Water Scarcity and Irrigation Efficiency in Egypt

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Abstract

This study provides quantitative assessments of the impacts of efficiency enhancement for different types of irrigation water under water scarcity conditions. It employs a single country CGE (STAGE 2) model calibrated to an extended version of a recently constructed SAM for Egypt 2008/09. The SAM segments the agricultural accounts by season and by irrigation scheme, including Nile- and groundwater-dependent as well as rain-fed agricultural activities. The simulations show that Egypt should manage potential reductions in the supply of Nile water with more efficient irrigation practices which increase the productivity of Nile water, groundwater and irrigated land. The results suggest a more ambitious plan to boost irrigation efficiency for summer rice would be desirable in order to outweigh any potential shrinkage in output and exports. Furthermore, even doubling all non-conventional water resources is not sufficient to compensate the potential adverse impacts of Nile water losses. This highlights the importance of irrigation efficiency for the Egyptian economy.

Key Words: *Water Availability, Irrigation Efficiency, Agricultural Productivity, Egypt, Computable General Equilibrium (CGE) Models.*
JEL: *Q25, Q15, O55, C68*

1. Introduction

Egypt faces a serious water scarcity issue that is made more critical by current economic and population growth rates, and its almost total reliance on the Nile for water. Water availability per capita, at around 1,000 m^3 per year, is already one of the lowest in the world. This is expected to halve by 2025 and thus fall below the scarcity rate. Moreover, with the rapidly increasing population, the per capita renewable water share has declined from 853.5 m^3 in 2002 to 785.4 m^3 in 2007 and to 722.2 m^3 in 2012, and is predicted to reach 534 m^3 by 2030 (FAO, 2014). Consequently, not only does Egypt face a crisis of scarcity, it also faces a major environmental problem.

The Nile provides 95% of Egypt's fresh water. Irrigated agriculture absorbs 85% of Egypt's annual water resources, which is equivalent to 89% of Nile water, with the remaining 15% is used by industry and households. However, Egypt's historic 66% share of Nile waters[4] is under negotiation with upstream countries demanding greater use of these waters. In April 2011, Ethiopia launched the construction of the Grand Ethiopian Renaissance Dam (GERD). The GERD will be the biggest hydroelectric power plant, with an energy generation capacity of 6,000 megawatts (MW), and one of the largest water reservoirs in Africa, with a water storage capacity of 63 billion cubic metres (BCM). Egyptian experts estimate a possible water reduction of 11-19 BCM over the dam's filling period, which is equivalent to 20-34% water reduction when the filling period overlaps with the dry season.

Reductions in Egypt's fresh water resources will have significant impacts on agriculture and the economy as a whole, which makes a reassessment of the productivity of irrigation water and land, as well as the efficiency of the overall irrigation system, a critical issue.

This paper reports the potential implications of reductions in water resources and enhancements in irrigation efficiency using a single-country Computable General Equilibrium (CGE) model that has been customised to encompass production, consumption and distributional impacts. The model is calibrated with a Social Accounting Matrix (SAM) for Egypt 2008/09 that has detailed water accounts. The SAM treats water as a factor of production used by three water activities: Nile water, groundwater and rain-fed agricultural activities. It also has detailed seasonal irrigation accounts. This seasonality is accounted for by distinguishing irrigation using (agricultural) activities, not only by irrigation scheme but

[4] Sudan also claims rights to 22% of the Nile waters, which only leaves 12% for upstream countries.

also by irrigation season. Nile water, groundwater, land irrigated by Nile water, land irrigated by groundwater and rain-fed land are segmented by irrigation season.

The simulation results address several key questions. How large are the potential effects of Nile water reductions on the agricultural sector and the economy? What are the necessary enhancements in irrigation efficiency required to compensate for the potential losses of Nile water? Is investing in securing non-conventional water resources a viable alternative strategy to one of improving irrigation efficiency?

The rest of the paper is organised as follows. Section 2 describes the existing irrigation scheme and resources, and provides a context for this study in relation to prior studies of Egypt. The SAM database and the model development are detailed in Section 3, while Section 4 explains the simulations and model configurations used in this study. Analysis of the results is reported in Section 5, with the results from sensitivity analyses reported in Section 6. The paper ends with concluding comments.

2. Water and the Egyptian Economy

Where irrigation is common, water for irrigation purposes typically accounts for the largest share of demand for water and hence irrigation is a major topic in natural resources and environmental economics and applied water policy analysis. The use of irrigation water has been modelled using partial and general equilibrium models and micro-macro modelling at country and global levels (see Dudu & Chumi, 2008; Ponce *et al*. 2012 and Dinar, 2014 for reviews). Recent literature demonstrates that CGE models are well equipped to examine the economy-wide impacts of water-related policy reforms, and the macro impacts of issues like water scarcity and irrigation policies and investments. This is because CGE models are flexible enough to include water both as a production factor and as a consumption commodity. Moreover, an economy-wide approach allows consideration of the effects of water use on all economic sectors, not only agriculture, and the evaluation of indirect effects due to changes in water supply and/or policies. However, the available surveys note that irrigation, water allocation and agricultural productivity are under-explored in the research and policy literature.

2.1 Water and Irrigation

Egypt only receives rainfall along a narrow strip in the northern coastal area where the average rainfall does not exceed 200 mm and is subject to appreciable temporal variability. Egypt relies on the Nile and groundwater as primary sources of water. The Nile accounts for 83% (51.7 BCM/year) of Egypt's irrigation water, while groundwater is the second largest source with 11% (5.2 BCM/year). In addition, Egypt makes use of small amounts of drainage (3.7 BCM/year) and treated sewage (1.5 BCM/year) water. Egypt is currently using close to its total volume of available water, except for groundwater where 11.3 BCM is available, see Table 1.

Groundwater is mainly located in the Nile aquifer system as well as the Western Desert region and Sinai. Nile water is replenished through leakages from the irrigation system alongside the Nile Valley and Nile Delta forming a Nile-reliant source of groundwater with an annual abstraction rate of 4.6 BCM. The Nubian Sandstone aquifer system, in the Western Desert, is another main source of groundwater in Egypt. The annual extraction rate from this non-renewable aquifer is 0.5 BCM (El Arabi, 2012).

Table 1: Available and Used Irrigation Water Resources

Source	Usage		Availability	
	Billion m^3/Annum	%	Billion m^3/Annum	%
Nile Water	51.70	82.59	55.50	75.20
Groundwater	5.20	8.30	11.30	15.30
Drainage Water	3.70	5.91	5.00	6.80
Treated Sewage Water	1.50	2.40	1.50	2.03
Rain	0.50	0.80	0.50	0.67
Total	**62.60**		**73.80**	

Source: compiled by the authors from different sources.

Keller & Keller (1995, p. 6) note that "Egypt's Nile Valley irrigation system (NVIS) is an excellent example of a multiple use-cycle system with a high global efficiency but low local efficiencies". The enduring nature of this paradox reflects the historic division of the Nile waters and the control of Nile waters made possible by the Aswan dams. Year-round availability of water and major reductions in seasonal floods were made possible by the Nasser Lake reservoir, from which annual flows of 56 BCM are sourced.

Irrigated land is heavily concentrated in the Nile Valley and Nile Delta, which accounts for 85% of the 8.7 million feddans of Egyptian irrigated land.[5] Groundwater is used for 11% of irrigated agricultural production, primarily in the Sinai, Western North Coast (Matruh), Western Desert and New Valley regions, where it is the sole source of water. Rain-fed agriculture is limited to the Mediterranean shore, with around 250,000 feddans in Sinai and 150,000 feddans in the Western North Coast dependent on seasonal rains.

Egypt follows a multi-cropping system with up to three crops a year. Crops are rotated across three irrigation seasons: winter (November-May), summer (May-September) and Nili, i.e. Nile flood, (September–November). The main crops are wheat, berseem and broad beans (winter season), cotton and rice (summer season) and maize and millet (flood season). This system enhances land productivity: berseem and broad beans are nitrogen-fixing legumes which improve fertility before cotton, which is more demanding on the soil, is planted in summer.

The bulk of irrigated land, however, depends on a low-efficiency surface (flood) irrigation scheme: a technology that requires large quantities of cheap water – the Nile waters. The surface irrigation scheme causes high water losses, declining land productivity, waterlogging and salinity problems (Karajeh *et al.* 2011). Moreover, poor agricultural practices and irrigation management affect the quality of the country's water resources. Reductions in irrigation water quality have damaged irrigated soils and crops due to, amongst other things, increased salinity. These problems have been recognised and hence "one of the main components of the agricultural development strategy is to achieve a gradual improvement of the efficiency of irrigation systems to reach 80 per cent in an area of 8 m feddans, and to reduce the areas planted to rice from 1.673 m feddan (2007) to 1.3 m feddan by 2030 in order to save an estimated 12 400 million cubic meters of water" (FAO 2013, p. 13).

Other non-conventional water resources are recycled drainage water and treated sewage water. Annual drainage water use in agriculture is estimated to be 3.7 BCM, with the potential to reach 5 BCM. Drainage water is evenly mixed with Nile water and used to irrigate 450, 000 feddans in North Sinai. Treated sewage water used in irrigation amounts to 1.5 BCM/year, with estimates that it will account for 2.4 BCM/year by 2027.

[5] Feddan is a non-metric measurement unit of land area used in Egypt, inter alia. A feddan is equivalent to 1.037 acres, 0.420 hectares or 4,220 m^2.

2.2 Previous Studies of Water and Irrigation in Egypt

Water scarcity in Egypt and the associated socio-economic and political factors, e.g. population, food demand, economic growth, climate change and debates over the allocation of the Nile's waters, have been discussed widely in the literature (Gohar & Ward, 2010).

CGE models have been used to examine the economic implications of water availability, e.g. as part of climate change impact analysis (Strzepek *et al.* 1995; Yates & Strzepek, 1996 and Yates & Strzepek, 1998), while some studies consider variability in water supply and the economic value of reducing variability. Strzepek & Yates (2000) use a recursive dynamic CGE model to examine impacts of changes in the Nile River on the Egyptian economy to the year 2060, while Strzepek *et al.* (2008) use a comparative static CGE model to evaluate the economy-wide impacts of the High Aswan Dam on the Egyptian economy.[6] The study specifies water as a nested Constant Elasticity of Substitution (CES) production function through a fixed land-water technology. Also, it explicitly specifies a risk premium. The results show a negative impact of the dam on summer crops.

Another strand of the literature explores different approaches for maximizing irrigation water efficiency in Egypt. Gohar & Ward (2011) examine the economic efficiency impacts of different irrigation water allocation policies in Egypt. They show that flexible irrigation patterns across locations, seasons and crops could improve the irrigation water efficiency. Bader (2004), applying a mathematical programming approach, claims that there is scope for improving farms' returns through the optimisation of irrigation water use and improved irrigation efficiency, which generate increases in farm income and crop production.

The effect of fiscal reforms, in the form of removing subsidies and taxes, were examined subject to physical supply constraints for both water and land (Robinson & Gehlhar, 1995a). The first order conditions for water and land constraints are given by linear cost functions with an explicit maximand, which ensured that at least one of the two constraints is binding. The same model was used to investigate the impacts of establishing a market for water and water pricing policies for the agricultural sector in Egypt (Robinson & Gehlhar, 1995b). More recently, He *et al.* (2004) have examined the impact of water pricing

[6] For a detailed description of the economic, social and environmental impacts of the High Aswan Dam, see Abu-Zeid & El-Shibini (1997).

and taxation policies on water efficiency in Egypt. The study employs a static partial equilibrium Agricultural Sector Model of Egypt (ASME).

3. Data and Model

3.1 An Extended SAM for Egypt 2008/09

A SAM provides a consistent framework, within which all expenditures and incomes for the agents in the economy are recorded. A SAM is a square matrix where each agent is represented by a column (expenditure) and a row (income) that record, respectively, each agent's expenditures and incomes. The SAM used for this study is an extension of a SAM for Egypt in 2008/09 (Osman *et al*. 2015a). The latter includes disaggregated agricultural activities and factors across different irrigation seasons, with Nile irrigation water represented as a separate production factor.[7]

The extended version of the SAM is based on national accounts and supply/use tables with 102 accounts: 54 activities, 16 commodities, 19 factors, 5 institutions, and 4 tax instruments, as well as trade margins, savings/investment, rest of the world and total accounts. The accounts are listed in Table 2.[8] This extended SAM makes three contributions: distinguishing agricultural activities and factors by irrigation season, introducing groundwater irrigation schemes and representing rain-fed agricultural activities.

Water and irrigated land are segmented by irrigation season, i.e. winter, summer, and Nili, as well as year-round, and by type of water. During the SAM construction process, detailed data on physical Nile water and land usage, differentiated by crop and season, were compiled from the Annual Bulletin of Irrigation and Water Resources Statistics, 2008 (CAPMAS, 2009). These data were used to estimate values for Nile water, which were then deducted from rental prices for irrigated land.

7 A stochastic variant of the cross-entropy (CE) method was used to estimate the SAM; this variant was developed by Robinson & McDonald (2006). For descriptions of the CE method, see Robinson *et al*. (1998), Robinson & El-Said (2000) and Robinson *et al*. (2001).

8 The production factor accounts numbered 81-89 in Table 2 are those added to the SAM reported in Osman *et al.* (2015a).

Table 2: Extended SAM Accounts, Egypt 2008/09

No	SAM Activity	No	SAM Activity	No	SAM Activity
1	Winter Wheat & Cereals	19	Nili Oily Crops	37	Education
2	Winter Legumes	20	Nili Medical Plants	38	Social Services
3	Winter Sugar Beet	21	Nili Vegetables	39	Arts Entertainment
4	Winter Fodders	22	Fruits	40	Other Services
5	Winter Fibres	23	Other Agriculture, Forestry, Fishing	41	Financial Services
6	Winter Medical Plants	24	Mining	42	Insurance
7	Winter Vegetables	25	Manufacturing	43	Public Services
8	Summer Rice	26	Electricity gas	44	Defence
9	Summer Other Crops	27	Water Supply	45	Public Safety
10	Summer Sugar Cane	28	Construction	46	Economic Affairs
11	Summer Cotton	29	Trade	47	Environmental Protection
12	Summer Fodders	30	Suez Canal	48	Housing and Community Amenities
13	Summer Oily Crops	31	Transportation	49	Health
14	Summer Medical Plants	32	Accommodation Services	50	Recreation, Culture and Religion
15	Summer Vegetables	33	Information Communication	51	Education
16	Nili Rice	34	Real Estate	52	Social Protection
17	Nili Other Crops	35	Professional Services	53	Non-profit Activities Serve Households
18	Nili Fodders	36	Administrative Services	54	Subsistence Household Activities
No	**SAM Commodity**	**No**	**SAM Commodity**	**No**	**SAM Production Factor**
55	Wheat	63	Food Products	71	Labour
56	Cereals	64	Other Transportable Goods	72	Capital
57	Rice	65	Metal & Machinery Equipment	73	Winter Nile-dependent Land
58	Vegetables	66	Construction	74	Summer Nile-dependent Land
59	Fruits	67	Trade	75	Nili Nile-dependent Land
60	Beverages	68	Financial Services	76	Year-round Nile-dependent Land
61	Other Agriculture, Forestry, Fishery	69	Business Services	77	Winter Nile Water
62	Ores, Minerals & Gas	70	Social Services	78	Summer Nile Water
No	**SAM Production Factor**	**No**	**SAM Production Factor**	**No**	**SAM Production Factor**
79	Nili Nile Water	83	Nili Groundwater-dependent Land	87	Nili Groundwater
80	Year-round Nile Water	84	Year-round Groundwater-dependent Land	88	Year-round Groundwater
81	Winter Groundwater-dependent Land	85	Winter Groundwater	89	Rain-fed Land
82	Summer Groundwater-dependent Land	86	Summer Groundwater	**No**	**SAM Institutions**
No	**SAM Institutions**	**No**	**SAM Institutions**	98	Tariffs
90	Non-financial Enterprises	94	Government	99	Savings-Investment
91	Financial Enterprises	95	Sales Tax	100	Trade Margins
92	Non-profit Institutions Serve Households	96	Indirect Tax	101	Rest of the World
93	Households	97	Direct Tax	102	Total

Source: Osman *et al*. (2015b).

Groundwater is introduced as another type of irrigation water, using data on groundwater and land irrigated by groundwater. Subsequently, Nile- and groundwater-dependent agricultural activities are distinguished. Due to lack of data on groundwater production costs, factor payments per unit of land area are assumed to be common across crops irrigated by Nile water and groundwater. For example, intermediate inputs and factor payments required to cultivate a feddan of Nile-dependent vegetables in the summer are the same for a feddan of groundwater-dependent vegetables in the summer. Using water and land requirements, production costs for groundwater-dependent crops are then estimated.

Rain-fed land is distinct from irrigated land and used to produce seasonal crops. Therefore, gross operating surplus is segmented between factor to capital used for crops produced on rain-fed land and payments to rain-fed land.

For consistency, groundwater-dependent activities and rain-fed activities follow the same seasonal classification as Nile-dependent activities. As such, activity accounts for crops irrigated by groundwater and for rain-fed crops are synchronised and segmented by irrigation season, i.e. winter, summer, and Nili, as well as year-round.

3.2 Main Economic Features

Agriculture in Egypt accounts for more than 10% of GDP, 8% of total labour payments and 13% of exports. The economy has a strong industrial base which makes up 40% of GDP, of which 30% is sourced from manufacturing activities. Services are the main activity, contributing almost half of GDP. Public services account for more than 7% of GDP with public employment providing a substantial share of the total (36%).

Vegetable production contributes 23% of agricultural output evenly spread over the winter and summer seasons and uses some 6% of Nile water in each of the irrigation seasons. The ‘Wheat & Cereals’ sector represents 13% of agricultural production, and is one of the main users of Nile land (almost 30%), and uses a tenth of Nile water. Fodder crop growing represents another 13% of agricultural production and is an intensive user of Nile water (more than 17%).

Rice accounts for more than 6% of agricultural output, with a substantial share of rice production exported; contributing more than 10% of total agricultural exports. Rice is water-intensive: it uses more than 30% of irrigation Nile water and more than half of the summer’s

Nile water. It is cultivated mainly in the summer season with only 0.4% of output grown in the Nili season.

Factor intensities by activity reflect the prevailing technology while factor allocations represent factor usage across activities, see Table A1 and Table A2. These two indicators are essential for understanding potential changes in factor rents and the consequent changes in factor allocations after a policy shock. Vegetables have the lowest Nile water intensity ratios (ranging 1-3% for seasonal vegetables) see Table A1; the contrast with summer rice (21% Nile water) and summer sugar cane (13% Nile water) is marked. As such, the vegetables sectors employ small shares of Nile water (6.3%) and Nile-dependent land (21%), see Table A2.

Nile water/land accounts for 15% of total agricultural value added and 90% of that for irrigated agriculture. Groundwater and land irrigated by groundwater have small shares in agricultural value added (less than 2%) and in irrigated agriculture (8%).

The water supply activity (SAM activity account number 27) mainly provides water for non-agricultural uses. This water supply service is presented in the SAM as part (2%) of the utilities distribution services (SAM commodity account number 67).

3.3 CGE Model

The model is a comparative static variant developed of the single-country CGE STatic Applied General Equilibrium (STAGE 2) model,[9] to encompass the characteristics of the Egyptian agricultural and irrigation systems. Specifically, the production system has been extended to include derived demand for Nile water and land, as well as other sources of irrigation water. An important feature of the model is the modelling of agriculture; activities are defined by their distinctive characteristics whose output mixes are responsive to changes in the prices of outputs.

Production Specification

Production relationships for agricultural activities are specified through five levels of nested CES functions (Figure 1). At the top level, value added and intermediate demand are combined using a CES aggregator. At the second level, CES production technology specifies

[9] The STAGE 2 model is described in detail in McDonald (2007) and McDonald & Thierfelder (2015). The model is a descendant of the USDA ERS model (Robinson *et al.* 1990). Luckmann & McDonald (2014) provide a detailed technical documentation for the STAGE_W CGE model.

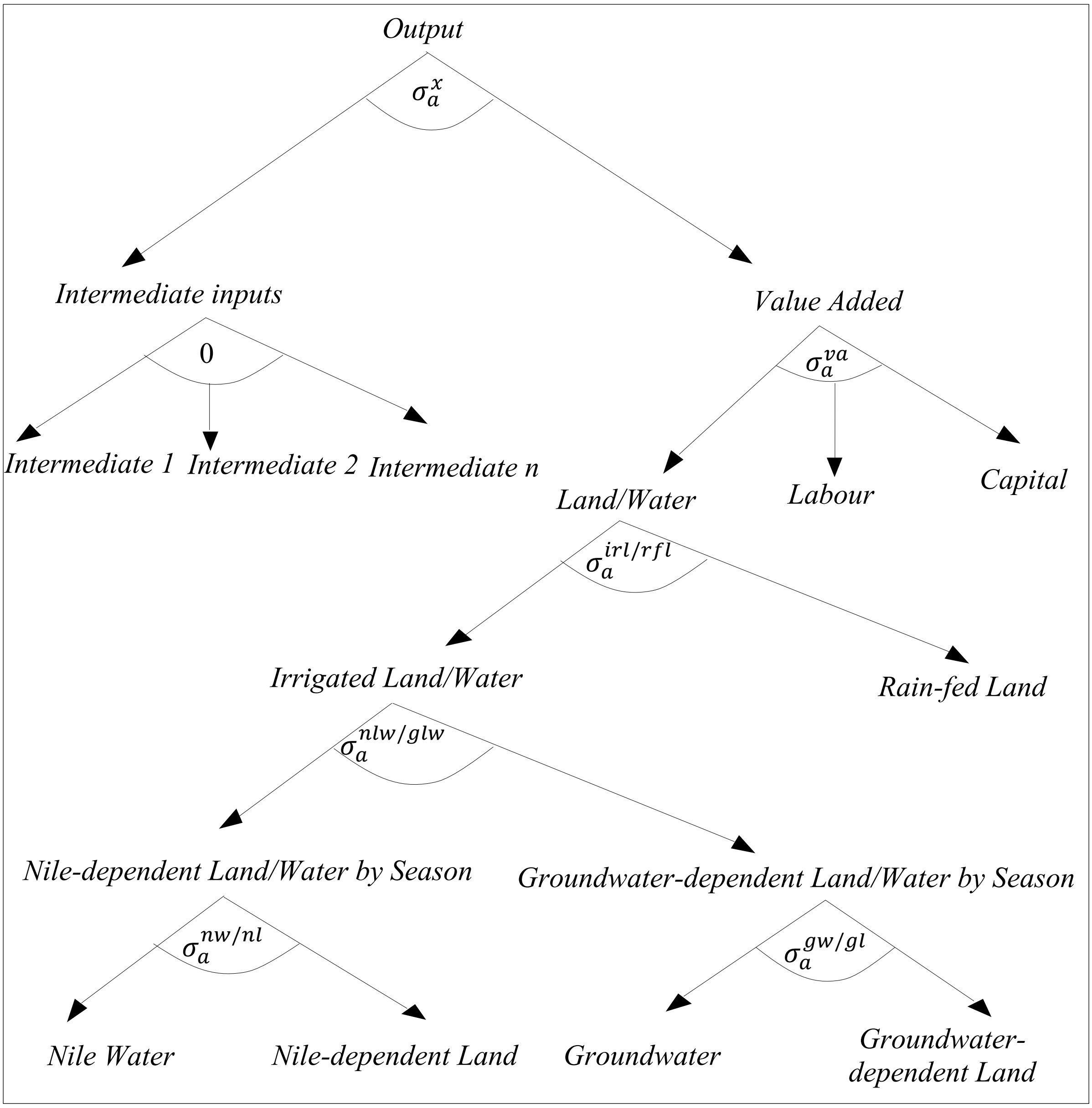
the aggregate value added for each activity as a function of primary inputs: capital, labour and a composite of land and water. The land/water composite is an aggregate formed by the third, fourth and fifth level functions.

At the bottom, fifth, level, natural water and land factors are combined in two CES aggregators – one each for Nile-dependent and for groundwater-dependent activities. For agricultural activities producing the same crop, water and land productivities vary according to their irrigation systems. For each irrigation season, both types of water and land are mobile across crops subject to changes in the ratios of rents. These two CES aggregators (Nile land/water and groundwater land/water) are (CES) aggregated at the fourth level to form the irrigated land/water composite. The latter is (CES) aggregated with rain-fed land at the third level to form the land/water composite.

The study uses estimates for elasticity values from the literature. The elasticity of substitution between intermediate demand and value added (σ_a^x) is set to be 2 while the elasticity of substitution between production factors (σ_a^{va}) is equal to 0.8 for all sectors. These elasticity values, given the lack of precise estimation of parameters for Egypt, in general, and with the disaggregation required by the SAM employed in this study particularly, are considered as cautious guesstimates for this case study. Calzadilla *et al*. (2011) estimated the elasticity of substitution between irrigation water and irrigated land for 15 world regions. This is based on the price elasticity of water use derived from Rosegrant *et al*. (2002). Thus, the applied elasticities of substitution between water and land ($\sigma_a^{irl/rfl}$, $\sigma_a^{nlw/glw}$, $\sigma_a^{nw/nl}$ and $\sigma_a^{gw/gl}$) have a value of 0.06. Systematic sensitivity analyses are used to evaluate the sensitivity of the results to the assumed elasticities.

Each agricultural activity has a distinct cost structure and it has been demonstrated (Devarajan *et al*. 1990) that substitution possibilities depend on elasticities and share parameters. The latter are determined by cost structures. Table A3 presents the values of share parameters for different types of water and land at the third, fourth and fifth levels of the production nest.

Figure 1: Agricultural Production Flows in the Model



Three points are worth highlighting. First, the model allows for the use of CES substitutions between zero (Leontief fixed coefficient technology) and infinity (though one is excluded). Second, the model specifies physical supply constraints for water and land where the quantity data are available. Quantities of land (by thousand feddans) and water are used as upper limits for the supply of land and water. And third, the model assumes no distribution costs for irrigation water.

4. Simulations

4.1 Scenarios

Four main scenarios are reported, see Table 3. The first scenario (N-Wtr Loss) represents the upper limit of the potential reduction in Egypt's share of Nile water due to filling of the GERD reservoir. A 34% reduction in Nile water supply is evenly spread across irrigation seasons, under the implicit assumption that Lake Nasser will be used to manage water availability.

Table 3: Simulation Scenarios

Scenario Code	Scenario Description
Water Scarcity	
1. N-Wtr Loss	34% reduction in Nile water supply over the whole year
Irrigation Efficiency or Water Compensation?	
2. Irrg-Eff	30% increase in irrigation efficiency
Nile Irrg-Eff	30% increase in Nile-dependent irrigation efficiency
Ground Irrg-Eff	30% increase in groundwater-dependent irrigation efficiency
3. X-Wtr Gain	95% increase in non-conventional irrigation water resources
Irrigation Efficiency under Water Scarcity	
4. N-Wtr Loss & Irrg-Eff	30% increase in irrigation efficiency & 34% reduction in Nile water supply

Scenarios two and three simulate alternative policies that Egypt can follow. They address the important question of whether Egypt should work on improving the efficiency of existing water resources or on securing more water from non-conventional sources. Hence, the second scenario (Irrg-Eff) considers improvements in irrigation efficiency specified as external shocks that increase the flow of services from a given quantity of water. At the fourth level of the production nest, Nile land/water and groundwater land/water productivities are assumed to increase by 30%.[10] To clarify the interpretation of the determinants of the result, this scenario is decomposed into two components according to the source of the simulated irrigation efficiency: Nile-dependent irrigation (Nile Irrg-Eff) and groundwater-dependent irrigation (Ground Irrg-Eff). The scenario does not specify the source of funding for the simulated improvements in irrigation efficiency, e.g. government expenditures on research and development are not explicitly specified.

[10] This improvement in irrigation efficiency is based on a pre-simulation scenario, specified to endogenously quantify changes in efficiency required to offset the water losses keeping agricultural output unchanged. The results imply that a 30% improvement in irrigation efficiency is virtually sufficient to offset the agricultural output reductions from potential Nile water losses.

The third scenario (X-Wtr Gain) assumes, *ceteris paribus*, more non-conventional water resources are secured to compensate for the simulated reductions in Nile water. It represents the case in which Nile water reductions are compensated for by increases in recycled drainage water and treated sewage water; the estimated potential (average) increase in these water resources is 95%.[11] Due to lack of data, an increase in groundwater is simulated as a proxy for potential increases in all other non-conventional water resources. Groundwater used in irrigation is roughly equivalent to both recycled drainage and treated sewage water combined (Table 1). This scenario simulates a 95% increase in groundwater supply across different irrigation seasons.[12]

The fourth, and main, scenario (N-Wtr Loss & Irrg-Eff) combines the simulated 34% reduction in Nile water with the 30% improvement in irrigation efficiency. This comprehensive scenario provides quantitative assessments for the impact of quality enhancements of different types of irrigation water under water scarcity conditions.

4.2 Model Closure Rules

Egypt is a small country in the world market; thus world prices for exports and imports are fixed. The current account balance is fixed at its initial level (in foreign currency units), and the exchange rate adjusts to clear the external balance. This is a typical choice for developing economies where foreign credit is limited and fixing the external balance reflects economic reality.

The model adopts an investment-driven closure in that saving rates adjust to generate the required funds to finance the base year investment. The combination of exogenous investments and foreign savings, known as Johansen closure, avoids the misleading change in household welfare due to change in foreign savings and investments in a single-period model (Lofgren *et al*., 2002).

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11 This is weighted according to their current shares of irrigation water.

12 Note that any costs associated with this change are not included within the model. Luckmann *et al.*, (2014) explores implications of water as a produced commodity, while Luckmann *et al*., (2016) explores the limits on water recycling.

Capital is mobile and fully employed (medium-run closure rule), while labour is mobile, albeit with underemployment. Underemployment in labour markets is the most reasonable assumption in a country where the unemployment rate is constantly above 10%. Water and land, for both Nile-dependent and groundwater-dependent activities, are fully employed, but season-specific. For the purposes of this study, water and land supply are fixed for each irrigation season. Thus, water and land are mobile across agricultural activities within each irrigation season but not across different seasons. This specification implies that water and land will have distinct seasonal prices. The model solves for water and land seasonal prices that ensure efficient allocation of water and land across crops cultivated in the same season.

5. Simulation Results

5.1 Macroeconomic Impacts

Reductions in the availability of Nile water (the N-Wtr Loss scenario) produce minor negative macroeconomic impacts (Table 4). These are offset by increases in the irrigation efficiency scenario, which generate around 0.5% increases in GDP and absorption, while potential increases in non-traditional water resources induce trivial positive macroeconomic impacts.[13]

The positive impacts under the Irrg-Eff scenario imply that the 30% improvements in irrigation efficiency are sufficient to offset the macroeconomic loss due to the 34% reduction in Nile water supply. This is confirmed by the results of the combined water reduction and irrigation (N-Wtr Loss & Irrg-Eff) scenario. The results are primarily driven by the enhancement in Nile-dependent irrigation efficiency. Consequently, the results suggest that the macroeconomic implications of reductions in the availability of Nile water are less than may be feared and that the inevitable, but small, negative consequences can be more than offset by enhancements to irrigation efficiency.

[13] An alternative scenario, where irrigation efficiency is improved by only 15%, exactly compensates for the negative macroeconomic impacts generated by the reduction in Nile water availability, with no changes in GDP and absorption.

Table 4: Macroeconomic Indicators (Real percentage change)

	N-Wtr Loss	Irrigation Efficiecny			X-Wtr Gain	N-Wtr Loss & Irrg-Eff
		Nile Irrg-Eff	Ground Irrg-Eff	Irrg-Eff		
Private Consumption	-0.30	0.53	0.03	0.55	0.02	0.26
Government Consumption	0.03	-0.06	0.00	-0.06	0.00	-0.03
Investment Spending	-0.13	0.22	0.01	0.23	0.02	0.10
Absorption	-0.23	0.41	0.02	0.43	0.02	0.20
Import Demand	-0.16	0.11	0.00	0.10	0.04	-0.07
Export Supply	-0.25	0.23	0.00	0.24	0.06	-0.03
GDP (Expenditure Side)	-0.26	0.45	0.02	0.47	0.02	0.22
Total Domestic Production	-0.32	0.56	0.03	0.59	0.02	0.27
Total Intermediate Inputs	-0.42	0.72	0.04	0.75	0.02	0.34

However, the extent to which these macroeconomic consequences are likely to be realised and the impacts on agricultural activities and farmers need to be assessed.

5.2 Sector-specific Impacts

At the sectoral level, changes in Nile water availability and irrigation efficiency generate substantial structural changes in agricultural production, see Figure 2. Generally, reductions in water availability cause decreases in the total agricultural output.[14] The pronounced declines in production volumes are more than offset by enhanced irrigation efficiency[15] but even so the extent of structural change is substantial, which implies that the adjustment to a new regime may take some time. Overall, however, it is noticeable that patterns of structural change mirror the patterns of water intensity in production.

Reductions in Nile water availability have noticeable adverse impacts on summer agricultural production (Figure 2). This is particularly the case for rice, ‘other crops’ and sugar cane. Other sectors (winter and summer vegetables) expand under the N-Wtr Loss scenario. It is worth noting that, under the N-Wtr Loss scenario, sectors with the highest expansions have negligible baseline shares in the overall agricultural structure, e.g. Nili rice (with a share of 0.01%) expands by 32% and Nili fodders (with a share of 0.15%) expands by 7%. Improving Nile-dependent irrigation efficiency generates positive effects for sectors like

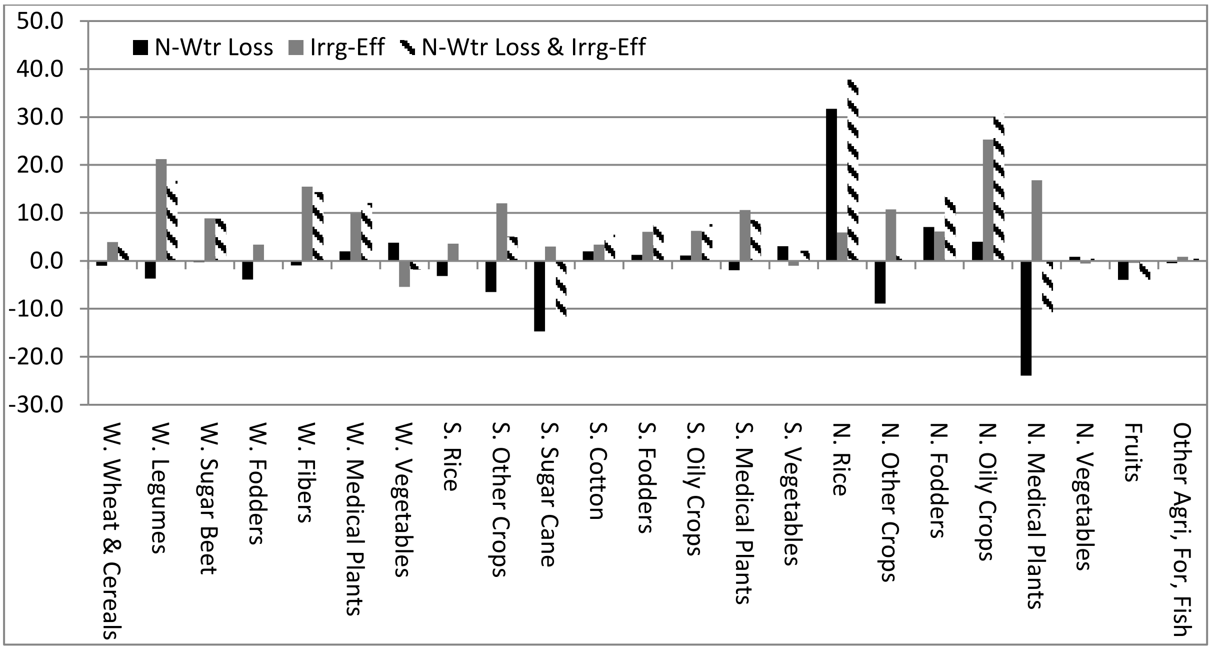
[14] The Laspeyres Volume Index of agricultural output (measured as an arithmetic average of quantities weighted by the baseline values) declines by 1.3%.

[15] The Laspeyres Volume Index of agricultural output increases by 2.3%.

winter legumes and summer ‘other crops’, whereas all the seasonal vegetable sectors shrink. The simulated increases in non-conventional water resources boost the fruits sector, which reflects the limitation on the use of non-conventional water resources.

Water loss has negative effects on exports of agricultural commodities while increasing irrigation efficiency generates positive outcomes. Under the N-Wtr Loss & Irrg-Eff scenario, the results are mixed as the combined effects of water loss and increased efficiency promote reallocation of factors and, consequently, new structures for domestic production and exports.

Figure 2: Domestic Agricultural Production (Percentage change)



Note: Here and thereafter, W. refers to winter, S. summer and N. Nili.

The N-Wtr Loss scenario has a strong negative impact (- 20%) on rice exports. Under the comprehensive N-Wtr Loss & Irrg-Eff scenario, rice exports drop by only 4%. Improving Nile-dependent irrigation efficiency boosts rice output (by 4% in the summer season and 6% in the Nili season) without increasing irrigation water requirements. Furthermore, combining irrigation efficiency with Nile water loss mitigates the negative impacts on rice exports (Table 5). Doubling all other non-conventional water resources has a negligible impact on summer rice. As mentioned, rice is one of the main agricultural activities and exports, which explains the emphasis being placed on enhancing irrigation efficiency in rice production.

The production of winter and summer vegetables increase under the N-Wtr Loss scenario. Reductions in water availability induce the agricultural structure to shift production to less water-intensive crops, with land and Nile waters moving into the winter and summer vegetable sectors, leading to expansions of 3-4%.[16] This reflects the assumption that water availability across seasons will not change with the reduction in the total availability of Nile waters. This assumption also explains why summer and Nili vegetable outputs increase but winter vegetable outputs decline under the comprehensive N-Wtr Loss & Irrg-Eff scenario. It is the relative water intensity of crops within seasons that matters rather than their absolute water intensity.[17]

Table 5: Commodity Exports (Percentage change)

	N-Wtr Loss	Irrigation Efficiency			X-Wtr Gain	N-Wtr Loss & Irrg-Eff
		Nile Irrg-Eff	Ground Irrg-Eff	Irrg-Eff		
Wheat	-3.95	16.87	1.22	18.16	0.19	13.70
Cereals	-7.18	44.42	1.74	46.82	0.00	36.19
Rice	-19.46	19.78	0.35	20.16	-0.05	-3.58
Vegetables	-3.42	8.81	0.39	9.20	0.01	5.46
Fruits	-6.57	-1.09	-0.06	-1.14	7.99	-7.62
Beverages	-6.26	10.12	0.60	10.71	0.03	4.03
Ores, Minerals & Gas	0.56	-0.82	-0.05	-0.86	-0.16	-0.30
Food Products	-0.20	0.46	0.02	0.47	-0.11	0.32
Other Transportable Goods	-0.31	0.60	0.03	0.62	-0.06	0.35
Metal & Machinery Equipment	-0.41	0.75	0.04	0.78	-0.04	0.42
Construction	0.19	-0.29	-0.02	-0.31	-0.05	-0.11
Trade	0.33	-0.49	-0.03	-0.52	-0.11	-0.18
Financial Services	0.25	-0.36	-0.02	-0.38	-0.08	-0.11
Business Services	0.33	-0.48	-0.03	-0.51	-0.10	-0.17
Social Services	0.44	-0.72	-0.04	-0.75	-0.09	-0.31

Clearly, interpreting these findings requires more detailed analyses of production technologies prevailing in the base year as well as changes in factor prices and rents under the scenarios. The next subsection addresses these effects.

5.3 Water and Irrigated Land Prices

Under the Nile Irrg-Eff scenario, Nile water and Nile-dependent land rents drop as they become more efficient.[18] The expanding activities (winter legumes, summer rice, summer

16 For more detailed sectoral results, see Table A4.

17 Nile water intensities for summer and Nili vegetables are virtually double and triple the Nile water intensity for winter vegetables, Table A1.

18 Increasing factor productivity implies higher effective factor endowment, which consequently affects factor demand and price. Within this framework, changes in the productivity of specific factors/sectors

‘other crops’ and cotton) absorb the mobile factors (labour, capital, year-round Nile water and year-round Nile-dependent land) leaving other activities and causing their prices and incomes to rise (Table 6).[19]

Table 6: Factor Income (Percentage change)

	N-Wtr Loss	Irrigation Efficiency			X-Wtr Gain	N-Wtr Loss & Irrg-Eff
		Nile Irrg-Eff	Ground Irrg-Eff	Irrg-Eff		
Labour	-0.42	0.78	0.04	0.81	0.03	0.41
Capital	-0.40	0.72	0.04	0.75	0.03	0.37
Rain-fed Land	7.60	-12.18	-0.68	-12.74	-0.16	-6.15
	Nile-dependent Factors					
Winter Land	-1.35	-2.52	-0.77	-3.23	-0.19	-4.51
Summer Land	-2.12	-0.65	-0.45	-1.07	-0.11	-3.21
Nili Land	-4.13	-0.73	-0.51	-1.22	-0.10	-5.39
Year-round Land	-3.78	0.13	0.01	0.14	4.25	-3.57
Winter Water	9.91	-2.27	-0.67	-2.88	-0.17	6.89
Summer Water	6.12	-2.31	-0.30	-2.57	-0.05	3.27
Nili Water	4.25	1.40	-0.28	1.12	-0.06	5.49
Year-round Water	6.75	0.13	0.01	0.14	4.25	6.99
	Groundwater-dependent Factors					
Winter Land	4.17	-10.95	8.27	-3.55	3.89	0.54
Summer Land	4.76	-8.98	8.58	-1.14	4.73	3.55
Nili Land	5.27	-8.85	8.74	-0.89	2.39	4.21
Year-round Land	-3.78	0.13	0.01	0.14	4.25	-3.57
Winter Water	4.20	-11.57	8.22	-4.26	-16.65	-0.17
Summer Water	3.60	-8.33	8.51	-0.49	-15.10	3.14
Nili Water	1.79	-7.61	8.63	0.40	-17.34	2.45
Year-round Water	-3.78	0.13	0.01	0.14	-11.78	-3.57

The increases in factor prices under the Nile-Irrg Eff scenario entail higher production costs for sectors that are relatively more dependent on water. As such, the seasonal vegetables sectors experience increasing production costs, which explain the reported shrinkage.

6. Systematic Sensitivity Analysis

To analyse the robustness of the results from the model, the elasticity of substitution between water and land is analysed through a systematic sensitivity analysis (SSA) using a standard

affect demand and price for other factors/sectors through different transmission channels. The higher the factor productivity, the lower is its effective price.

19 In a general equilibrium framework, the causal relationship between factor demand and factor rents works in two directions. Excess demand for a factor raises its price to clear the market. Simultaneously, producers substitute this more expensive factor for other factors according the elasticities of substitution in CES production functions.

Monte Carlo approach.[20] It is assumed that the elasticity of substitution between water and land for each agricultural activity follows an independent identically distributed (i.i.d.) normal distribution, N (μ, σ^2), where the mean is the employed elasticity value, i.e. 0.06, and the variance is one third of the mean.[21] This SSA simulates 5,000 Monte Carlo independent draws for the Irrg-Eff scenario, under which a 30% increase in irrigation efficiency is simulated for both Nile-dependent and groundwater-dependent irrigation schemes. For each draw, a new elasticity parameter is selected for each commodity not related to the draw for other commodities. Once the new elasticity is selected, it remains constant along the lower three levels of the production tree.

Table 7 reports the minimum and maximum values, as well as the percentage change between them, the mean and the standard deviation for sectoral agricultural production (valued at the base year prices).

Table 7: Agricultural Production, Systematic Sensitivity Analysis

	Minimum (Billion LE)	Maximum (Billion LE)	%	Mean (Billion LE)	SD
W. Wheat & Cereals	26.36	26.45	0.36	26.41	0.012
W. Legumes	1.12	1.16	3.83	1.13	0.004
W. Sugar Beet	3.13	3.27	4.33	3.19	0.016
W. Fodders	23.92	24.18	1.07	24.03	0.03
W. Fibres	0.15	0.16	3.3	0.15	0.001
W. Medical Plants	0.42	0.43	2.88	0.43	0.001
W. Vegetables	18.24	18.62	2.07	18.37	0.045
S. Rice	12.3	12.37	0.6	12.34	0.009
S. Other Crops	15.09	15.46	2.42	15.33	0.042
S. Sugar Cane	5.32	5.46	2.79	5.38	0.016
S. Cotton	4.39	4.5	2.56	4.45	0.013
S. Fodders	3.49	3.59	2.77	3.55	0.011
S. Oily Crops	2.25	2.31	2.66	2.28	0.006
S. Medical Plants	0.16	0.17	3.7	0.17	0.001
S. Vegetables	19.87	20.07	0.99	19.99	0.02
N. Rice	0.05	0.06	6.43	0.05	0
N. Other Crops	2.34	2.43	3.79	2.4	0.01
N. Fodders	0.41	0.43	4.24	0.42	0.002
N. Oily Crops	0.01	0.01	9.53	0.01	0
N. Medical Plants	0	0	5.83	0	0
N. Vegetables	2.95	3.01	2.08	2.98	0.008
Fruits	10.85	10.85	0.02	10.85	0
Other Agriculture, Forestry, Fishing	39.73	39.74	0.03	39.74	0.001

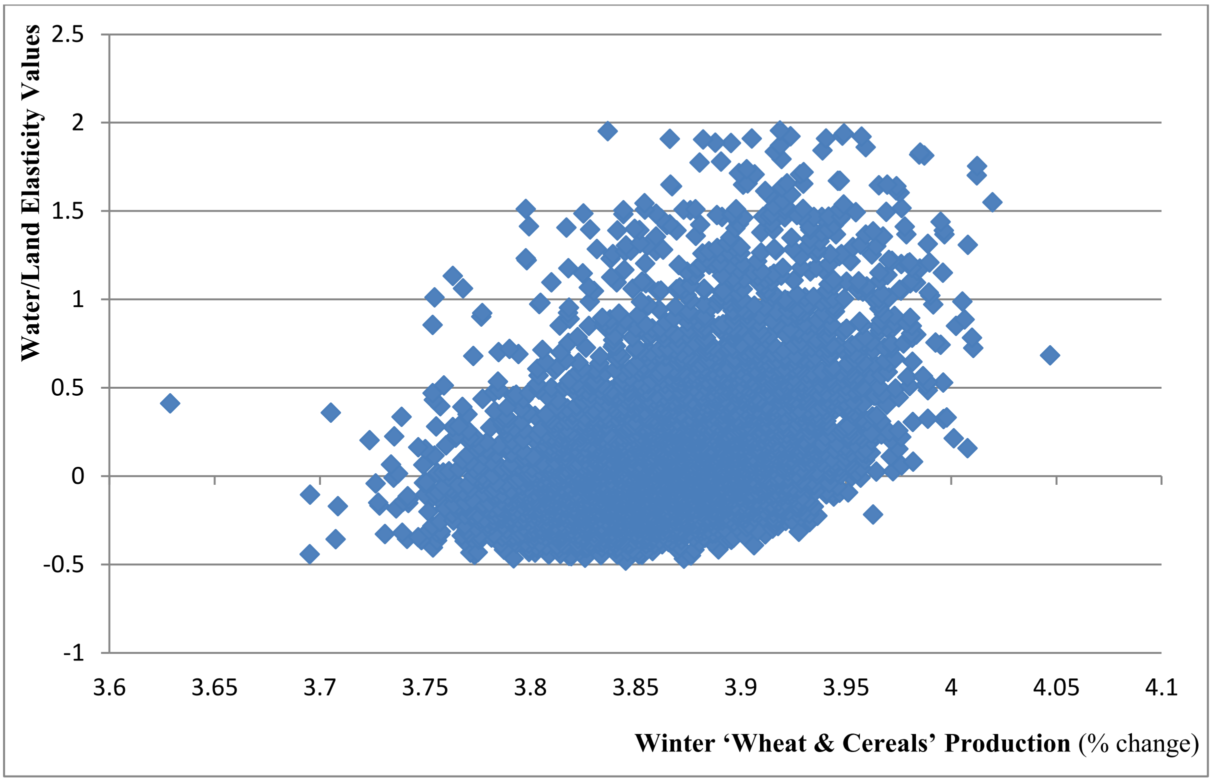
Note: LE is the abbreviation of the French caption of the Egyptian pounds - *livre égyptienne.* In 2008/09, an Egyptian pound was equivalent to 0.18 USD (The World Bank, 2010).

[20] For an explanation of the Monte Carlo approach, see Belgodere & Vellutini (2011).

[21] The distribution is truncated on the left side to keep a well-behaved functional form of the CES production function (the elasticity values enter the CES function as a power in the equivalent terms), see Equation 1, Appendix.

The analysis shows the robustness of the model in relation to the elasticity of substitution between water and land. The SSA explicitly shows that the results of the model are clearly determined by the shocks selected and by the initial share parameters (see Table A3) more than the level of elasticities selected. Figure 3 shows the upward sloped relationship between percentage change of output and elasticity values. The Monte Carlo SSA confirms the robustness of the results to variations in values of the elasticity of substitution between water and land.

Figure 3: Systematic Sensitivity Analysis Scatter



7. Conclusions and Discussion

The results suggest that Egypt should be able to manage the potential reductions in the supply of Nile water with more efficient irrigation practices. If Egypt can achieve a 30% increase in the productivity of irrigation water, there will be (aggregate) positive benefits for the economy. The results imply that the negative impacts of reductions in the availability of Nile waters in Egypt may be less severe than feared.

However, the results indicate that the agricultural sectors will be required to undertake substantial structural changes and that the extent of the required structural changes will only be partially offset by improvements in the efficiency of irrigation systems. Given the extent of implied structural changes and the degree of the required efficiency changes, it is likely that the adjustment period will not be short. Moreover, the potential distributional implications may be more pronounced than expected.[22]

Furthermore, the results show that even doubling all non-conventional water resources is not sufficient to compensate the potential adverse impacts of Nile water reductions. This highlights the importance of enhancing irrigation efficiency. Since it is inevitable that the availability of Nile waters in Egypt will decline, the sooner changes in irrigation methods begin to be implemented, the better.

There are a number of research avenues that can be explored to enhance the analyses in this study. The scenarios do not explore the extent to which the Egyptian government can use the capacities of the Nile dams' reservoirs to adjust the seasonality of Nile water availability so as to influence structural changes in cropping decisions across seasons. In the longer term, the Egyptian government's ability to take such action will be limited to its control over the Aswan dams, so the option of collaboration with Ethiopia and Sudan during the period when the GERD's lake is filling may be fruitful. Similarly, the analysis does not take account of the extent to which the cost effectiveness of improvements in irrigation efficiencies may differ across crops[23] and hence the potential benefits of targeting. This analysis also presumes that there will be no changes in the Egyptian government's policy on food subsidies, which are a source of budgetary concern. Thus it may be pertinent to explore the extent to which changes in food subsidies influence the operation of domestic markets towards or away from water-intensive domestically produced agricultural commodities. Moreover, since the extent of structural changes suggests that distributional issues may be important, the analysis would be enhanced by disaggregation of the household and labour accounts.

[22] The distributional impacts cannot be quantified in this study due to the SAM limitations.

[23] It is implicitly assumed that the extent to which different crops can respond to changes in irrigation technology is equiproportionate.

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Table A1: Factor Intensity by Agricultural Activity (Percent)

	Labour	Capital	Nile-dependent Land	Nile Water	Groundwater-dependent Land	Groundwater	Rain-fed Land	Total
W. Wheat & Cereals	13.8	56.4	20.0	3.4	1.8	0.2	4.5	100
W. Legumes	22.2	29.8	34.6	4.6	1.3	0.0	7.5	100
W. Sugar Beet	12.3	64.2	16.9	2.8	0.0	0.0	3.8	100
W. Fodders	2.5	83.7	6.0	5.1	0.4	0.0	2.2	100
W. Fibres	14.4	59.0	18.4	3.8	0.1	0.0	4.3	100
W. Medical Plants	10.2	68.7	15.3	2.2	0.2	0.0	3.4	100
W. Vegetables	7.7	84.1	5.8	0.8	0.4	0.1	1.3	100
S. Rice	13.8	54.1	6.1	20.6	0.1	0.0	5.2	100
S. Other Crops	23.1	47.0	17.0	7.4	0.6	0.1	4.7	100
S. Sugar Cane	11.4	70.1	2.3	13.1	0.1	0.0	3.1	100
S. Cotton	24.7	59.0	10.9	2.7	0.0	0.0	2.6	100
S. Fodders	4.8	77.8	9.7	2.7	2.2	0.4	2.4	100
S. Oily Crops	15.1	62.5	15.6	2.4	1.0	0.0	3.4	100
S. Medical Plants	12.1	64.6	14.6	5.0	0.0	0.0	3.8	100
S. Vegetables	11.4	74.3	10.4	1.3	0.4	0.1	2.2	100
N. Rice	11.4	54.3	13.4	0.5	17.6	0.2	2.7	100
N. Other Crops	23.0	47.2	12.9	9.9	2.3	0.2	4.4	100
N. Fodders	5.5	76.9	10.9	0.0	4.5	0.1	2.1	100
N. Oily Crops	18.4	39.7	30.4	1.8	3.6	0.0	6.1	100
N. Medical Plants	11.8	56.4	5.3	21.2	0.0	0.0	5.3	100
N. Vegetables	11.4	73.6	8.5	2.9	1.3	0.1	2.2	100
Fruits	14.4	63.2	9.5	4.7	4.8	3.4	0.0	100
Other Agriculture, Forestry & Fishing	58.0	42.0	0.0	0.0	0.0	0.0	0.0	100

Note: here and thereafter, W. refers to winter, S. summer and N. Nili.

Table A2: Factor Shares in Agricultural Value Added (Percent)

	Labour	Capital	Nile-dependent Land	Nile Water	Groundwater-dependent Land	Groundwater	Rain-fed Land
W. Wheat & Cereals	12.9	12.6	29.8	10.7	27.2	9.7	25.2
W. Legumes	0.7	0.2	1.8	0.5	0.7	0.0	1.4
W. Sugar Beet	1.4	1.8	3.1	1.1	0.1	0.0	2.6
W. Fodders	2.5	20.1	9.7	17.3	7.4	2.3	13.1
W. Fibres	0.1	0.1	0.2	0.1	0.0	0.0	0.1
W. Medical Plants	0.2	0.3	0.4	0.1	0.1	0.0	0.3
W. Vegetables	5.9	15.5	7.1	2.0	5.2	2.4	5.8
S. Rice	6.2	5.8	4.4	30.7	0.9	0.0	14.0
S. Other Crops	11.2	5.5	13.3	12.1	5.2	2.6	13.8
S. Sugar Cane	2.2	3.3	0.7	8.5	0.3	0.0	3.6
S. Cotton	4.0	2.3	2.8	1.5	0.0	0.0	2.5
S. Fodders	0.7	2.6	2.2	1.3	5.2	3.0	2.0
S. Oily Crops	1.3	1.2	2.1	0.7	1.3	0.1	1.7
S. Medical Plants	0.1	0.1	0.1	0.1	0.0	0.0	0.1
S. Vegetables	8.5	13.3	12.4	3.2	5.0	2.1	10.0
N. Rice	0.0	0.0	0.0	0.0	0.6	0.0	0.0
N. Other Crops	1.8	0.9	1.6	2.5	2.9	0.9	2.0
N. Fodders	0.1	0.3	0.3	0.0	1.2	0.1	0.2
N. Oily Crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N. Medical Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N. Vegetables	1.3	2.0	1.6	1.1	2.4	0.5	1.5
Fruits	6.2	6.5	6.5	6.6	34.1	76.2	0.0
Other Agriculture, Forestry & Fishing	32.8	5.7	0.0	0.0	0.0	0.0	0.0
Total Agricultural Value Added	100	100	100	100	100	100	100

Table A3: Share Parameters for Land and Water at Different Levels of the CES Nest

	Third level of CES nest		Fourth level of CES nest		Fifth level of CES nest			
	Land/Water		Irrigated Land/Water		Nile Land/Water		Ground Land/Water	
	Irrigated Land/Water	Rain-fed Land	Nile-dependent Land/Water	Groundwater-dependent Land/Water	Nile-dependent Land	Nile Water	Groundwater-dependent Land	Groundwater
W. Wheat & Cereals	0.7286	0.2714	0.8398	0.1602	0.9134	0.0866	0.9489	0.0511
W. Legumes	0.7237	0.2763	0.9080	0.0920	0.9369	0.0631	0.9980	0.0020
W. Sugar Beet	0.7203	0.2797	0.9817	0.0183	0.9165	0.0835	0.9998	0.0002
W. Fodders	0.7230	0.2770	0.8895	0.1105	0.5528	0.4472	0.9567	0.0433
W. Fibres	0.7202	0.2798	0.9807	0.0193	0.8925	0.1075	1.0000	0.0000
W. Medical Plants	0.7217	0.2783	0.9466	0.0534	0.9283	0.0717	0.9999	0.0001
W. Vegetables	0.7280	0.2720	0.8530	0.1470	0.9356	0.0644	0.9295	0.0705
S. Rice	0.7180	0.2820	0.9725	0.0275	0.1664	0.8336	0.9963	0.0037
S. Other Crops	0.7222	0.2778	0.9112	0.0888	0.7516	0.2484	0.9225	0.0775
S. Sugar Cane	0.7164	0.2836	0.9689	0.0311	0.0905	0.9095	0.9993	0.0007
S. Cotton	0.7197	0.2803	1.0000	0.0000	0.8643	0.1357	0.0000	0.0000
S. Fodders	0.7413	0.2587	0.7373	0.2627	0.8460	0.1540	0.9063	0.0937
S. Oily Crops	0.7263	0.2737	0.8727	0.1273	0.9249	0.0751	0.9937	0.0063
S. Medical Plants	0.7194	0.2806	1.0000	0.0000	0.8083	0.1917	0.0000	0.0000
S. Vegetables	0.7245	0.2755	0.8967	0.1033	0.9426	0.0574	0.9371	0.0629
N. Rice	0.8049	0.1951	0.4597	0.5403	0.9869	0.0131	0.9981	0.0019
N. Other Crops	0.7301	0.2699	0.8142	0.1858	0.5876	0.4124	0.9596	0.0404
N. Fodders	0.7599	0.2401	0.6383	0.3617	1.0000	0.0000	0.9898	0.0102
N. Oily Crops	0.7324	0.2676	0.8131	0.1869	0.9767	0.0233	1.0000	0.0000
N. Medical Plants	0.7161	0.2839	1.0000	0.0000	0.1361	0.8639	0.0000	0.0000
N. Vegetables	0.7322	0.2678	0.8048	0.1952	0.8061	0.1939	0.9736	0.0264

Table A4: Domestic Agricultural Production (Percentage change)

	N-Wtr Loss	Irrigation Efficiency			X-Wtr Gain	N-Wtr Loss & Irrg-Eff
		Nile Irrg-Eff	Ground Irrg-Eff	Irrg-Eff		
W. Wheat & Cereals	-1.03	3.64	0.28	3.90	0.04	2.90
W. Legumes	-3.72	20.25	0.87	21.26	0.00	16.66
W. Sugar Beet	-0.30	8.84	0.06	8.90	0.01	8.79
W. Fodders	-3.87	3.28	0.10	3.38	-0.04	-0.54
W. Fibres	-0.92	15.31	0.14	15.48	-0.01	14.36
W. Medical Plants	2.02	9.81	0.11	9.93	-0.07	12.05
W. Vegetables	3.78	-5.37	-0.08	-5.45	0.00	-1.82
S. Rice	-3.13	3.55	0.03	3.59	0.00	-0.48
S. Other Crops	-6.51	11.72	0.31	12.03	0.11	5.09
S. Sugar Cane	-14.70	3.25	-0.27	2.98	-0.11	-11.66
S. Cotton	2.01	3.72	-0.32	3.42	-0.12	5.45
S. Fodders	1.27	4.72	1.46	6.10	0.63	7.46
S. Oily Crops	1.14	5.86	0.40	6.23	-0.15	7.69
S. Medical Plants	-1.98	10.85	-0.21	10.64	-0.09	8.52
S. Vegetables	3.08	-0.96	-0.07	-1.04	-0.02	2.15
N. Rice	31.73	-4.02	10.93	5.90	-0.96	37.78
N. Other Crops	-8.92	9.46	1.26	10.74	0.29	1.11
N. Fodders	7.05	3.53	2.77	6.16	-0.11	13.45
N. Oily Crops	3.99	22.63	2.32	25.27	-0.25	30.66
N. Medical Plants	-23.93	16.95	-0.14	16.81	-0.08	-11.09
N. Vegetables	0.83	-0.98	0.49	-0.54	0.02	0.45
Fruits	-3.94	-0.38	-0.02	-0.40	4.64	-4.28
Other Agriculture, Forestry & Fishing	-0.48	0.84	0.04	0.88	0.02	0.43

Appendix

The CES production technologies specify, for instance, aggregate value added as a function of the primary inputs *f* used in each activity a, as,

$$FD_{f,a} = ADVA_{a} * \left(\sum_f \delta_{f,a}^{va} * \left(ADFD_{f,a} * FD_{f,a}\right)^{-\rho_a^{va}}\right)^{-1/\rho_a^{va}} \quad (1)$$

where $FD_{f,a}$ is the demand for factor *f* by activity a, $ADVA_a$ is the shift parameter and $\delta_{f,a}^{va}$ the share parameter, and ρ_a^{va} is the elasticity parameter. $ADFD_{f,a}$ is a stock-flow parameter defining the relationship between the stock of a factor and the flow of services from that stock. The elasticity of substitution between production factors is $\sigma_a^{va} = \left(1/\left(1+\rho_a^{va}\right)\right)$.

The first-order conditions for the profit-maximising/cost-minimising optimal mix of factor inputs is

$$WF_f * WFDIST_{f,a} * \left(1 + TF_{f,a}\right) = \frac{PVA_a * QVA_a * \left(\delta_{f,a}^{va} * ADFD_{f,a}\right)^{-\rho_a^{va}} * \left(FD_{f,a}\right)^{-\rho_a^{va}-1}}{\sum_f \delta_{f,a}^{va} * \left(ADFD_{f,a} * FD_{f,a}\right)^{-\rho_a^{va}}} \quad (2)$$

where WF_f is the average factor price, $WFDIST_{f,a}$ are the ratios for factor prices in each activity relative to the average factor price, and $TF_{f,a}$ is the factor use tax rate. PVA_a and QVA_a are the price and quantity of aggregate value added, respectively.