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

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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, ongoing rapid urbanization, and government programs to provide access to water to millions of previously excluded populations. This article employs a general equilibrium approach to examine the economy-wide impacts of selected macro and water-related policy reforms on water use and allocation, rural livelihoods, and economy at large. The analyses reveal that implicit crop-level water quotas reduce the amount of irrigated land allocated to higher-value horticultural crops and create higher shadow rents for production of lower-value water-intensive field crops, such as sugarcane and fodder. Accordingly, liberalizing local water allocation within irrigation agriculture 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 nonagricultural uses fuelled by higher competition for water from urbanization leads to greater water shadow prices for irrigation water with reduced income and employment benefits to rural households and higher gains for nonagricultural households. The analyses show difficult trade-offs 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.

JEL classifications: C68, Q15, Q25, Q28

Keywords: Water resources; Irrigation; General equilibrium

1. Introduction

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

SA's agricultural sector enjoyed high protection in the past for food security and other political reasons. The sector received a direct price subsidy on water use as well as nonprice protection (i.e., water quota system) that remains largely in place today. Moreover, previous water allocation regimes were biased in favor of large-scale white farmers seriously disadvantaging other segments of the rural population of mostly smallholder

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Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell, Inc. is not responsible for the content or functionality of any supporting information supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

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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 being implemented. Major macroeconomic reforms have been introduced to correct the grave socio-economic injustices of the past, particularly in providing basic services (e.g., water and sanitation, housing, health, and education) and income and employment opportunities to millions of previously service-deprived communities. These shifts in public policy and investment priorities have major implications for water use and allocation within the economy, and the need to reform water policy commensurate with these new policy initiatives.

A new National Water Policy (NWP) was adopted in 1997 marking a radical shift in the strategic objectives and principles of water management in SA (DWAF, 1998). Implementation of the new NWP and subsequent National Water Act (NWA) is expected to have long-term effects on the way water resources are developed, allocated, and managed in SA. As many of these policy changes may have unintended and undesirable consequences for other nontarget activities and serve conflicting goals (e.g., the typical trade-offs between implications of reforms pursuing macroeconomic stabilization and efficiency versus social equity objectives), their net effect on the economic and social well-being of the people of SA is 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 article analyzes the potential effects of ongoing and intended macro and water-sector-level policy changes on the SA economy 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 should inform scheduled efforts for revising the current water resource management strategy in 2009 for the 5-year period to follow (DWAF, 2008).

2. Water resources management and the SA economy

SA receives about 450 mm of rainfall per annum (compared to world average of 860 mm) and is expected to approach the limits of potentially available water supplies by 2025 (DWAF, 2004). Not only is the natural availability of fresh water spatially diverse in SA, but so too is the distribution of major economic activities, populations, and development centers. Moreover, urban and peri-urban pockets often do not lie within areas of water abundance. To match supply with demand for water at these centers, the country has made huge investments in developing sophisticated water supply and delivery infrastructures that allow transfers of water from surplus to deficit areas (e.g., inter-basin transfers) and between seasons (storage dams). This has given the country the ability to control and manage water resources within a national interlinked system of supply.

Only 60% of annual runoff (19.5 billion m^3) is available as surface water yield and the rest provides base-flow support. Half of the available surface water is kept in stream as ecological reserve and the rest (9.6 billion m^3) constitutes the bulk water supply resources managed and distributed by the Department of Water Affairs and Forestry (DWAF) to the economic system for domestic consumption and production purposes (DWAF, 2004). The country has massive water storage infrastructure with total dam capacity of 32.4 billion m^3—equal to two-thirds of total mean annual runoff (DWAF, 2004).

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

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

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

One key intervention instrument to balance resource availability and priority needs is the transfer of water from surplus to deficit WMAs. Accordingly, the NWRS establishes plans for inter-regional water transfers based on estimated strategic requirements and available water supplies within each WMA, i.e., water transfers between WMAs are currently not guided by market incentives but exogenously determined (Table S2 in Data Appendix S1). 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 whose economy-wide impacts require careful assessment.

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

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

3. Modeling irrigation water management in the economy of SA

To overcome limitations of partial equilibrium approaches in incorporating important inter-sector and inter-market linkages and endogenous prices, recent efforts have attempted to develop economy-wide modeling frameworks for analyzing economic and policy aspects of water management. Examples of earlier 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 disaggregation, implications for international trade (Peterson et al., 2004), equity and distributional effects, and environmental impacts (Letsoalo et al., 2005).

While CGE models better handle economy-wide effects they suffer from high aggregation of economic activities into key sectors, which limits their ability to investigate feedback effects from micro or sector changes and interventions to the macroeconomy and vice versa. Recent attempts have been made to develop CGE models that can handle such feedback linkages and allow tracing micro effects of macro-level policy changes, e.g., trade, as well as feedback effects on macro-economic aggregates of micro-level policy changes, e.g., farm level water allocation and trading regimes (Diao et al., 2008; Roe et al., 2005). This, however, is implemented sequentially in a two-step analytical structure with a micro farm model component separated from the macro CGE model. The Water CGE model developed for SA and described below attempts to overcome this limitation by directly incorporating a highly disaggregated structure of water and agricultural activities within the CGE model. This enables simultaneous rather than sequential assessments of both macro and micro effects and adjustments. Most previous work on modeling the economics and policy of water resource management in SA falls under the partial equilibrium tradition. A few studies attempt to capture multi-sector linkages, but do so by employing much simpler model structures (Hassan, 2003; Letsoalo et al., 2005; Matete and Hassan, 2007).

3.1. *The SA Water SAM and CGE model structure*

A new agriculture and water-focused SAM and CGE model was constructed for SA in this study to examine the economy-wide impacts of selected macro and micro (water-related) policies. Apart from the model's treatment of water, it also contains detailed information on production, trade, and consumption, which are discussed below. A full description of the SA SAM is documented in Hassan et al. (2008) and the mathematical specification of the model is provided in Data Appendix B.

3.1.1. *Production and employment*

The model contains 40 sectors or commodities, including 17 agricultural and 15 industrial sectors.[2] Agricultural production is divided into field crops (summer cereals; winter cereals; oil crops and legumes; fodder crops; cotton and tobacco; and sugarcane), horticultural crops (vegetables; fruits-citrus, subtropical, deciduous; viticulture; and other horticulture), livestock (livestock sales; dairy; poultry; and other livestock products); and fishing and forestry.[3] Field crops are further separated into irrigated and rain-fed whereas all horticultural production is

[2] Tables B1 and B2 in Data Appendix B provide the mathematical specification of the model, and Table B3 lists the model's sectors, factors, and household groupings.

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

Table 1
Structure of the South African economy (2002)

	Share of total (%)				Export intensity	Import intensity
	GDP	Employment	Exports	Imports		
Total GDP	100.00	100.00	100.00	100.00	13.48	13.31
Agriculture	4.32	7.87	3.65	2.17	15.05	9.27
Field crops	1.79	2.93	0.59	1.46	5.93	13.53
Summer cereals	0.43	0.89	0.31	0.40	11.09	13.55
Winter cereals	0.17	0.33	0.01	0.26	1.00	18.97
Oils & legumes	0.18	0.34	0.18	0.48	15.62	34.07
Fodder crops	0.03	0.06	0.00	0.00	2.61	0.00
Sugarcane	0.84	0.99	0.00	0.00	0.00	0.00
Cotton & tobacco	0.14	0.32	0.09	0.32	11.02	30.69
Horticultural crops	1.00	1.85	2.16	0.23	42.05	7.08
Vegetables	0.22	0.55	0.07	0.00	5.60	0.00
Citrus fruits	0.15	0.24	0.53	0.02	67.91	6.76
Subtropical fruits	0.08	0.11	0.07	0.00	16.52	0.00
Deciduous fruits	0.45	0.65	1.30	0.00	62.57	0.00
Other horticulture	0.10	0.30	0.19	0.22	34.26	35.71
Livestock	1.28	2.80	0.85	0.27	10.88	3.46
Other agriculture	0.26	0.29	0.05	0.21	3.89	13.53
Industry	33.38	29.27	75.84	83.46	22.17	21.96
Mining	8.72	4.96	33.72	10.28	71.10	43.45
Manufacturing	19.90	17.65	42.12	73.18	16.87	23.30
Food processing	3.03	2.51	3.03	2.98	7.77	5.98
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.

assumed irrigated. Together, these agricultural sub-sectors account for 4.3% of the national GDP—making agriculture a relatively small part of the economy (Table 1). By contrast, the industrial sectors comprise one-third of national GDP, ranging from the more capital-intensive mining, metals, and energy sectors, to the more labor-intensive food processing, textiles, and construction.

One key new and unique feature of the SA Water SAM (SAWSAM) is its disaggregation of 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 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.[4] The characteristics of these WMAs vary considerably. For example, Table S1 in Data Appendix S1 shows that agriculture is only 1% of the Upper Vaal's GDP (i.e., GautengProvince), but more than a third of Breede's GDP (i.e., the grape-growing regions surrounding Cape Town). The largest agricultural area in terms of GDP is Mvoti-Umzimkulu (i.e., the sugarcane growing region outside of Durban), but in terms of land area it is the Middle Vaal (i.e., the maize growing region in Free State province). Thus, while the regional disaggregation of the model is motivated by WMAs, it also captures the varying importance of agriculture and other sectors in different parts of the country.

To capture differences in production technologies, the model identifies six factors of production: three types of labor (unskilled, skilled, and highly skilled), agricultural land, irrigation water, and capital. Higher-skilled labor and capital are assumed to be fully employed with flexible real wages.[5] 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. Regional labor markets allow workers to migrate across sectors within each WMA, but 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.

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

[5] Labor employment data are taken from the 2004 Labor Force Survey (September) (StatSA, 2005).

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

3.1.2. Domestic and international trade

Producers in each region[6] 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.

Substitution possibilities also exist between imported and domestic goods under a CES Armington specification.[7] The final ratio of imports to domestic goods is determined by the cost minimizing decision making of domestic demanders based on the relative prices of imports and domestic goods (both of which include relevant taxes). Under the small-country assumption, SA faces perfectly elastic world demand/supply at fixed world prices. There are, therefore, four endogenous commodity prices in the model: a single national supply price reflecting region-specific producer prices; an export and an import price based on world prices and the exchange rate; and a composite market price. The final market price is the same in all regions and includes transaction costs and indirect taxes.

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

3.1.3. Household incomes and demographic structure

The model distinguishes between various institutions, mainly government and a number of representative household groups. Households in each WMA are disaggregated across rural/urban areas and national expenditure quintiles. Households receive income in payment for producers' use of their factors of production[8] and pay direct taxes to government (based on fixed tax rates),[9] save (based on marginal propensities to save), and make transfers to the rest of the world. Households use their income to consume commodities under a linear expenditure system (LES) of demand.

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

3.1.4. Model closure

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

3.1.5. Agricultural water use and shadow prices

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

In order to incorporate irrigation water into the model, it is necessary to identify the productivity effects of water on crop yields. This study extended the approach of Hassan and Mungatana (2006) to include additional crops modeled in the

[6] Note that "region" and "WMA" are interchangeably used throughout this article to mean the same thing.

[7] Trade elasticities are taken from the Global Trade Analysis Project (Dimaranan, 2006).

[8] Note that the SAWSAM does not have an "enterprise" account and hence capital payments are paid directly to households. Land and irrigation water rents are similarly distributed across households.

[9] Since the SAWSAM does not have a separate enterprise account, corporate taxes are taken directly from capital to the government direct tax account. Similarly, it was assumed that all industrial and domestic water value-added is paid to the government at a 100% tax rate.

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

SAWSAM and updated their estimates of the value of marginal product (VMP) of water using 2002 market output prices (see Hassan et al., 2008, for more discussion on modeling agriculture and nonagriculture water use). Irrigated water therefore appears as a factor of production in the CGE model and is used exclusively by irrigated agricultural sectors. The returns to the irrigated water factor (i.e., the shadow price) are distributed to higher-income rural households according to their ownership of the returns to commercial agricultural land. The government also charges a fixed raw water tariff that varies by WMA depending on what supply schemes are providing water.

3.1.6. Nonagricultural water use and distribution system

Although the model pays particular attention to agriculture and irrigated water, it also captures industrial and domestic water use. Unlike irrigated water, the provision of nonagricultural water takes place via the water distribution system. In other words, it is treated as an intermediate input and not as a 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, 2007). However, to simplify the system, the CGE model only distinguishes between two groups: (i) heavy industry and (ii) light industry and households. This is because water tariffs charged to heavy industries (e.g., mining and energy) are substantially below those charged to households and light industries.

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

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

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

4.1. The selected policy scenarios

As discussed in Section 2, water allocation between WMAs and between competing economic uses within WMAs remains governed by quantitative restrictions and nonmarket factors. The Water CGE model is useful for evaluating the net impacts of potential shifts in water policy toward more market-based allocation regimes which the NWRS aspires to promote. The Water CGE model is accordingly employed in this section to examine a number of water-related issues in SA. The economy-wide (micro and macro) impacts of the following policy scenarios have been evaluated:

4.1.1. Scenario I: Liberalizing regional irrigation markets

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

4.1.2. Scenario II: Liberalizing national irrigation markets

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

4.1.3. Scenario III: Urbanization under current water restrictions

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

4.1.4. Scenario IV: Urbanization with liberalized water markets

The final scenario liberalizes water markets allowing for market-based water transfers out of irrigation to meet the growth in demand for domestic and industrial use introduced under

Table 2
Micro impacts of the *Regional* (I) water market liberalization scenario

Change in water shadow prices

Water management area (WMA)	Average base value (R per 1000 m^3)	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

Crop type	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	–	–
Rain-fed 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	–	–

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

Scenario III. It is expected that this will lead to declines in agricultural GDP, rural employment, and incomes with offsetting gains from expansions in urban-based nonagricultural sectors' income and employment.

4.2. *Results of the policy scenario analyses*

4.2.1. *Micro impacts of the regional (Scenario I) and national (Scenario II) irrigation water market liberalization*

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

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

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

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

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

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,[12] as well as a number of natural flows along rivers connecting WMAs (see Table S3 in Data Appendix S1). Given existing infrastructure and natural river-based flows, the second scenario (*National Irrigation Market Liberalization*) focuses on equalizing SPs for irrigated water both *within* all WMAs and also *across* two of the main water transfer schemes.

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

According to Table S4 in Data Appendix S1, 348 million m^3 of the total 431 million m^3 currently transferred under Thukela-Vaal scheme would need to be reversed in order to equalize SPs with the Vaal River WMAs at a price R0.46 per 1000 m^3. This 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 R 0.68 per 1000 m^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 (see Table S4 in Data Appendix S1). While some of the newly irrigated lands are used to replace the decline in dry-land production, there is an overall decline in production of most field crops. This is because expanding irrigated land allows farmers in the Thukela WMA to increase production of higher-value vegetables and citrus fruits. By contrast, the reduction in irrigated water supply in the Vaal WMAs encourages a shift out of irrigated cereals and into dry-land production.

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

4.2.2. Macro impacts of the regional (Scenario I) and national (Scenario II) irrigation water market liberalization

With regional and national liberalization of irrigation water markets, imported cereals increase in order to replace falling domestic cereals production (caused by the shift to low-yield rain-fed production). Declining cereal exports is more than offset by increased horticultural exports, such that overall agricultural exports rise under both scenarios (see Table 3). This causes a slight decline in the relative price of tradables to nontradables driven by lower demand for internationally traded commodities.

Ultimately, agricultural GDP increases by 4.5% under regional market liberalization (*Scenario I*), driven almost

[11] This model's predicted shift toward increased irrigated wheat has already occurred according to field observations from the Douglas/Vaal/Orange Riet and Modderrivier irrigation areas.

[12] The first of the three transfer schemes is the Orange River Project, which transfers water from the Upper Orange WMA (i.e., Free State) via the Orange-Fish tunnel, to supply half of the water used in the Fish-Tsitsikamma WMA (i.e., Eastern Cape). Secondly, a number of schemes transfer water between the Thukela and Upper Vaal WMAs, the largest of which is the Drakensberg Pumped Storage Scheme, which pumps about half of the water in the Thukela WMA over the Drakensberg escarpment to the Sterkfontein Dam, which 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.

Table 3
Macro and consumer price results from the *regional* (I) and *national* (II) water market liberalization scenarios

	Base value	Regional scenario	National scenario
	Percent 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
Nonagriculture	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
Nonagriculture	96.35	−0.88	−1.08
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
Nonagriculture	97.83	0.27	0.30
	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.

entirely by increased horticultural production and exports. Adjusting water transfers under national liberalization (*Scenario II*) also affects WMAs outside of the two transfer schemes (i.e., economy-wide impacts from WMA level policies). For instance, falling cereals and vegetables production in the Vaal and Orange River WMAs drives up the national price of these commodities, thereby encouraging production in other WMAs. Conversely, increased citrus fruit production in the transfer recipient WMAs lowers prices and encourages other regions to reduce citrus production. Overall, national liberalization increases agricultural GDP further (i.e., expanding by 5.4% instead of 4.5%). This is again driven by shifting land from lower-value dry-land field crops into higher-value horticulture.

Nonagricultural 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 nonagricultural exports in particular. Overall, there is little change in total economy-wide GDP, in part due to agriculture's relatively small contribution, as noted above. Irrigation water market liberalization also causes the consumer price index to increase slightly due to the rising price of cereals (in spite of substantial declines in horticultural prices). This causes a shift in agricultural production away from consumer-intensive commodities, such as cereals, toward more export-intensive horticultural products. SA therefore becomes a larger net importer of cereals (i.e., maize and wheat).

Increased agricultural production also creates additional employment for lower-skilled workers that is more than double the number of workers displaced in the nonagricultural sectors in *Scenario I* (see Table 4). In other words, despite resource competition between agriculture and nonagriculture, there is a net increase in national employment when regional water markets are liberalized. Employment gains for lower-skilled workers are even higher under *Scenario II*. As agricultural production is less skill- and capital-intensive, and its wages are about two-thirds of average nonagricultural wage, the shift into agricultural employment causes a slight decline in economy-wide wages for the three labor skill groups as well as for 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. Together this raises incomes and per capita expenditures amongst lower-income households. By contrast, demand for high-skilled labor and capital declines with the shift out of nonagriculture causing these factors' returns to decline.

Interestingly, rural households are the main beneficiaries from irrigation water market liberalization (see Table S5 in Data Appendix S1). 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 nonagricultural production, declining higher-skilled workers' wages, and rising agricultural commodity prices. This suggests that liberalization of irrigation water markets leads to both efficiency and equity gains. Finally, the regions whose rural households benefit overall are generally those whose water SPs rose as a result of liberalization (e.g., Usutu-Mhlatuze, Tukela, Lower Vaal, Fish-Tsitsikamma, and Gouritz). Of the WMAs outside of the transfer schemes benefiting under the *national* liberalization scenario are those that were initially more focused on field crop rather than horticulture production, since field crops' prices rise relative to horticultural prices.

In summary, current quantitative restrictions governing the allocation of irrigation water in SA distort the allocation of productive resources across crops and WMAs. Liberalizing regional and national water markets generates significant gains for the agricultural sector as a whole, although expanded high-value crop production comes at the cost of lower cereals production and higher cereals prices. Moreover, those regions that are currently net recipients of water transfers may experience declining agricultural incomes. However, despite rising cereals prices and the resultant decline in real urban incomes, liberalizing water

Table 4
Factor market impacts of the *regional* (I) and *national* (II) water market liberalization scenarios

	All sectors			Agriculture only		
	Base value	Regional scenario	National scenario	Base value	Regional scenario	National scenario
Factor employment	Absolute change			Absolute change		
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 (value units)	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	Percent change			Percent 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.

markets in SA is pro-poor, with significant welfare gains for rural households, especially at the bottom of the income distribution. There appears then to be some tension between urban and rural interests, which may be further exacerbated by increased water demand from urbanization and industrialization.

4.2.3. Macro and micro economic implications of competition under water-restricted (Scenario III) and water-liberalized urbanization (Scenario IV)

Agricultural GDP grew at 0.4% per year during 1994–2007, while industry and services grew at 2.6% and 4.3%, respectively (SARB, 2008). These transitional forces pulled labor from agriculture as per capita incomes grew, and reflects SA's accelerating shift away from primary sector production (including mining) toward greater industrialization and a more prominent role for services. These structural changes have been partly facilitated by removal of subsidies and trade protection from many agricultural products, and by greater openness of the economy, which has fostered capital deepening contributing to real wages and nonagricultural export growth (Hérault and Thurlow, 2010).

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

In this section, we present two scenarios reflecting the current structural and demographic changes taking place in SA. In the first scenario (*III*) we examine the impact of rural-to-urban migration on urban household water demand and the additional pressures that this places on water resources under current water allocations (the *water-restricted urbanization* scenario). In the second scenario (*IV*) we implement *Scenario III* under liberalized regional water markets allowing for market-based transfers of water between irrigation agriculture and nonagriculture within WMA's (*water-liberalized urbanization*) while maintaining current inter-basin transfers unchanged (i.e., between WMAs).

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 share falls to around 20%). We assume that migrants move from rural quintiles to equivalent urban quintiles, thereby increasing labor endowment of this representative household in the model and hence its share of labor incomes earned within their WMA-specific labor market. Moreover, new migrants and their families adopt urban consumption patterns, allowing us to capture increased demand for water resources caused by urbanization.

Rural-to-urban migration shifts the composition of aggregate household demand toward urban consumption patterns, which are considerably more water-intensive. This causes a 3% increase in the price of domestic water under the *water-restricted urbanization* scenario (see Table 5). Urban consumers also spend a larger share of their incomes on processed foods and other nonagricultural goods. Thus, the shift in demand composition caused by urbanization increases nonagricultural GDP, but reduces demand for less-processed agricultural goods, as reflected in consumer price changes.

Table 5
Macroeconomic results of the *water-restricted* (III) and *water-liberalized* (IV) urbanization scenarios

	Base value	Percent change	
		Water-restricted scenario	Water-liberalized scenario
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
Nonagriculture	96.35	0.09	0.17
Imports	−28.95	−0.05	−0.07
Agriculture	2.17	−13.57	−13.32
Nonagriculture	97.83	0.26	0.23
Exchange rate	1.000	1.002	1.002
Consumer prices (CPI)	1.000	0.998	0.998
Agriculture	1.000	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.

Agricultural employment declines by 59,000 jobs (equivalent to 8.4% of current agricultural workforce; Table 6). While new nonagricultural jobs are created for migrant workers, they are insufficient to offset the decline in agricultural employment. These results indicate how the lower labor intensity of industry vis-à-vis agriculture may increase national unemployment in SA as urbanization proceeds. The decline in labor-intensive agricultural production reduces the overall level of employment in the country under *water-restricted urbanization* causing slight declines in household worker populations for these higher-income households.

As discussed above, urbanization reduces demand for agricultural goods, which causes agricultural production and employment to decline. While rural expenditure per worker for the lower quintiles declines with urbanization, higher-income rural households benefit from larger returns to high-skilled labor and capital. Due to the larger initial incomes per worker for this group and the fact that supply of low paid agricultural labor declines pushing wages upward, the impact is sufficient to raise average rural incomes. Conversely, the shift in consumer demand towards nonagricultural goods and the increase in nonagricultural GDP increases expenditures per worker in urban areas. However, the inflow of lower-paid migrants into urban areas causes average urban expenditures to decline (see Table S6 in Data Appendix S1).

In *Scenario III* we assumed no change in the supply of urban/industrial water resources, which, coupled with rising domestic water demand, caused domestic water prices to rise by 3.1% (see Table 5). In the *water-liberalized urbanization* (*Scenario IV*) we allow for the transfer of irrigation water to urban/industrial use such that national urban/industrial water prices is unchanged. In order to neutralize rising water prices under higher urbanization, 7.1% of irrigation water at the national level must be transferred to domestic use. This causes agricultural production and GDP to decline further. Production expands substantially for the domestic water distribution sector, which lowers the national domestic water price. However,

Table 6
Factor market impacts of the *water-restricted* (III) and *water-liberalized* (IV) urbanization scenarios

	All sectors			Agriculture only		
	Base value	Water-restricted scenario	Water-liberalized scenario	Base value	Water-restricted scenario	Water-liberalized scenario
Factor employment	Absolute change			Absolute change		
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	Percent change			Percent 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.

the small size of water charges relative to sectors' overall production costs leads to only small changes in nonagricultural GDP.

The decline in irrigation water and a consequent increase in its SP cause a substantial drop in agricultural production, primarily for irrigation-intensive crops such as fruits. This reduces agricultural employment by 1% of total agricultural workforce (see Table 6), causing rural expenditures per worker to decline for all expenditure quintiles (see Table S6 in Data Appendix S1). While urban households benefit more than rural households from lower water prices, the overall effect of the domestic transfer on urban consumption per worker is small.

The above results suggest that liberalizing water trade involves difficult trade-offs in allocating water resources between alternative uses. While industrialization and urbanization create additional nonagricultural jobs and raise household incomes in urban areas, these processes also cause substantial increases in water prices. These two outcomes apparently justify increased transfers away from subsidized irrigation use. On the other hand, transferring water from irrigation to domestic use leads to substantial declines in agricultural production, which raise agricultural and food prices, and lower 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

Pressure on existing water resources in SA is predicted to worsen with planned growth strategies, observed recent demographic changes, and unfavorable global climatic and economic conditions. The implications are expected to be particularly severe for irrigation agriculture which currently uses more than 60% of water resources in the country. The country is also undergoing radical water sector reforms which aim to correct for previous social injustices and economic inefficiencies in water use and allocation with 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 the adoption of an economy-wide approach to properly evaluate their net impacts on rural livelihoods and the overall economy. The present study attempted to develop a comprehensive general equilibrium framework to account for both inter-sector linkages and micro–macro feedbacks. Accordingly, a new SAM and CGE model was constructed to specifically examine the economy-wide impacts of selected macro and water-related policies on water use and allocation within the national economy. The CGE model incorporates agricultural and nonagricultural water use and contains detailed information on production, trade, and consumption.

Currently water resources' management within the SA economy is based on some strategic allocation regimes that determine the distribution of managed total water supplies between regions (WMAs) and economic sectors at fixed (not market determined) water charges. Sectoral and economy-wide impacts of four policy changes were considered in this article that experimented with relaxing nonprice 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 the basis of economic efficiency (i.e., market based) in order to equalize water shadow prices across all crops within the same WMA. Implicit crop-level water quotas were found to reduce the amount of irrigated land allocated to higher-value horticultural crops, while creating higher shadow rents for farmers producing lower-value and water-intensive field crops, such as sugarcane and fodders. Liberalizing regional irrigation water markets would therefore improve the efficiency of water allocation within WMAs, expand agricultural production and exports, and create additional jobs for farm laborers. These jobs are especially important for lower-income rural households. However, regional water market liberalization increases the price of cereals, hurting urban consumers. Accordingly, liberalizing local water allocation within irrigation agriculture was found to work in favor (increased area and production) of high value crops such as horticulture, expand agricultural production and exports and farm employment.

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

The third policy scenario introduced water competition between nonagricultural urban uses and irrigation agriculture by increasing the level of urbanization in SA. This leads to higher water SPs for irrigation water with reduced income and employment benefits to rural households and higher gains for nonagricultural households. Similarly, the final policy experiment considered competition from industrial expansion and urbanization, while also transferring water from irrigation to domestic use in order to maintain national water prices. This had major negative consequences on the agricultural economy. The final two experiments therefore revealed difficult trade-offs between general economic gains and higher water prices, which seriously questions the current subsidization of water supply to irrigated agriculture.

While the above analysis has examined a number of key policy issues relating to the allocation of water in SA, this was by no means an exhaustive study. For example, a key assumption in our analysis was fixed national water supplies, which was appropriate given our focus on current water policies. However, long-run environmental factors, such as climate change, may alter future water availability in SA. Although reducing water supply should not significantly alter our conclusions regarding the distributional impacts of national water market liberalization, it could have profound implications, both for the economy and for specific regions or household groups. The analytical framework developed in this study is ideally suited to evaluating the impacts of long-run climate change, as well as the macro–micro outcomes of managing SA's already scare water resources.

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