examine the impact of liberalizing local water allocation among crops so as to equalize the SP of irrigation water across crops within each WMA. This scenario does not introduce changes in total water use at the WMA-level (i.e. implying current inter-region water transfers are not changed) and also does not change allocation of available water between irrigation and other uses (e.g. industry and domestic users). The regional irrigation water market liberalization (*Regional Irrigation Market*) scenario however, allows for more efficient allocation of water resources among crops within WMAs based on crop-specific water demands (VMP). We expect the model to allocate relatively more water to those activities that in the base solution had relatively high shadow price (SP) values (i.e. water restricted). However, since the elasticities of water demand vary by crop and are affected by product market adjustments (with product price adjusting less if the crop is relatively foreign trade intensive), some SP values may rise or fall by lager magnitudes relative to the base than other SP values. Consequently, the initial SP values only provide a partial prediction of the direction of the final result. This scenario leads to estimation of general equilibrium SPs for irrigated water for the various WMAs;

Scenario II allows 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). Water allocation between irrigation and non-agricultural use remain unchanged in this scenario which liberalizes national irrigation water markets (*National Irrigation Market* scenario). This scenario equalizes irrigation water SPs both within and between all WMA's and thus establishes a national general equilibrium SP;

Scenario III introduces increased competition for water from predicted expansions in non-agricultural uses and rapid urbanization through rural-urban migration. This scenario however, does not liberalize water markets (i.e. does not allow transfer of or trade in water between irrigation and competing non-agricultural uses, i.e. for industrial, mining, services and domestic purposes). It also maintains current inter-basin water transfers unchanged (*Water-Restricted -Urbanization* scenario).

Urban residents consume substantially more water resources than rural residents, implying that urbanization and industrial expansions will greatly increase urban water demand over the coming decades. This is expected to heighten competition for scarce water resources between urban users (residents and urban-based industries) and agriculture increasing the opportunity cost of subsidizing irrigation water, and may warrant a reallocation of water resources from agricultural to non-agricultural and domestic use. This establishes the potential gain from liberalizing water markets to allow water trade between irrigation agriculture and non-agriculture sectors.

Scenario IV liberalizes water markets allowing for market-based water transfers out of irrigated agriculture to municipal areas to meet the growth in demand for domestic and industrial use introduced under scenario III. This scenario (*Water-Liberalized Urbanization*) is expected to transfer significant amounts of water out of irrigation agriculture leading to declines in agricultural GDP, rural employment and incomes. The net impacts on the national economy will ultimately determined by the magnitudes of offsetting gains from expansions in urban-based non-agricultural sectors' income and employment.

Regional (scenario I) and National (scenario II) irrigation water market liberalization simulations: Micro impacts

The previous section estimated crop-level differences in water SPs caused by irrigated water quotas assigned to farmers based on the types of crops they grow (Figure 3)[22]. Although we apply the same crop-specific SPs throughout the country, differences in cropping patterns imply that average SPs vary across WMAs. As shown in Table 9, the shift from a crop-specific to a uniform market-based regional irrigation water price under scenario I (*Regional Irrigation Market*) has different effects on average SPs across WMAs, with some regions' prices rising and others falling. This outcome depends on initial crop patterns and water SPs. For instance, as expected initial water SPs are lowest in major water exporting regions (surplus WMAs – see Table 2) such as the Upper Orange, Usutu-Mhlatuze and Thukela. On the other hand, average base SPs in water importing regions such as the Berge, Olifants, Crocodile and Fish WMAs 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 Table 5) show relatively higher SPs. This is in contrast with the case of water importing WMAs such as Middle and Lower Vaal which show low SPs due to the fact that most of the land in these regions are planted to lower value field crops (e.g. summer and winter cereals – Table 5).

Table 9 shows changes in national agricultural production and water use. Crops with low initial SPs show 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, most horticultural crops have a high willingness-to-pay for irrigated water and their irrigated production expands significantly (especially citrus fruits and vegetables) after liberalizing local irrigated water markets (*Regional Irrigation Market* scenario).

[22] This assumes that crop yield levels reported in the 2002 Census of Commercial Agriculture (StaSA, 2002) reflect yield levels achieved under particular per ha water quota allocations that are crop specific.

Finally, while there is a general shift in irrigated land from field crops to horticulture, some field crops do benefit under water market liberalization. For example, the amount of irrigated land allocated to higher-value cotton and tobacco increases but their dry-land production decreases. However, the higher yields achieved under irrigation causes a substantial increase in total cotton and tobacco production.

Table 9 shows a large decline in sugarcane and summer cereals production, and a shift of irrigated water resources towards citrus fruits. Since the SP of citrus fruits is substantially higher than that of either of these field crops, we observe an overall increase in regional irrigation water market prices for regions like Thukela where field crops currently dominate. By contrast, the three Vaal WMAs are better suited to growing field crops rather than horticulture (Table 5). 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[23]. Furthermore, summer cereals are more water-intensive than winter cereals (Table 6) and their reduction therefore creates an excess supply of irrigated water in the region, thus driving down the regional price water. The only exception is the Lower Vaal, where the market-based irrigation water price rises as a result of producing higher-value deciduous fruits and viticulture.

The final irrigation water market price is expected to be lower in regions where water resources are more abundant and higher in water scarce regions. The final ranking of irrigated water market prices follows expectations with upstream WMAs having lower prices than downstream WMAs. For example, the regional irrigation water price for the Upper Vaal WMA is lower than the Middle Vaal's, which in turn is lower than the 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. This indicates possible gains from *interregional* liberalization allowing changes in current inter-basin water transfers as simulated in Scenario II below.

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[23] 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 (Kirsten, personal communications).

The previous scenario (*Regional Irrigation Market* liberalization) focused on equalizing irrigated water SPs *within* WMAs. However, the results from this scenario indicate that, while the largest SP differences are indeed at the crop-level, there are also substantial differences *between* WMAs. 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 (Table 10).

The first of the three transfer schemes is the Orange River Project, which transfers water between the Upper Orange WMA (i.e., Free State) and the Fish-Tsitsikamma WMA (i.e., Eastern Cape). Water is transferred from the Gariep Dam via the Orange-Fish tunnel, where it supplies half of the water used in the Fish-Tsitsikamma WMA. Secondly, a number of schemes transfer water between the Thukela and Upper Vaal WMAs, the largest of which is the Drakensberg Pumped Storage Scheme. About half of the water in the Thukela WMA is pumped from the source of the Thukela River over the Drakensberg escarpment to the Sterkfontein Dam. It is then transferred to the industrial and metropolitan areas around Gauteng, where it accounts for one-third of total water use. Finally, the Lesotho Highlands Water Project transfers water from source of the Orange River in Lesotho to the Upper Vaal WMA via a tunnel running under the Lesotho border. Although smaller in terms of volume, the more-recently completed Lesotho scheme is the largest inter-basin transfer scheme in the world and is considered more economically viable than the Thukela-Vaal schemes (Earle et al., 2005).

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 9). 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 (*National Irrigation Market*) 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. Conversely, reducing irrigation water supplies will raise irrigation water prices in the outflow WMAs and reduce production of higher-value water-intensive crops. As mentioned earlier both scenario I and II are limited to irrigated agriculture and does not introduce changes in current allocations between agriculture and non-agriculture uses, which will be considered in Scenarios III and IV.

Table 11 shows the amount of water that would have to be transferred in order to equate regional SPs for the selected WMAs. For example, 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. This would generate the same price of irrigated water in all four of these WMAs (i.e., 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 (Tables 11 and 12). 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 is also a decline in vegetables production in the Upper and Middle Vaals, and deciduous fruit and viticulture production in the Lower Vaal. Overall, reversing of the Thukela-Vaal water transfer reduces the production of field crops in the affected WMAs, partly because it encourages a shift into low-yield dry-land cereals production and into higher-value irrigated horticulture.

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 use newly irrigated lands to 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 irrigation water prices by increasing dry-land production of cereals and fodder crops and reducing irrigated vegetable production. Since yields are significantly lower on dry-lands, there is an overall decline in field crop production, especially for winter cereals. Thus, extending the transfer of irrigated water under the Orange River Project reduces cereals and vegetables production and encourages more high-value water-intensive citrus fruit farming in the Eastern Cape. These results are in line and consistent with the regional liberalization effects of scenario I.

Regional (scenario I) and National (scenario II) irrigation water market liberalization simulations: Macro impacts

Regional and national liberalization of irrigation water markets has important impacts at the macro- or national-level which are compared and discussed in this section. 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 the *Regional Irrigation* water market liberalization scenario, driven almost entirely by increased horticultural production and exports. Adjusting water transfers under the *National Irrigation* water liberalization scenario 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 drives up the national price of these commodities (Table 13), 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 (*National Irrigation Market)*, 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). Liberalizing irrigation water markets thus 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, with 32,000 new jobs created in the sector under scenario I (see Table 14), which is more than double the number of displaced workers from the contracting non-agricultural sectors. Employment gains are higher under scenario II incremental expansion in GDP creating an additional 12,900 jobs in the sector (i.e. from 32,000 to 42,900), primarily for lower-skilled workers. Agricultural production is less skill- and capital-intensive, and its wages are about two-thirds of the average non-agricultural wage. As such, the shift into agricultural employment causes a slight decline in the economy-wide wages for the three labor skill groups and in the 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. Finally, as mentioned earlier, the national average returns to irrigation water falls slightly, as irrigation water market liberalization causes water resources to be released by large water-intensive crops, such as summer cereals and sugarcane. 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 (Table 15). This suggests that liberalization of irrigation water markets leads to both efficiency and equity gains, making this policy consistent with and in the spirit of the broader policy reforms discussed in the introduction section. 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 offsets any income gains for higher-income households. Rising consumer prices for cereals also reduces real expenditures for urban more than rural consumers. However, since the transitional growth of the SA economy, as discussed above, is one of growth in the non-farm sector, these negative effects are likely to be short lived.

The increased returns to lower-skilled workers benefits lower-income households in both rural and urban households (i.e., expenditure quintiles 1 and 2). Higher-income households' consumption falls due to falling returns to capital and high-skilled workers' wages. 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). Per capita expenditures increase in the water transfers recipient regions (i.e., Thukela and Fish-Tsitsikamma). Conversely, expenditure in the Lower Orange WMA declines since the region is currently heavily dependent on higher-value irrigated horticulture, which is no longer feasible after reducing the supply of irrigation water. Of the other WMAs outside of the transfer schemes benefiting under the *National Irrigation market* 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.

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

Agriculture is an important sector, especially as an employer for many rural households. However, it is industry and services that dominate the South African economy, and which have outperformed agriculture over the 15 years following the end of Apartheid. Agricultural GDP grew at 0.4 percent per year during 1994-2007, while industry and services grew at 2.6 and 4.3 percent, respectively (StatsSA, 2008). These transitional forces pulled labor from agriculture as per capita incomes grew. This reflects SA's accelerating shift away from primary sector production (including mining) towards greater industrialization and a more prominent role for services (e.g., transport, communication and finance). These structural changes have been at least partly facilitated by the removal of agricultural subsidies and trade protection for many agricultural products, and by the greater openness of the economy, which has fostered capital deepening that contributed to the rise in real wages and nonagricultural export growth (Hérault and Thurlow, forthcoming).

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. While SA has long been undergoing an urbanization of its population, the rate at which the rural population has migrated to larger metropolitan areas has risen sharply since the mid-1980s. During 1960-1985, the rural and urban populations grew at similar rates of 2.2 and 2.6 percent per year, respectively (World Bank, 2008). However, towards the end of Apartheid, there was a rapid divergence in population growth, with rural and urban populations growing at 0.9 and 3.0 percent, respectively during 1985-2005. As a result, the urban population share rose by 9.9 percentage points between 1985-05 (compared to 2.8 percentage points during 1960-1985), such that by 2005 about 60% of the population live in urban centers (compared to 49.4 percent in 1985).

While some of the 'urbanization' of the population may be attributed to higher HIV/AIDS-related mortality in rural areas, there is evidence that workers and their families are leaving rural areas and moving to major metropolitan centers (Posel and Casale, 2003 and 2006). Furthermore, many migrants are moving into informal metropolitan settlements (i.e., 'townships') (Collinson et al., 2006) in search of higher wages and better services (Choe and Chrite, 2007). New migrants place pressure on local municipalities to provide basic services, including water and sanitation. As shown in Table 16, poorer urban households consume more water per capita than their rural counterparts. For example, the poorest urban quintile consumes eight times more water per capita than rural households at similar levels of expenditure.[24] Thus the continued migration of lower-income households from rural areas to urban centers will dramatically increase the amount of water demanded via established distribution networks.

In this section we present two scenarios reflecting the current structural and demographic changes taking place in SA. The first scenario (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, i.e. not allowing for changes in current regional and sectoral availability of water (i.e. the *Water-Restricted Urbanization* scenario). The second scenario (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 percent). We assume that migrants move from rural quintiles to equivalent urban quintiles within their own WMA. For example, migrant workers and their families in the lowest rural quintile move into the lowest urban quintile, thereby increasing the labor endowment of this representative household in the model and hence its share of labor incomes earned within their WMA-specific labor market.

[24] Part of the difference in rural/urban water use may be attributed to the lack of formal water distribution systems in rural areas, such that rural households reported using less water than urban households in the household survey (i.e., they paid less for water). However, this gap also exists for higher-income rural/urban households, who have better access to formal water distribution networks, thus confirming the higher per capita water demand in urban areas.

Moreover, new migrants and their families adopt urban consumption patterns, allowing us to capture increased demand for water resources caused by urbanization.

Migration of workers and their families from rural to urban areas shifts overall composition of household demand towards urban consumption patterns, which are considerably more water-intensive (Table 18). As a result the price of domestic water resources increases by 6% under the *Water-Restricted Urbanization* scenario. Urbanization also increases demand for other services, such as electricity. Continued urbanization (rural-urban migration) therefore places considerable pressure on the provision of local services, leading to heightened competition of scarce resources, particularly water for household uses.

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. For example, food processing GDP expands by a total of 3.3 percent (Table 17). Changing aggregate demand patterns causes significant declines in raw agricultural production (Table 17). Agricultural employment declines as a result under *Water-Restricted Urbanization* scenario by 59,000 jobs, which is equivalent to 8.4% of the current agricultural workforce (Table 18). 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 rural-urban migration mechanism we adopt reallocates workers from rural to urban areas focusing on the lowest three expenditure deciles. Table 20 shows the changing household worker populations, which accounts for changes in populations resulting from both migration and changing levels of overall employment. As seen in the table, the rural working population the lowest three quintiles is approximately halved under the *Water-Restricted Urbanization* scenario, as workers migrate to urban areas. Since most of the workers in the country’s lowest quintile reside in rural areas, the out-migration of rural workers causes the working population in the lowest urban quintile to more than double. By contrast, most of the country’s population in the third quintile lives in urban areas, such that rural out-migration increases the urban population of this group by around 50 percent. 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.

Table 21 also shows the impact of urbanization on consumption per worker for different household groups. Generally speaking, if rural and urban household consumption patterns are similar and urban migrants are able to find similarly paid employment, then the migration of workers from rural to urban areas will not greatly affect *per worker* consumption spending in rural and urban areas. However, as discussed above, urbanization reduces demand for agricultural goods, which causes a decline in agricultural production and employment. 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 in absolute terms 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.

The final scenario (*Water-Liberalized Urbanization*) examines the impact of responding to increased industrial and urban water demand by transferring water from irrigation to urban/industrial use within each WMA. In the previous scenario we assumed that there was no change in the supply of urban/industrial water resources. This constrained supply, coupled with rising domestic water demand, caused domestic water prices to rise by 3.1 percent (Table 17). In this *Water-Liberalized Urbanization* scenario we include the effects of urbanization from the previous scenario, but now allow for transfer of irrigation water to urban/industrial use, such that the national urban/industrial water price remains unchanged.

As shown in Table 21, in order to neutralize the rising water price, 7.1 percent 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 17). 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. Thus, there are only small changes in other nonagricultural sectors' GDP under this scenario.

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 (Table 18). This reduces agricultural employment by a further 6,900 jobs, which is equivalent to one percent of the total agricultural workforce (Table 19). This causes rural expenditures per worker to decline for all expenditure quintiles. Moreover, the small increase in non-agricultural GDP and the low labor intensity of the water distribution sector means that there are only 900 new non-agricultural jobs created relative to the *Water-Restricted Urbanization* scenario. Thus, 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 raises 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

SA is water stressed. The pressure on existing water resources is predicted to worsen with planned growth strategies, observed recent demographic changes and unfavorable global climatic and economic conditions. A drive toward ambitious industrial expansion accompanied by rapid growth in services' economies and urbanization, and government strategic priority to extend access to basic services such as clean water and sanitation to millions of previously excluded populations are expected to increase the competition for the already stressed water resources. The implications are expected to be particularly severe for irrigation agriculture which currently uses more than 60% of water resources in the country. On top of all this, the country is 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 (water management areas - WMA) and economic sector 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 have a significant influence on the structure of agricultural production. They reduce the amount of irrigated land allocated to higher-value horticultural crops, while creating higher shadow rents for farmers producing lower-value water-intensive field crops, such as sugarcane and fodder crops. Liberalizing regional irrigation water markets would therefore improve the efficiency of water allocation within WMAs. It would also expand agricultural production and exports, and create additional jobs for farm laborers. These jobs are especially important for lower-income rural households who rely on incomes from on-farm employment. However, regional water market liberalization would also increase the price of cereals, thus increasing SA's dependence on imported grains and raising concerns for 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. However, it favors 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 the recipient 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 (water-restricted urbanization) introduced competition for water from non-agriculture urban uses with irrigation agriculture. This leads to much higher competition and 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. (See Table 22 for a matrix of impacts of the various policy scenarios.)

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Appendices

Appendix A1. Sectors in the CGE model

	Agriculture		Industry
	Field crops	18	Mining (coal, gold)
1	Summer cereals (maize, sorghum)	19	Food & agricultural processing
2	Winter cereals (wheat, barley)	20	Textiles, clothing & footwear
3	Oil crops & legumes (groundnuts, beans)	21	Wood & paper products
4	Fodder crops (Lucerne, grain maize)	22	Chemicals & petroleum
5	Sugarcane	23	Nonmetallic mineral products
6	Cotton & tobacco (incl. other field crops)	24	Metals & machinery
	Horticultural crops	25	Electrical machinery
7	Vegetables	26	Scientific equipment
8	Citrus fruits	27	Transport equipment (incl. vehicles)
9	Subtropical fruits	28	Other manufacturing (incl. furniture)
10	Deciduous fruits and viticulture	29	Electricity generation
11	Other horticulture (tea, nuts)	30	Domestic & light industrial water distribution
	Livestock	31	Heavy industry water distribution
12	Livestock sales (cattle, sheep, pigs)	32	Construction
13	Dairy		Services
14	Poultry (chickens, eggs)	33	Retail & wholesale trade
15	Other livestock products (wool, game)	34	Hotels & catering
	Other agriculture	35	Transport
16	Fisheries	36	Communication
17	Forestry	37	Financial & insurance services
		38	Business services & real estate
		39	Community & other private services
		40	Government services

Appendix A2: Specification of the South African Water-CGE model

This appendix presents the equations and variables of Water-CGE model, which is an adaptation of the IFPRI standard static model documented in Lofgren et al. (2002). Most model equations' parameters are calibrated to values in the Water-SAM. However, there are a number of quantity-based parameters and behavioral elasticities in the Water-CGE model that are calibrated using other data sources. These are provided in the accompanying Microsoft Excel® files.

Tables A2.1 and A2.2 list the variables and equations of the Water-CGE model. Activity production in Water-CGE model is governed by a constant elasticity of substitution (CES) production function (Equation 13). This assumes constant returns to scale and allows producers to shift demand for different factors depending on their relative prices. This factor demand is derived from the production function's first order condition (Equation 14). Composite factors (from Equation 13) are combined with fixed-share intermediates under a Leontief specification (Equations 11 and 12). 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. In other words there is no regional subscript in the Water-CGE model. The aggregation of different WMAs' output into a composite commodity is also governed by a CES aggregation function (Equation 17). This allows substitution between different WMAs' based on their relative producer prices so as to minimize the marketed supply price of a commodity (Equation 18).

Marketed supply from domestic producers is either exported or sold in domestic markets. This decision to supply domestic or foreign markets is based on a constant elasticity of transformation (CET) function (Equation 19). Profit maximization drives producers to sell in those markets where they can achieve the highest returns based on relative domestic and export prices (Equation 20). Export prices include any transaction costs incurred in transporting the commodity from the border to the final sales market (Equation 2). Commodities that are not exported are supplied to domestic markets and also incur transaction costs (Equation 3). 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 (Equation 22). The final ratio of imports to domestic goods is determined by the cost minimization based on the relative prices of imports and domestic goods (Equation 23), with the latter including import tariffs and import transaction costs (Equation 1). 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 (Equation 26). 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 (Equations 27 and 28). Factor taxes include corporate taxes and the returns to domestic and industrial water resources (see the Water-SAM in Section 4). Households also receive income from government and inter-household transfers (Equations 28 and 29). Households then save and pay taxes, and the remaining disposable income is used for consumption expenditures (Equation 30). Commodity consumption expenditure is derived from maximizing a Stone-Geary utility function, which results in a linear expenditure system (LES) of demand (Equation 31).

Commodity demands from other components of domestic absorption are assumed to be proportional to base-year demand quantities (Equations 32 and 33). 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 (Equation 40). Since household savings rates are fixed, the Water-CGE model assumes a savings-driven investment closure.[25] 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 (Equation 39). 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 (Equation 38). Together the total amount of commodities demanded must be equal to total composite supply in equilibrium (Equation 37). This includes commodity demand generated by transaction costs (Equation 25).

The Water-CGE model is coded using GAMS. The specification and calibration of the model is done in the 1model.gms file. The model file is a general specification of the CGE model, while the associated 1model.dat and 1model.xlsx contain the South African Water-SAM and other country-specific data. After running and saving the GAMS model file, the 2simulation.gms file restarts and contains the designed simulations and their macroeconomic and factor market closures.

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

Table A2.1: Model sets, parameters and variables

Sets		**Sets**	
a	Activities	i	Institutions
c	Commodities	$h \subset i$	Households
f	Factors		
Exogenous parameters		**Exogenous parameters**	
$cwts_c$	Weights in consumer price index	$trn_{f,i}$	Factor transfer to institutions
$dwts_c$	Weights in domestic price index	$wfd_{f,a}$	Activity wage distortion factor
$fsav$	Foreign savings in foreign currency	$wfh_{f,h}$	Household average wage distortion factor
$ica_{c,a}$	Intermediate input per unit of output	$\alpha^{ac}_{a,c}$	Commodity aggregation shift parameter
$icd_{c,c'}$	Trade input per unit domestic sales unit	α^{q}_{c}	Armington function shift parameter
$ice_{c,c'}$	Trade input per exported unit	α^{t}_{c}	CET function shift parameter
$icm_{c,c'}$	Trade input per imported unit	α^{va}_{a}	Production function shift parameter
$inta_a$	Intermediate input per activity unit	β_h	Household consumption budget share
iva_a	Value-added input per activity unit	$\delta^{ac}_{a,c}$	Commodity aggregation share parameter
qg_c	Base-year government demand quantity	δ^{q}_{c}	Armington function share parameter
$qinv_c$	Base-year private investment quantity	δ^{t}_{c}	CET function share parameter
mps_h	Household savings rate	δ^{va}_{a}	Production function share parameter
pwe_c	Export price in foreign currency	$\gamma_{c,h}$	Household subsistence consumption
pwm_c	Import price in foreign currency	$\pi_{h,h'}$	Inter-household transfers shares
$qfsh_{f,h}$	Household worker population	$\theta_{a,c}$	Yield of output per unit of activity output
th_h	Household personal tax rate	ρ^{va}_{a}	CES value-added function exponent
tm_c	Import tariff rate	ρ^{ac}_{c}	Commodity aggregation function exponent
tq_c	Sales tax rate	ρ^{q}_{c}	Armington function exponent
$tw_{f,a}$	Factor quantity demand tariff	ρ^{t}_{c}	CET function exponent
Endogenous variables		**Endogenous variables**	
CPI	Consumer price index	QE_c	Export quantity
DPI	Domestic or producer price index	$QF_{f,a}$	Activity factor demand
EG	Government expenditures	QFS_f	Total factor supply
EH_h	Consumption spending for household	QG_c	Government commodity demand
EXR	Exchange rate in local per foreign units	$QH_{c,h}$	Quantity commodity consumption
$GADJ$	Public consumption adjustment factor	$QINTA_a$	Quantity of aggregate intermediate input
$GSAV$	Government savings	$QINT_{c,a}$	Activity's intermediate input quantity
$IADJ$	Investment adjustment factor	$QINV_c$	Commodity investment demand quantity
PA_a	Activity price	QM_c	Commodity import demand quantity

PDD_c	Domestic demand price	QQ_c	Domestic quantity of sold domestically
PDS_c	Domestic supply price	QT_c	Trade input quantity
PE_c	Export price in domestic currency	QVA_a	Aggregate value-added quantity
$PINTA_a$	Aggregate intermediate input price	QX_c	Aggregate domestic output quantity
PM_c	Import price in domestic currency	$QXAC_{a,c}$	Activity commodity output quantity
PQ_c	Composite commodity price	$SHIF_{f,h}$	Household factor income share
PVA_a	Value-added price	$TRHH_{h,h'}$	Inter-household transfer values
PX_c	Aggregate producer price	WF_f	Average factor price
$PXAC_{a,c}$	Activity commodity producer price	YF_f	Total factor income
QA_a	Activity output quantity	YG	Total government revenue
QD_c	Domestic quantity sold domestically	YH_h	Total household income

Table A2.2: Water-CGE model equations

Price equations	
$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{ct} (PQ_c \cdot icm_{ct,c})$	(1)
$PE_c = pwe_c \cdot EXR + \sum_{ct} (PQ_c \cdot ice_{ct,c})$	(2)
$PDD_c = PDS_c + \sum_{ct} (PQ_c \cdot icd_{ct,c})$	(3)
$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c$	(4)
$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c$	(5)
$PA_a = \sum_{c} (PXAC_{a,c} \cdot \theta_{a,c})$	(6)
$PINTA_a = \sum_{c} (PQ_c \cdot ica_{c,a})$	(7)
$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a$	(8)
$CPI = \sum_{c} (PQ_c \cdot cwts_c)$	(9)
$DPI = \sum_{c} (PDS_c \cdot dwts_c)$	(10)
Production and trade equations	
$QINTA_a = inta_a \cdot QA_a$	(11)
$QVA_a = iva_a \cdot QA_a$	(12)
$QVA_a = \alpha_a^{va} \cdot \sum_{f} \left(\delta_{f,a}^{va} \cdot QF_{f,a}^{-\rho_a^{va}}\right)^{-1/\rho_a^{va}}$	(13)

$$WF_f \cdot wfd_{f,a} + tw_{f,a} = PVA_a \cdot QVA_a \cdot \sum_{f}^{f'} \left(\delta^{va}_{f',a} \cdot QF_{f',a}^{-\rho^{va}_a}\right)^{-1} \cdot \delta^{va}_{f,a} \cdot QF_{f,a}^{-\rho^{va}_a-1} \quad (14)$$

$$QINT_{c,a} = ica_{c,a} \cdot QINTA_a \quad (15)$$

$$QXAC_{a,c} = \theta_{a,c} \cdot QA_a \quad (16)$$

$$QX_c = \alpha^{ac}_c \cdot \sum_{a} \left(\delta^{ac}_{a,c} \cdot QXAC_{a,c}^{-\rho^{ac}_c}\right)^{-1/\rho^{ac}_c} \quad (17)$$

$$PXAC_{a,c} = PX_c \cdot QX_c \cdot \sum_{a}^{a'} \left(\delta^{ac}_{a',c} \cdot QXAC_{a',c}^{-\rho^{ac}_c}\right)^{-1} \cdot \delta^{ac}_{a,c} \cdot QXAC_{a,c}^{-\rho-1} \quad (18)$$

$$QX_c = \alpha^t_c \cdot \sum_{c} \left(\delta^t_c \cdot QE_c^{\rho^t_c} + (1-\delta^t_c) \cdot QD_c^{\rho^t_c}\right)^{1/\rho^t_c} \quad (19)$$

$$QE_c = QD_c \cdot \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta^t_c}{\delta^t_c}\right)^{1/\rho^t_c-1} \quad (20)$$

$$QX_c = QD_c + QE_c \quad (21)$$

$$QQ_c = \alpha^q_c \cdot \sum_{c} \left(\delta^q_c \cdot QM_c^{-\rho^q_c} + (1-\delta^q_c) \cdot QD_c^{-\rho^q_c}\right)^{-1/\rho^q_c} \quad (22)$$

$$QM_c = QD_c \cdot \left(\frac{PDD_c}{PM_c} \cdot \frac{1-\delta^q_c}{\delta^q_c}\right)^{1/1+\rho^q_c} \quad (23)$$

$$QQ_c = QD_c + QM_c \quad (24)$$

$$QT_c = \sum_{c}^{c'} \left(icm_{c,c'} \cdot QM^{c'}_c + ice_{c,c'} \cdot QE^{c'}_c + icd_{c,c'} \cdot QD^{c'}_c\right) \quad (25)$$

Institutional incomes and expenditures

$$YF_f = \sum_{a} WF_f \cdot wfd_{f,a} \cdot QF_{f,a} \quad (26)$$

$$SHIF_{f,h} = {qfsh_{f,h}}\Big/{\textstyle\sum_{h}^{h'} qfsh_{f,h'}} \cdot whd_h \quad (27)$$

$$YH_h = \sum_f SHIF_{f,h} \cdot (1 - tf_f) \cdot YF_f + \sum_{h}' TRHH_{h,hp} + trn_{h,gov} \cdot CPI \cdot \sum_f qfsh_{f,h} \tag{28}$$

$$TRHH_{h,h'} = \pi_{h,h'} \cdot (1 - mps'_{h'}) \cdot (1 - th'_{h'}) \cdot YH'_h \tag{29}$$

$$EH_h = \left(1 - \sum_{h} \pi_{h',h}\right) \cdot (1 - mps_h) \cdot (1 - th_h) \cdot YH_h \tag{30}$$

$$PQ_c \cdot QH_{c,h} = PQ_c \cdot \gamma_{c,h} + \beta_{c,h} \cdot \left({EH_h}/{\Sigma_f qfsh_{f,h}} - \sum_{c}' PQ'_c \cdot \gamma_{c',h} \right) \tag{31}$$

$$QINV_c = IADJ \cdot qinv_c \tag{32}$$

$$QG_c = GADJ \cdot qg_c \tag{33}$$

$$YG = \sum_h th_h \cdot YH_h + \sum_f tf_f \cdot YF_f + \sum_a (ta_a \cdot PA_a \cdot QA_a + tw_{f,a} \cdot QF_{f,a}) + \sum_c (tm_c \cdot pwm_c \cdot QM_c + tq_c \cdot PQ_c \cdot QQ_c) \tag{34}$$

$$EG = \sum_c PQ_c \cdot QG_c + \sum_{f,h} trn_{h,gov} \cdot qfsh_{f,h} \cdot CPI + trn_{"row","gov"} \cdot EXR \tag{35}$$

System constraints or equilibrium conditions

$$\sum_a QF_{f,a} = QFS_f \tag{36}$$

$$QQ_c = \sum_a QINT_a + \sum_{f,h} QH_h \cdot qfsh_{f,h} + QG_c + QINV_c + QT_c \tag{37}$$

$$\sum_c (pwm_c \cdot QM_c - pwe_c \cdot QE_c) + trn_{"row","gov"} = fsav \tag{38}$$

$$YG = EG + GSAV \tag{39}$$

$$\sum_h mps_h \cdot (1 - th_h) \cdot YH_h + GSAV + fsav \cdot EXR = \sum_c PQ_c \cdot QINV_c \tag{40}$$

Table 1: Value added and employment indicators of water use (RSA 2000)

		Water use	Value added (GDP) indicators				Employment indicators	
		Total in m^3	**R million**	**% of GDP**	**% of total water**	**GDP / m^3 (R)**	**Employment (million)**	**Employment / 000 m^3**
Agriculture	Irrigation	7,921	23,045	2.7 %	72.6 %			
	Rainfed crops	0			0.0 %			
	Rainfed livestock	313			2.9 %			
	Forestry	431	4,406		3.9 %			
	Total	8,665	27,451	3.3 %	79.4 %	3	1.10	0.13
Power gen		297	19,431	2.3 %	2.7 %	65	0.08	0.26
Mining	Gold	127	16,949	2.0 %	1.2 %	133		
	Other	261	46,442	5.5 %	2.4 %	178		
	Total	388	63,391	7.6 %	3.6 %	163	0.48	1.23
Manufacturing	Food processing	123	24,613	2.9 %	1.1 %	200		
	Other	577	137,852	16.4 %	5.3 %	239		
	Total	700	162,465	19.4 %	6.4 %	232	1.50	2.14
Trade & services	Construction	110	21,114	2.5 %	1.0 %	192		
	Transport	120	50,003	6.0 %	1.1 %	417		
	Government	152	133,158	15.9 %	1.4 %	876		
	Other	483	361,205	43.1 %	4.4 %	748		
	Total	865	565,480	67.5 %	7.9 %	654	7.07	8.17
Domestic	Urban	1,697						
	Rural	261						
	Total	1,958						
	TOTAL	**12,873**	**838,218**	100.0 %	100.0%	**77**	**10.22**	**0.94**
Population		**43,686**						
Water use & GDP per capita		**0.295**	**19,187**					

Source: Adapted from Hassan and Crafford (2006) and StaSa (2006)

Table 2 Water supply and use in South Africa by Water Management Areas in 2000 (units are in million m^3)

Water Management Area	MAR	Ecological Reserve	Yield			Transfers In	Use		Transfers Out	Water Balance
			Surface Water	Groundwater	Return Flows /		Production	Households		
Limpopo	986	156	160	98	23	18	280	42	-	(23)
Luvuvu/Letaba	1,185	224	244	34	23	-	297	36	13	(36)
Crocodile-West/Marico	855	164	203	146	369	519	889	295	10	43
Olifants River	2,040	460	410	99	100	172	868	97	8	(192)
Inkomati	3,539	1,008	816	9	71	-	787	58	311	(260)
Usuthu to Mhlatuze	4,780	1,192	1,019	39	52	40	667	50	114	319
Thukela	3,799	859	666	15	56	-	288	46	506	(103)
Upper Vaal	2,423	299	599	34	501	1,311	669	376	1,379	19
Middle Vaal	888	109	(67)	57	62	829	310	60	502	6
Lower Vaal	181	49	(54)	125	54	548	599	44	-	30
Mvoti to Umzimkulu	4,798	1,160	433	6	84	34	510	287	-	(240)
Mzimvubu to Keiskamma	7,241	1,122	776	21	57	-	297	77	-	480
Upper Orange	6,981	1,349	4,311	65	71	2	881	87	3,149	333
Lower Orange	502	69	(1,083)	25	97	2,035	1,009	19	54	(8)
Fish to Tsitsikamma	2,154	243	260	41	122	575	855	46	-	97
Gouritz	1,679	325	191	64	20	-	301	37	1	(64)
Olifants/Doorn	1,108	156	266	45	24	3	365	8	-	(35)
Breede	2,472	384	687	109	68	1	600	32	196	37
Berg	1,429	217	380	57	45	194	444	260	-	(28)
RSA	49,040	9,545	10,217	1,088	1,899	-	10,915	1,958	170	186

Source: DWAF (2004) and StatSa (2006)

Table 3. Structure of the South African economy

	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 4. 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.

Figure 1. Water Management Areas (WMA)

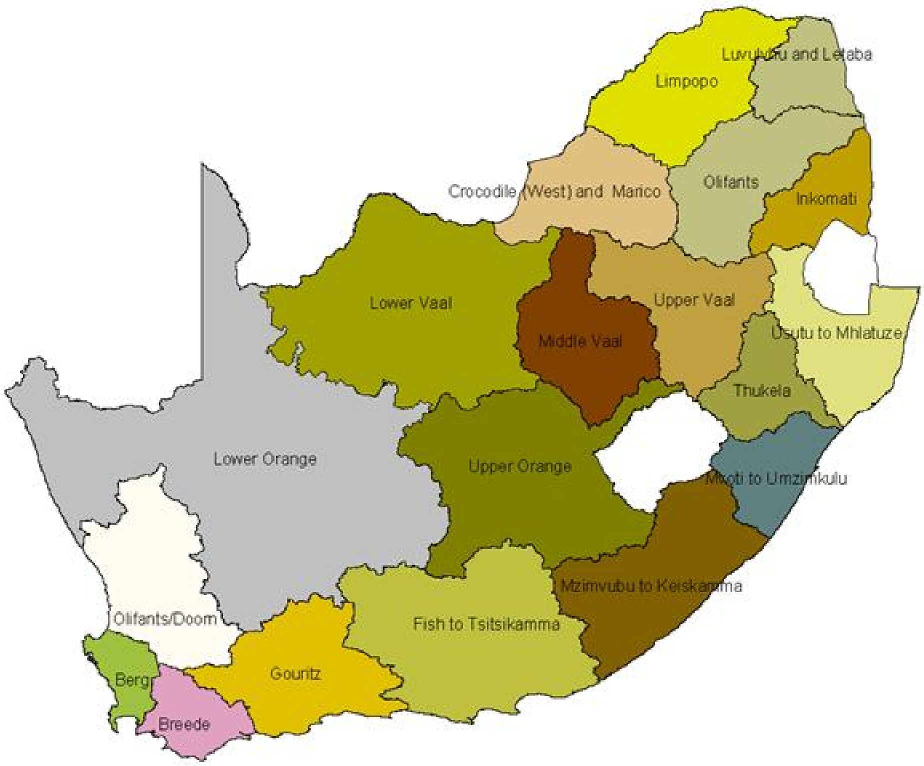


Table 5. Agricultural land allocation by Water Management Area

	All crops (000 ha)	Agricultural land allocated to crops (percent): Summer cereals	Winter cereals	Oils & legumes	Fodder crops	Sugar-cane	Cotton tobacco	Horti-culture
National	7,629	44%	14%	14%	13%	6%	1%	8%
Limpopo	227	28%	3%	46%	7%	0%	7%	8%
Luvulvhu-Letaba	91	3%	0%	0%	3%	0%	0%	92%
Crocodile-Marico	246	40%	9%	25%	15%	0%	2%	10%
Olifants	420	74%	3%	10%	4%	0%	3%	5%
Inkomati	123	24%	1%	7%	11%	31%	2%	23%
Usutu-Mhlatuze	225	41%	1%	13%	6%	34%	1%	4%
Thukela	173	35%	5%	13%	10%	33%	2%	2%
Upper Vaal	999	61%	11%	15%	13%	0%	0%	2%
Middle Vaal	2,017	63%	10%	19%	6%	0%	0%	1%
Lower Vaal	976	62%	5%	24%	7%	0%	1%	1%
Mvoti-Umzimkulu	404	8%	0%	1%	15%	72%	0%	4%
Mzimvubu-Keiskamma	52	12%	10%	0%	60%	12%	0%	10%
Upper Orange	302	34%	30%	9%	25%	0%	1%	1%
Lower Orange	121	31%	20%	2%	21%	0%	2%	24%
Fish-Tsitsikamma	134	7%	4%	0%	66%	0%	1%	22%
Gouritz	133	2%	21%	2%	63%	0%	1%	11%
Olifants/Doorn	262	1%	48%	1%	17%	0%	0%	33%
Breede	361	2%	40%	4%	21%	0%	0%	33%
Berg	361	1%	57%	3%	12%	0%	0%	27%

Source: South Africa 2002 Water-SAM and CGE model.

Table 6. Agricultural production and water use by crop

	Production quantity (1000 mt)	Land area: Total (1000 ha)	Land area: Irrigated (%)	Yields: Rainfed (mt / ha)	Yields: Irrigated (mt / ha)	Irrigation water use: Volume (mil m^3)	Irrigation water use: (1000 m^3 / ha)
Total	-	7,629	20.46	-	-	7,274	4.66
Summer cereals	10,377	3,356	8.99	2.82	5.83	1,242	4.12
Winter cereals	2,689	1,047	15.57	2.17	4.72	593	3.63
Oils & legumes	1,422	1,103	5.31	1.24	2.14	190	3.24
Fodder crops	2,943	956	24.66	2.49	4.86	655	2.78
Sugarcane	21,157	470	28.30	41.30	54.43	1,386	10.42
Cotton & tobacco	150	59	53.31	1.86	3.10	91	2.87
Vegetables	4,482	187	100.00	-	24.02	796	4.27
Citrus fruits	1,472	63	100.00	-	23.22	451	7.12
Subtropical fruits	602	51	100.00	-	11.77	375	7.33
Deciduous fruits	3,339	249	100.00	-	13.43	1,293	5.20
Other horticulture	171	87	100.00	-	1.95	203	2.32

Source: South Africa 2002 Water-SAM and CGE model.

Table 7. Estimated value of marginal product (VMP) of water use for selected crops

	Crop-water production function coefficients (kg and mm)			Average water use (mm)	Price in 2002 (R/kg)	VMP in 2002 (R/m^3)
	β_0	β_1	β_2			
Banana	-330,000 *	683.3 *	-0.3333 *	1,008	2.08	2.42
Cotton	-10,783 *	54.8 *	-0.0352 **	297	0.88	2.99
Lucerne	6,130 *	12.6 *	-0.0022 *	376	0.89	1.16
Maize	-10,783 *	54.8 *	-0.0352 **	430	0.89	2.18
Nectarine	0 *	150.0 *	0.0000 *	678	1.20	3.01
Peaches	0 *	28.6 *	0.0000 *	460	1.10	3.13
Potatoes	-226,523 *	990.9 *	-0.9356 *	451	1.74	3.15
Sorghum	912	21.6 *	-0.0034	108	0.93	1.94
Soyabean	-12,625 *	48.7 *	-0.0288 **	409	1.02	2.58
Sugarcane	-350,688 *	608.3 *	-0.2113 *	1,042	0.13	2.20
Sunflower	-824 *	28.0 *	-0.0429 *	120	1.29	2.28
Wheat	1,564 *	5.7 *	0.0083 *	374	1.89	2.25

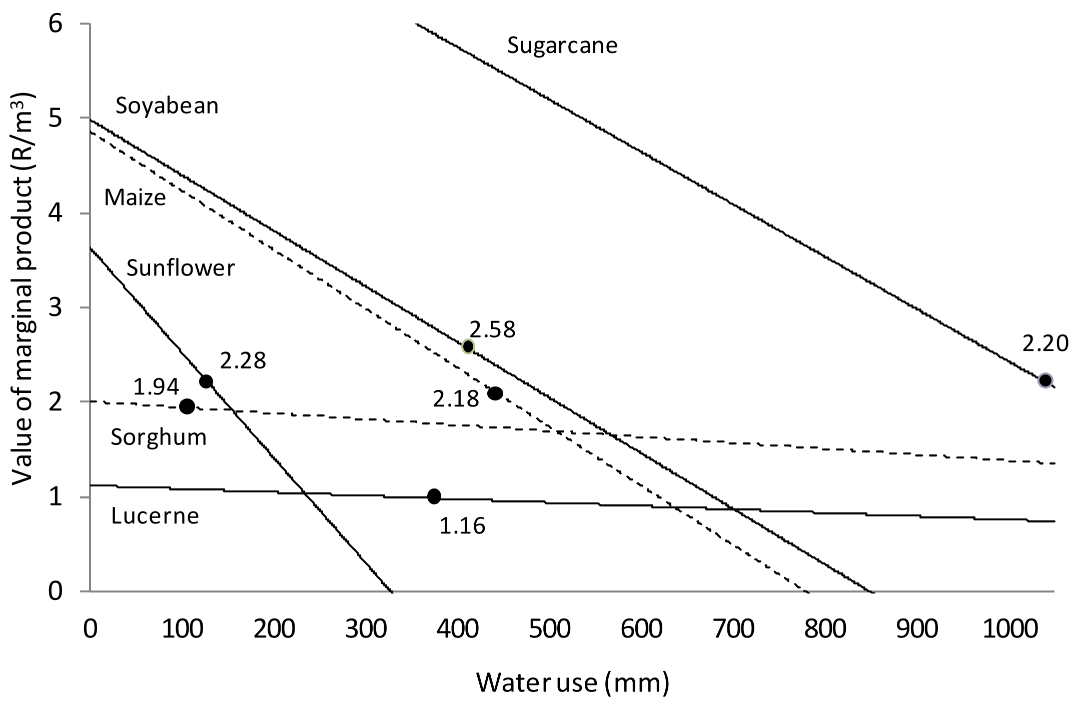
Source: Own estimates using crop water use data from research field trials (ARC, 2000). Prices are from the United Nation's Food and Agriculture Organization (FAO, 2007). * and ** denotes significance at 10 and 20 percent level respectively. Average crop water use calculated using production yields from the 2002 Census of Commercial Agriculture (StatsSA, 2002).

Table 8. Water use by WMA and water users

	Water use, 2002 (million m^3)				
	Irrigation	Heavy industries	Light industries	Domestic (households)	Total water use
National	7,274	296	9,498	4,432	21,500
Limpopo	193	8	104	40	346
Luvulvhu-Letaba	451	6	649	34	1,140
Crocodile-Marico	342	24	1,304	459	2,130
Olifants	339	41	359	78	817
Inkomati	662	4	159	30	854
Usutu-Mhlatuze	526	3	233	74	836
Thukela	312	10	199	54	575
Upper Vaal	254	99	2,233	1,968	4,555
Middle Vaal	371	6	274	132	784
Lower Vaal	552	5	194	107	858
Mvoti-Umzimkulu	479	41	2,303	503	3,326
Mzimvubu-Keiskamma	34	5	178	123	339
Upper Orange	271	9	159	83	521
Lower Orange	407	1	255	70	733
Fish-Tsitsikamma	371	6	87	151	614
Gouritz	129	2	145	45	321
Olifants/Doorn	497	1	20	28	546
Breede	648	1	39	46	733
Berg	435	24	603	407	1,470

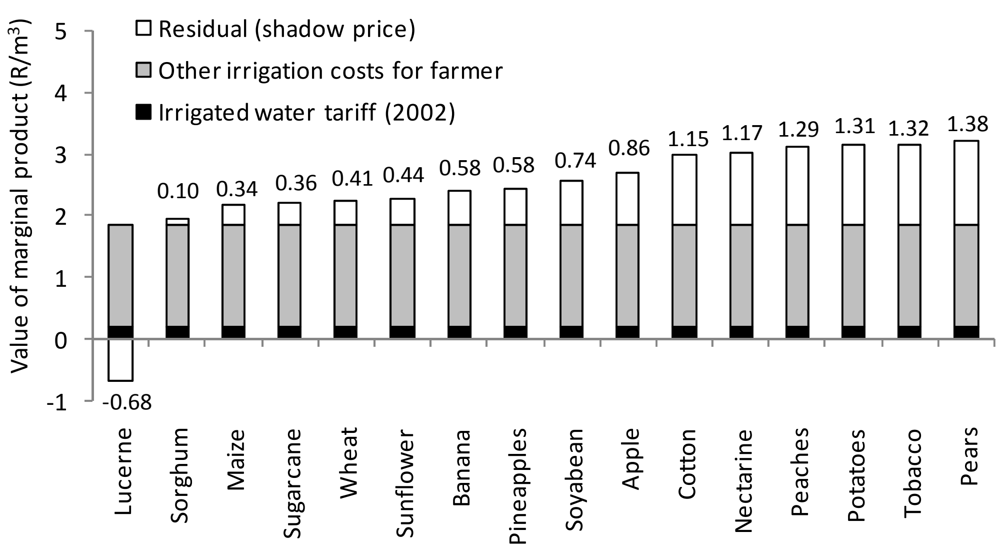
Source: South Africa 2002 Water-SAM and CGE model.

Figure 2. National water demand curves for selected crops



Source: Authors' estimates using crop water use data from research field trials (ARC, 2000). Current average water use and corresponding value of marginal product is marked on each crop's demand curve.

Figure 3. Water shadow prices for selected crops



Source: Own estimates using crop water use data from research field trials (ARC, 2000). Average tariff and irrigation costs from Hassan and Matlanyani (2004). Estimated shadow price after removing irrigation tariffs and costs are reported for each crop.

Table 9. 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 10. Existing natural and manmade interregional water transfers

	Total water transferred (mil. m^3)	Share of transfer in… (%)	
		Sending region	Receiving region
<u>Total interregional water transfers</u>	5,528	-	-
<u>Water transfer schemes</u>	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
<u>Major river-based transfers</u>	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 StatsSA (2000).

Table 11. 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
All crops	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
Irrigated field crops	-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
Rainfed field crops	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.

Table 12. Regional agricultural production under the *National Irrigation* water liberalization scenario

	Absolute change in production compared to the *Regional Irrigation water liberalization* scenario (1000mt)								
	All Regions	Thukela-Vaal scheme				Orange River Project			Other regions
		Thukela	Upper Vaal	Middle Vaal	Lower Vaal	Upper Orange	Lower Orange	Fish-Tsitsikamma	
All crops									
Summer cereals	17.1	-23.5	-5.8	-6.1	23.9	-31.7	23.1	-4.5	41.7
Winter cereals	-15.1	17.2	-25.7	35.0	-42.9	-105.3	0.6	-0.4	106.3
Oils & legumes	-5.7	-1.1	-6.6	-3.6	-4.3	2.1	0.2	0.0	7.6
Fodder crops	-15.3	-15.4	23.5	9.9	17.1	19.8	64.3	-101.5	-33.0
Sugarcane	-90.4	-373.4	0.0	0.0	0.0	0.0	0.0	0.0	283.1
Cotton & tobacco	-23.8	0.8	-1.3	-14.4	0.2	-21.1	2.7	2.5	6.9
Vegetables	-35.2	258.9	-58.2	-77.7	10.9	-159.3	-783.3	12.6	760.9
Citrus fruits	1,165.0	510.3	-1.2	-1.0	-2.1	0.0	-2.5	1,038.0	-376.6
Subtropical fruits	3.6	0.4	-0.1	0.0	0.0	0.0	-1.7	12.1	-7.2
Deciduous fruits	-139.8	0.0	-20.0	-3.0	-56.5	-3.2	-1.6	67.2	-122.8
Other horticulture	1.6	0.0	0.0	-0.1	0.0	0.0	5.1	-0.3	-3.2
Irrigated field crops									
Summer cereals	-197.2	12.3	-79.9	-38.5	-25.0	-71.3	-12.7	0.3	17.6
Winter cereals	-254.8	17.6	-47.4	-26.8	-50.4	-133.5	-21.8	0.2	7.5
Oils & legumes	-26.6	3.5	-9.2	-6.8	-9.6	-4.6	-1.0	0.0	1.1
Fodder crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane	216.8	158.4	0.0	0.0	0.0	0.0	0.0	0.0	58.4
Cotton & tobacco	-24.6	0.9	-1.3	-14.7	0.0	-21.2	2.3	2.9	6.5
Rainfed field crops									
Summer cereals	214.3	-35.8	74.1	32.4	48.9	39.6	35.8	-4.8	24.1
Winter cereals	239.7	-0.4	21.8	61.8	7.5	28.2	22.5	-0.6	98.8
Oils & legumes	20.9	-4.6	2.6	3.2	5.3	6.7	1.1	0.0	6.5
Fodder crops	-15.3	-15.4	23.5	9.9	17.1	19.8	64.3	-101.5	-33.0
Sugarcane	-307.1	-531.8	0.0	0.0	0.0	0.0	0.0	0.0	224.7
Cotton & tobacco	0.7	-0.1	0.0	0.3	0.1	0.1	0.4	-0.4	0.4

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

Table 13. 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 14. 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 15. 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.

Table 16. Household water demand by expenditure quintile

	Population		Per capita	Water demand			
	Number (1000s)	Share (%)	spending (R)	Total (mil m^3)	Share (%)	Per capita (1000 m^3)	Urban-rural ratio
National	44,770	100.0	16,404	4,432	100.0	99	-
Urban	25,207	56.3	23,062	4,157	93.8	165	11.7
Quintile 1	2,439	5.4	1,702	50	1.1	21	7.9
Quintile 2	3,545	7.9	3,516	140	3.2	40	6.6
Quintile 3	4,860	10.9	6,340	303	6.8	62	5.0
Quintile 4	6,211	13.9	12,697	626	14.1	101	4.0
Quintile 5	8,152	18.2	55,823	3,038	68.5	373	3.1
Rural	19,564	43.7	7,824	275	6.2	14	-
Quintile 1	6,734	15.0	1,843	18	0.4	3	-
Quintile 2	5,535	12.4	3,548	33	0.8	6	-
Quintile 3	4,008	9.0	6,440	50	1.1	12	-
Quintile 4	2,341	5.2	13,889	60	1.3	25	-
Quintile 5	945	2.1	66,362	115	2.6	121	-

Source: South Africa 2002 Water-SAM and CGE model. Per capita spending is average consumption spending on all commodities. Rural-urban ratio is calculated on capita water demand.

Table 17. 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 18. Agricultural production results of the *Water-Restricted* (III) and *Water-Liberalized Urbanization* (IV) scenarios

	Base production (1000 mt)	Change from base (%)	
		Water-restricted urbanization	Water-liberalized urbanization
Summer cereals	10,377	3.4	3.4
Winter cereals	2,689	0.4	0.3
Oils & legumes	1,422	-23.7	-24.0
Fodder crops	2,943	-11.0	-11.2
Sugarcane	21,157	-2.6	-3.0
Cotton & tobacco	150	-18.7	-19.3
Vegetables	4,482	-24.2	-24.1
Citrus fruits	1,472	21.8	17.3
Subtropical fruits	602	-14.5	-17.0
Deciduous fruits	3,339	-4.7	-7.9
Other horticulture	171	-15.0	-16.1

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

Table 19. 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.

Table 20. 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.

Table 21. Domestic water transfers under the *Water-Liberalized Urbanization* scenario

	Water use, 2002 (mil. m^3)		Domestic Urban transfer (mil. m^3)	Share of irrigation water use (%)
	Irrigation	Domestic Urban		
National	7,274	9,794	514	-7.1
Limpopo	193	112	6	-2.9
Luvulvhu-Letaba	451	655	35	-7.8
Crocodile-Marico	342	1,328	71	-20.6
Olifants	339	400	19	-5.7
Inkomati	662	163	9	-1.3
Usutu-Mhlatuze	526	236	13	-2.4
Thukela	312	209	11	-3.4
Upper Vaal	254	2,332	121	-47.5
Middle Vaal	371	280	15	-4.0
Lower Vaal	552	199	10	-1.9
Mvoti-Umzimkulu	479	2,344	125	-26.0
Mzimvubu-Keiskamma	34	182	10	-28.6
Upper Orange	271	168	9	-3.2
Lower Orange	407	256	14	-3.4
Fish-Tsitsikamma	371	92	5	-1.3
Gouritz	129	147	8	-6.1
Olifants/Doorn	497	21	1	-0.2
Breede	648	40	2	-0.3
Berg	435	627	33	-7.5

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

Table 22. Impact matrix of simulated policy scenarios

POLICY IMPACTS	POLIC Y SCENARIOS			
	Liberalize regional irrigation water markets	Liberalize national irrigation water markets	Water-restricted competition from higher urbanization	Water-liberalized competition from higher urbanization
Irrigation water use	No change	No change	No change	--
Non-agriculture	No change	No change	+	++
Irrigation water	--	-	+	++
Total GDP	+	+	+	+
Agricultural GDP	++	++	--	--
Non-agriculture GDP	-	-	+	+
Absorption	+	+	+	+
Production of food	-	-	+	+
Price of food crops	+	+	-	-
Exchange rate	+	+	+	+
Consumer prices	+	+	-	-
Rural incomes	+	+	-	--
Urban incomes	-	-	+	+
Total employment	+	+	--	--
Rural employment	++	++	--	--
Non-agriculture	+	+	+	+
Total exports empl.	+	+	+	+
Agricultural exports	++	++	-	--
Non-agriculture	-	-	+	+
Total imports	+	+	-	-
Agricultural imports	++	++	--	--
Non-agriculture	+	+	+	+