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Water Scarcity and Irrigation Efficiency in Egypt

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This study provides quantitative assessments for the impacts of efficiency enhancement for different types of irrigation water under water scarcity conditions. It employs a single country CGE (STAGE) 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; Nile water- and groundwater-dependent as well as rain-fed agricultural activities. The simulations show that Egypt should manage potential reductions in the supply for Nile water with more efficient irrigation practice that secures higher productivity for Nile water, groundwater and irrigated land. The results suggests more ambitious plan to boost irrigation efficiency for summer rice in order to overweight any potential shrinkages in its 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.

Keywords: Water Availability, Agriculture Productivity, Nile Basin, Computable General Equilibrium (CGE) Models.

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1. Water Scarcity in Egypt[4]

Under the current economic and population growth as well as the prospective environmental challenges, Egypt is rapidly facing serious water scarcity issue. Water availability per capita rate is already one of the lowest in the world. In 2000, water withdrawal per capita was around 1000 m^3. This is supposed to halve and, hence, fall below the scarcity rate by 2025. Also, per capita renewable water share has been declining from 853.5 m^3 (2002) to 785.4 m^3 (2007) and reached 722.2 m^3 (2012). This is predicted to reach 534 m^3 by 2030 (FAO, 2014).

Nile is the main source of freshwater in Egypt with a share of more than 95 percent. Agriculture is by far the main consumer of fresh water resources in Egypt. Irrigated agriculture absorbs 85 percent of the annual water resource and 89 percent of Nile flows. Besides, agriculture and irrigation in Egypt are virtually fully reliant on Nile water (80 percent of irrigation requirements).

The issue of Egypt's share of Nile waters is under negotiations. In April 2011, Ethiopia has launched the construction of the Grand Ethiopian Renaissance Dam (GERD). With water storage capacity of 63 BCM and energy generation capacity of 6,000 megawatt (MW), the GERD is anticipated to be the biggest hydroelectric power plant and one of the largest water reservoirs in the continent. Egyptian experts give indications of a possible water reduction between 20 and 34 percent when the filling period overcuts the drought period. This is estimated to be 11-19 BCM over the Dam's filling period.

These facts emphasize the importance of potential impact of Nile water availability on the Egyptian economy. Shortage of fresh water resources would have outstanding impacts on agricultural activities and the whole economy. The urgent tasks are thus to reassess the productivity of irrigation water and land as well as the efficiency of the overall irrigation system and to examine the optimal allocation of irrigation resources.

Indeed, the significance and direction of irrigation efficiency impacts on agriculture is an empirical exercise. Overall economic responsiveness to water availability and efficiency shocks depends on the macroeconomic structure. In accordance with the forward and backward linkages across sectors, the net effect is formulated and the new production mix is defined. Furthermore, temporal and spatial water availability and efficiency generate

[4] Disclaimer: the views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

differentiated impulses among agricultural activities and across irrigation seasons. Clearly, Computable General Equilibrium (CGE) models provide a theoretically consistent and empirically sensible framework for contemplating such interlinked economy-wide impacts.

This study aims at examining the potential implications of enhancements in irrigation efficiency under water scarcity conditions. It employs a single-country CGE model calibrated to an extended version of a recently constructed Social Accounting Matrix (SAM) for Egypt 2008/09. The SAM contains an unprecedented level of details on the Egyptian agricultural and irrigation schemes.

The simulation results answer several research questions. How significant are potential effects of Nile water reductions on the agricultural sector and the whole economy likely to be? What are the sufficient enhancements in irrigation efficiency required to compensate the potential losses of Nile water? Is investing in securing non-conventional water resources, actually, a viable alternative strategy to the irrigation efficiency strategy?

The rest of the paper is organized as follows. Section 2 describes the existing irrigation scheme and irrigation resources. Section 3 places this study in its appropriate position within the relevant literature. Based on the underlying database (described in Section 4) main features of the agricultural and irrigation schemes are examined in Section 5. Section 6 describes the main developments conducted on the employed model to serve the purposes of this study. Section 7 presents the simulation scenarios and Section 8 interprets simulation results. Section 9 runs a sensitivity analysis to test the robustness of the model results with respect to variations in the model settings. Section 10 discusses the main findings and concludes.

2. Efficient Plantation and Inefficient Irrigation

As Keller and Keller (1995, p. 6) describe “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 following brief description of the irrigation scheme and usage of irrigation resources in Egypt illustrates this paradox.

Egypt follows a multi-cropping system that permits planting up to three crops a year. Planting crops rotates round the year during three irrigation seasons; winter (November-May), summer (May-September) and Nili (i.e. Nile flood), from September to November. The main crops are wheat, berseem and broad-beans (in the winter rotation), cotton and rice (in the summer rotation) whereas maize and millet are flood crops. This rotating irrigation system helps in improving land productivity. For example, cultivating berseem in winter improves the soil quality before soil-demanding cotton is being planted in summer.

Nevertheless, the bulk of irrigated land depends on low-efficiency surface irrigation scheme.

This surface irrigation mainly depends on a single conventional source of water – Nile water. The storage reservoir of Nasser Lake provides 56 billion m^3 (BCM) per annum. Nile water naturally serves irrigated land in the Nile Valley and Nile Delta. These irrigated lands constitute 85 percent out of the 8.7 million feddans of Egyptian irrigated land.

The existing surface irrigation scheme causes high water losses, decline in land productivity, waterlogging and salinity problems. Moreover, unsustainable agricultural practices and improper irrigation management affect the quality of the country's water resources. Reductions in irrigation water quality have, in their turn, harmful effects on irrigated soils and crops. The FAO's Country Programming Framework (2013, p. 13) states that "… 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".[5]

Indeed, it is crucial for Egypt to form a comprehensive strategy that simultaneously aims at enhancing the efficiency of existing usage of irrigation water and boosting water supply from various conventional and non-conventional resources. The relevant question is what the potentials for securing more irrigation water are. The rest of this Section addresses this question.

Table 1: Available and Used Irrigation Water Resources

Source	**Usage**		**Availability**	
	Billion m3/Annum	%	Billion m3/Annum	%
Nile Water	51.7	82.59	55.5	75.2
Groundwater	5.2	8.3	11.3	15.3
Drainage Water	3.7	5.91	5	6.8
Treated Sewage Water	1.5	2.4	1.5	2.03
Rain	0.5	0.8	0.5	0.67
Total	**62.6**		**73.8**	

Source: compiled by the authors from different sources.

Groundwater is the second largest source for irrigation; accounting for 8 percent of the irrigation water. Virtually 11 percent of irrigated agricultural production depends on groundwater. Moreover, it is the sole source of water in areas like Sinai, Western North Coast (Matruh), Western Desert and the New Valley. Egypt has large potentials for groundwater estimated to be 11.3 BCM (Table 1).

[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.

Egypt does not receive rainfall except for a narrow strip along the Northern coastal area where the average rainfall does not exceed 200 mm (about 1.5 BCM/year). This amount cannot be considered as a reliable source of water due to its spatial and temporal variability. Land irrigated by rainfall water locates alongside the Mediterranean shore. Besides, around 250 thousand feddans in Sinai and 150 thousand feddans in the Western North Coast depend on seasonal rains.

Other non-conventional water resources are basically recycled drainage water and treated sewage water. Annual drainage water utilized in agriculture is estimated to be 3.7 BCM with potentials to reach 5 BCM. Drainage water is evenly mixed by Nile water and reused in irrigating 450 thousand feddan in North Sinai. Treated sewage water used in irrigation is 1.5 BCM with estimations to reach 2.4 BCM in 2027.

3. Literature Review

Irrigation water is a central aspect of both natural resources and environmental economics and applied water policy analysis. Dudu and Chumi (2008) and Ponce et al., (2012) review the partial and general equilibrium literature on modelling water at country and global level. The most recent literature indicates how CGE model are well equipped to answer questions related to water, in particular water scarcity and irrigation issues. CGEs prove to be flexible enough to adapt their nested production function to include water both as a production factor (in different position of the nest according to the choice of the modeller) used mainly by farmers and as a commodity consumed by households. Besides, the economy-wide approach allows researchers to consider effects of water scarcity on all economic sectors, not only in agriculture, and to consider indirect effects as income effects due to change in water supply (or policies affecting the water sector). At the same time, these surveys pinpoint that the areas of irrigation, water allocation and agricultural productivity is still scarcely explored by the literature and have potential for further research.

The issue of water scarcity in Egypt, together with its possible exacerbating factors (e.g., economic, population and food demand growth, climate change and the current debate over the allocation of the Nile's waters among its ten Basin countries) is widely recognized in the current literature (Gohar and Ward, 2010).

Many studies employing a CGE model have examined the economic implications of water availability e.g., as part of climate change impact analysis (Strzepek et al. (1995), Yates and Strzepek (1996) and Yates and Strzepek (1998)).

A few studies consider variability in water supply and the economic value of reducing variability. Strzepek and Yates (2000) employ a recursive dynamic CGE model to examine impacts of changes in the Nile River on the Egyptian Economy to the year 2060. Strzepek et al., (2008) use a comparative static CGE to evaluate the economy-wide impacts of the High Aswan Dam on the Egyptian economy.[6] The study specifies water as a nested CES production function through a fixed land-water technology. Also, it explicitly specifies a risk premium. The results, among others, show negative impact of the Dam on summer crops.

Another strand of the relevant literature explores different approaches for maximizing irrigation water efficiency in Egypt. Gohar and Ward (2010) examine the economic efficiency impacts of different irrigation water allocation policies in Egypt. They show that flexible irrigation pattern across locations, seasons and crops could improve the irrigation water efficiency. Bader (2004), applying a Mathematical Programming approach, claims that there is scope for improvement farms' returns through optimisation of irrigation water use and for improvement of irrigation efficiency which leads to increase in farm income and crop production.

He et al., (2004) examine the impact of water pricing and taxation policies on water efficiency in Egypt. The study employs a static partial equilibrium Agricultural Sector Model of Egypt (ASME) model for Egypt.

Robinson and Gehlhar (1995a) examine the effect of fiscal reforms by removing subsides and taxes. The study specifies physical supply constraints for both water and land. The first order conditions for water and land constraints are given by a linear cost function. To ensure that at least one of the two constraints is binding, the model introduces an explicit maximand. The same authors also investigate the impacts of establishing a market for water and water pricing policies for the agricultural sector in Egypt (Robinson and Gehlhar, 1995b).

Overall, the implication of irrigation water scarcity and variations of agricultural factor productivities for economic and trade structures in Egypt are not yet thoroughly examined. Indeed, impacts generated under different water supply and productivity widely vary from an irrigation

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

scheme to another. Furthermore, changes in availability and productivity generate differentiated impulses not only among agricultural sectors but also across irrigation seasons. Therefore, studies that do not represent different irrigation schemes and neglect irrigation seasonality do not produce complete results.

The current study provides a rigorous quantitative impact assessment of changing water productivity under water scarcity scenario for Egypt. It offers major contributions to the CGE literature on water issues in Egypt. Firstly, the study introduces water as a separate production factor. The study employs an elaborated version of a recently constructed SAM for Egypt 2008/09(see Section 4), which for the first time explicitly represents irrigation water in Egypt. Furthermore, the study accounts for different irrigation schemes. It represents Nile water-, groundwater- and rain-fed-dependent activities. This detailed representation of irrigation schemes and agricultural activities requires specifying a five level nested CES production function (see Section 6). Finally, the study takes into account irrigation seasonality distinguishing irrigation activities not only by irrigation scheme but also by irrigation season. Nile water, ground water, irrigated land and rain-fed land are segmented by irrigation season; i.e. winter, summer, Nili as well as year-round.

4. An Extended SAM for Egypt 2008/09

A Social Accounting Matrix (SAM) provides a consistent framework, within which flows of expenditure and income for the different agents in the economy at hand are recorded. A SAM is a square matrix where each agent is represented by a column and a row that record, respectively, the account's expenditures and receipts.

The study employs an extended version of a recently constructed SAM for Egypt 2008/09, (Osman et al., forthcoming). The SAM is specifically developed to take into account the Egyptian multi-cropping irrigation system. It provides detailed representation for the agricultural activities and factors across different irrigation seasons. Furthermore, it introduces irrigation water as a separate production factor. Nile water and irrigated land are segmented by irrigation season.

For the purpose of this study, the 2008/09 SAM has been developed in order to represent different irrigation systems. Three main contributions are added to the 2008/09 SAM: introducing groundwater irrigation scheme, representing rain-fed-dependent agricultural activities and distinguishing agricultural activities and factors by irrigation season.

Firstly, groundwater is introduced as another type of irrigation water. Detailed data on cultivated land area and groundwater used to irrigate crops are compiled from (CAPMAS, 2009). Subsequently, Nile water- and groundwater-dependent agricultural activities are distinguished. Due to lack of data, the study assumes that production cost structures for these groundwater-dependent are similar to the corresponding seasonal crops irrigated by Nile water. In other words, intermediate inputs and factor payments required to cultivate a feddan of Nile-dependent winter vegetables are exactly the same for a feddan of groundwater-dependent winter vegetables. Using water and land requirements, production cost for groundwater-dependent crops are then computed.

Table 2: Extended SAM Accounts, Egypt 2008/09

No	SAM Activity	No	SAM Activity	No	SAM Activity
1	Winter Wheat	19	Nili Oily Crops	37	Education
2	Winter Cereals	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 Fibbers	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 HH
18	Nili Fodders	36	Administrative Services	54	Subsistence HH Activities
No	**SAM Commodity**	**No**	**SAM Commodity**	**No**	**SAM Factors**
1	Wheat	9	Food Products	1	Labour
2	Cereals	10	Other Transportable Goods	2	Capital
3	Rice	11	Metal machinery equipment	3	Winter Nile-dependent Land
4	Vegetables	12	Construction	4	Summer Nile-dependent Land
5	Fruits	13	Trade	5	Nili Nile-dependent Land
6	Coffee Tea	14	Financial Services	6	Year-round Nile-dependent Land
7	Other Agriculture Forestry Fi	15	Business Services		
8	Ores Minerals Gas	16	Social Services	**No**	**SAM Factors**
No	**SAM Factors**	**No**	**SAM Factors**	15	Winter Groundwater
7	Winter Nile Water	11	Winter Groundwater-dependent Land	16	Summer Groundwater
8	Summer Nile Water	12	Summer Groundwater-dependent Land	17	Nili Groundwater
9	Nili Nile Water	13	Nili Groundwater-dependent Land	18	Year-round Groundwater
10	Year-round Nile Water	14	Year-round Groundwater-dependent Land	19	Rain-fed Land

Source: Osman et al., forthcoming.

Furthermore, seasonal crops cultivated by rainfalls are taken into account. Rain-fed land is distinct from irrigated land. Therefore, gross operating surplus is segmented further into capital and rain-fed land. Factor payments by crop activities to rain-fed land are deducted from their payments to capital.

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

A stochastic version of the cross-entropy (CE) methodology is used to balance the original SAM, disaggregate the agricultural activity and commodity, and estimate the extended SAM. Aggregates from national accounts and supply/use tables are used to control the transaction values for the extended SAM.7 As portrayed in Table 2, the extended SAM contains 101 accounts: 54 activities, 16 commodities, 19 factors, 5 institutions, 4 tax instruments as well as trade margin, savings/investment and rest of the world accounts.

5. Main Economic Features

Agriculture plays a significant role in the Egyptian economy. Agriculture accounts for more than 10 percent of GDP and employs 8 percent of total labour payments. The agricultural exports constitute 13 percent of exports. The economy has also strong industrial base, forming 40 percent of GDP, of which 30 percent is sourced from manufacturing activities. Services are the main productive activity, contributing almost half of GDP. Public services account a sizable share of GDP (more than 7 percent). Furthermore, public employment constitutes a substantial share of labour force (36 percent).

Vegetables comprise 23 percent of agricultural output evenly spread over the winter and summer seasons. The sector roughly consumes 6 percent of Nile water used in each of the irrigation seasons. Wheat represents 13 percent of agricultural production. It is one of the main users of Nile land (almost 30 percent) and uses a tenth of Nile water. Rice is of a great importance to the Egyptian economy. It contributes more than 6 percent of agricultural production. Furthermore, it is one of the main exporting sectors. Rice is cultivated mainly in the summer season with only 0.4 percent of rice output grows in the Nili season. This water-intensive crop consumes more than 30 percent of annual irrigation Nile water and more than half of summer Nile water. Fodder crops, represents another 13 percent of agricultural production and an intensive users of Nile water (more than 17 percent).

[7] For detailed information on Cross Entropy, see Robinson and El Said, (2000) and Robinson et al., (2000).

Factor intensity reflects the prevailing technology in different activities while factor allocation represents factor usage across activities; see Table A1 and Table A2. These two indicators are essential for understanding any potential change in factor rents and the consequent changes in factor allocation after a policy shock. Among the agricultural sectors, vegetables have the lowest Nile water/land intensity ratios. Nile water/land intensity ratios for the seasonal vegetables sectors range 6-12 percent. As such, the vegetables sectors are relatively less Nile water/land-intensive compared to other sectors. Besides, the vegetables sectors employ small shares of Nile-water (6.3 percent) and Nile-land; 21 percent.

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

6. Single Country STAGE CGE Model

This study uses a variant of the comparative static single-country CGE Static Applied General Equilibrium (STAGE) model.[8] In this version of the model, called STAGE-WL, a Constant Elasticity of Substitution (CES) nest is added to the production function representing derived demand for Nile water and land as well as other sources of irrigation water.

6.1 Production Specification

Production relationships for agricultural activities are specified through a five level standard nested CES function (Figure 1). At the top level, value added and intermediate demand are combined using a CES aggregator. At the second level of the nest, a CES production technology specifies the aggregate value added as a function of primary inputs demand in each activity. The primary inputs are capital, labour and aggregate water/land for agriculture. By maximizing profit, farmers determine the optimal supply of crops according to the production technology prevailing in each activity. This *per se* specifies their derived demand for production factors. Farmers' demand of production factor equalizes its marginal product with its return rate in each activity.

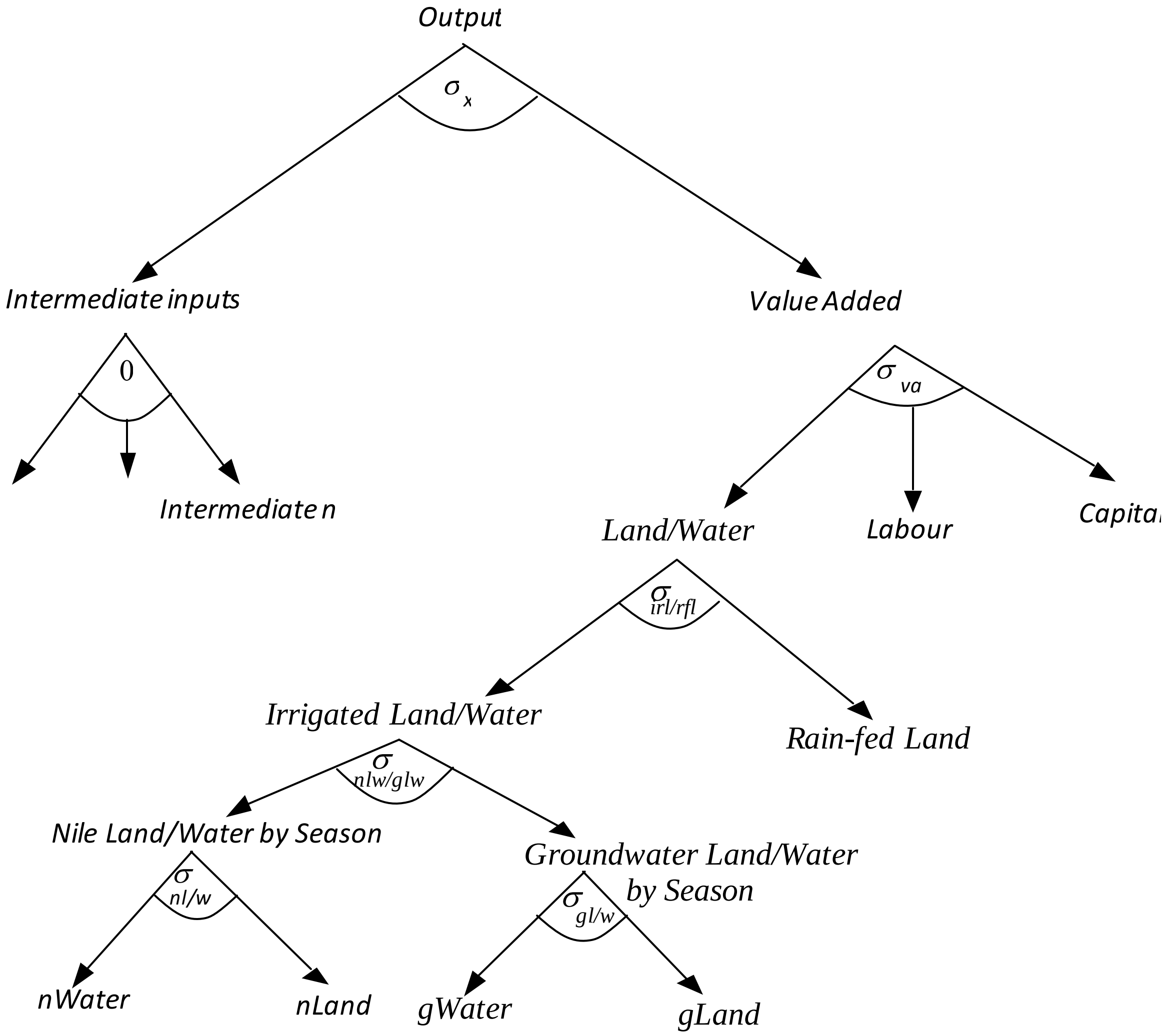
[8] STAGE model, described in detail in McDonald S. (2007), is a descendant of the USDA ERS model (Robinson et al., 1990). Luckmann and McDonald (2014) provide a detailed technical documentation for the STAGE_W CGE model. In this advanced variant of the model, different types of water are specified as production factors, productive activities and as produced commodities. This elaborated presentation of water allows for simulating a wide range of policy scenarios.

For the purposes of this study, aggregate land for agriculture is modelled as a composite of irrigated and rain-fed land. At the third level of the agricultural production function, rain-fed land and composite irrigated land are combined through a CES aggregator. Composite irrigated land is land irrigated by either Nile water or groundwater.

The model segments groundwater-dependent agricultural activities from Nile water-dependent agricultural activities. At the fourth level of the agricultural production function, Nile land/water composite and groundwater land/water composite are combined through a CES aggregator. This allows for specifying different substitutability between these two irrigated lands. Both types are mobile across crops subject to changes in the ratios for land rent in each activity to the average land rent.

At the bottom level, water and land are combined according to two CES aggregators – each for Nile water-dependent and for groundwater-dependent activities. The greater the irrigation water quality available for specific activities, the lower is the water price, and the higher is the land rent. The price for composite irrigated land/water changes depending, *inter alia*, on the prevailing irrigation technology. The latter is measured by factor intensity for irrigated land and water. The activities with increasing irrigated land/water price withdraw irrigated land/water from other activities according to the elasticity of substitution between two irrigated lands: Nile water-dependent land and groundwater-dependent land. Excess irrigated land supply pushes irrigated land rent to drop to clear the market. Farmers utilize irrigated land to equalize its marginal product with its rent rate in each activity. This *per se* specifies the optimal derived demand for irrigated land. The elasticity of substitution between water and land are based on estimations provided by Calzadilla et al., (2011) for the Middle-East region which is equal to 0.06.

Figure 1: Agricultural Production Flows in STAGE-WL CGE Model



Source: authors' elaboration

Three points are worth highlighting. Firstly, the model allows for an alternative specification for coefficient at the different levels of the water/land production nest: the typical Leontief fixed coefficient approach. Secondly, the model specifies physical supply constraints for water and land. Demand volume transactions for land (by thousand feddan) and water by agricultural activities are employed as upper limits for supply of water and land. Finally, water supply activity deals with non-agricultural uses of water.

The model assumes no distribution cost of irrigation water. Under an additional closure rule, the model sets production volumes to be fixed at their baseyear levels. This is applied at the third level of the CES production function for all agricultural activities except 'Other

Agriculture Forestry Fishery'. This specification allows endogenously quantifying changes in efficiency required to offset the water losses keeping agricultural output unchanged. Under different levels of water loss, generated changes in efficiency are measured for the land/water composite production factor.

6.2 Model Closure Rules

Egypt is a small country in the world market. It is, thus, plausible to fix world prices for exports and imports. The model assumes that current account balance is fixed at its initial benchmark. To clear the external balance, real exchange rate adjusts. This is the typical choice for developing economies where foreign credit is limited and fixing current account reflects the economic reality. The model adopts an investment-driven closure; saving rate adjusts to generate the required savings 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)[9].

Capital is mobile and fully employed (medium-run closure rule). On the other hand, labour is mobile, albeit under employed. Unemployment in labour markets is the most reasonable assumption in a country where unemployment rate is constantly above 10 percent. Water and land, for both Nile water-dependent and groundwater-dependent activities, are fully employed, but season-specific. For the purposes of this study, water and land supply are set to be 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 would have distinct seasonal prices.

7. Simulation Scenarios

Four main simulation scenarios distinguish irrigation systems according to different levels of irrigation efficiency (Table 3). The conventional definition of efficiency for a given input is measured by the generated output. Keller and Keller (1995) demonstrate that the classical definition of irrigation water efficiency is applicable to examining irrigation design and management but is not precise in the case of studying water allocation. Failure to consider the

[9] The result could be misleading because increase of foreign savings (or investment decrease) raises households' welfare while a comparative static analysis does not take into account possible welfare decreases in following periods due to a higher foreign debt or a smaller capital stock.

inevitable water discharge, which occurs during irrigation in form of runoff or seepage, and the recycled drainage water leads to ill-defined measure of efficiency. For the purpose of this study, it is appropriate to use productivity as an approximate for efficiency. For agricultural activities producing the same crop, water quality and, hence, land productivity varies according to the employed irrigation system: Nile water-dependent versus groundwater-dependent.

The first scenario (N-Wtr Loss) simulates the Nile water loss in isolation, which reflects the upper limit of potential reductions of Egypt's share of Nile water due to filling of the GERD reservoir. It assumes a 34 percent reduction in Nile water supply evenly spread across irrigation seasons.

The second scenario (Irrg-Eff) considers improvements of irrigation efficiency. This is specified as external shocks of factor-specific productivities. At the fourth level of the production nest, Nile land/water and groundwater land/water productivities rise by 30 percent. For better interpretation of the determinants of the results, this scenario is decomposed into two components according to the source of the simulated irrigation efficiency: Nile water-dependent irrigation (Nile Irrg-Eff) and groundwater-dependent irrigation (Ground Irrg-Eff). The simulation scenario does not specify the underlying source for funding the simulated improvements in irrigation efficiency. In other words, government expenditures on R & D, for example, are not explicitly specified.

Table 3: Simulation Scenarios

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

Source: authors' elaboration

The third scenario (N-Wtr Loss & Irrg-Eff) combines the simulated 34 percent reduction in Nile water with the 30 percent 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.

The last scenario (X-Wtr Gain) assumes *ceteris paribus* more non-conventional water resources are secured to compensate the simulated reductions in Nile water. It implicitly represents the case in which Nile water loss is compensated by increases in recycled drainage water and treated sewage water. As discussed earlier, the potential average increase in these two water resources is estimated to be 95 percent.[10] 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 percent increase in groundwater supply across different irrigation seasons.

8. Simulation Results

8.1 Macro-economic Impacts

Economy-wide minor negative impacts are reported under the N-Wtr Loss scenario (Table 4). The simulated irrigation efficiency scenario generates around 0.5 percent increases in GDP and absorption. Potential increases in non-traditional water resources induce trivial positive economy-wide impacts.

Table 4: Macroeconomic Indicators (Real percentage change)

	N-Wtr Loss	Efficiecny			N-Wtr Loss & Irrg-Eff	X-Wtr Gain
		Nile Irrg-Eff	Ground Irrg-Eff	Irrg-Eff		
private consumption	-0.30	0.53	0.03	0.55	0.26	0.02
government consumption	0.03	-0.06	0.00	-0.06	-0.03	0.00
investment consumption	-0.13	0.22	0.01	0.23	0.10	0.02
absorption	-0.23	0.41	0.02	0.43	0.20	0.02
import demand	-0.16	0.11	0.00	0.10	-0.07	0.04
export supply	-0.25	0.23	0.00	0.24	-0.03	0.06
GDP from expenditure	-0.26	0.45	0.02	0.47	0.22	0.02
total domestic production	-0.32	0.56	0.03	0.59	0.27	0.02
total intermediate inputs	-0.42	0.72	0.04	0.75	0.34	0.02

Source: authors' elaboration on model results

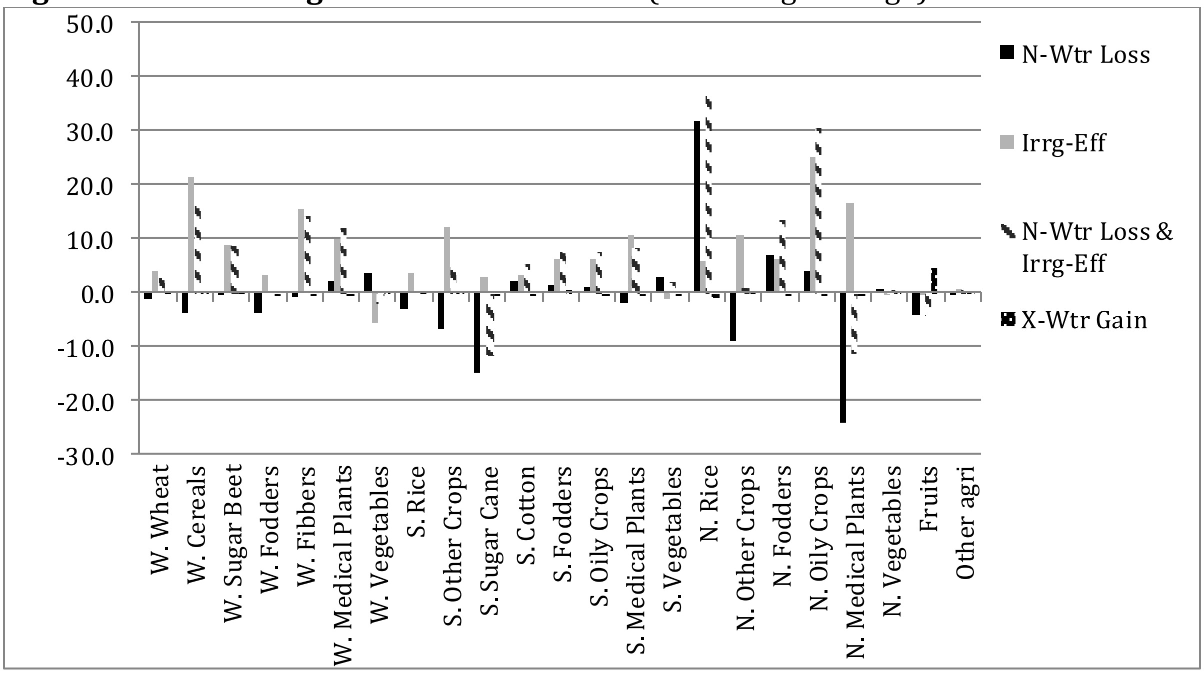
[10] This is weighted according to their current shares of irrigation water.

The generated positive effects under the Irrg-Eff scenario imply that the simulated 30 percent improvement in irrigation efficiency is sufficient to offset the macroeconomic loss due to the 34 percent reduction in Nile water supply. The results are primarily driven by the simulated enhancement in Nile water-dependent irrigation efficiency. This is attributed to the major importance of the Nile water-land for agriculture as a whole and irrigated agricultural in particular.

8.2 Sector-specific Impacts

At the sectoral level, 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 (e.g. winter and summer vegetables) expand under the N-Wtr Loss scenario. Improving Nile water-dependent irrigation efficiency generates positive effects for sectors like winter cereals and summer other crops whereas all seasonal vegetable sectors shrink. The simulated increases in non-conventional water resources boost the fruits sector.

Figure 2: Domestic Agricultural Production (Percentage change)



Source: authors' elaboration on model results

The N-Wtr Loss scenario has a strong negative impact (-20 percent) on rice exports. Under the comprehensive N-Wtr Loss & Irrg-Eff scenario, rice exports drop by only 4 percent. Improving Nile water-dependent irrigation efficiency boosts rice output (by 4 percent in the summer and 6 percent in the Nili seasons) 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 negligible impact on summer rice. From this perspective, more ambitious plan to boost irrigation efficiency for this sector is recommended in order to overweight any potential shrinkage in rice output and exports.

Table 5: Commodity Exports (Percentage change)

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

Source: authors' elaboration on model results

Interestingly, winter and summer vegetables output rise under the N-Wtr Loss scenario. According to the factor market clearing conditions, water and land are allowed to move across activities within each irrigation season, but not across seasons. Reduction in water availability pushes the agricultural structure to be more concentrated in less hydro-water crops. As such, the winter and summer vegetable sectors attract excess Nile water and land leading to expansions of 3-4 percent.[11]

Improving Nile water-dependent irrigation efficiency adversely affects the vegetables sectors in all irrigation seasons. These negative impacts are worse under the comprehensive irrigation efficiency scenario.

Clearly, interpreting these findings requires more detailed analyses for production technology prevailing in the base year as well as changes in factor prices and rents under the simulation scenarios. The next sub-section addresses these effects.

[11] For more detailed sectoral results, see Table A3.

8.3 Water and Irrigated Land Prices

Under the Nile Irrg-Eff scenario, Nile water and Nile water-dependent land rents drop as they become more efficient.[12] The expanding activities (e.g. winter cereals, summer rice, summer other crops and cotton) absorb the mobile factors (i.e. labour, capital, year-round Nile water and year-round Nile-water dependent land) leaving other activities and push their prices and incomes to raise (Table 6).[13]

Table 6: Factor Income (Percentage change)

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

Source: authors' elaboration on model results

The experienced increases in factor prices under the Nile-Irrg Eff scenario entail higher production costs for sectors that are relatively more dependent on these factors. As such, the seasonal vegetables sectors experience increasing production cost. Hence, these explain the reported shrinkages.

[12] Increasing production factor productivity implies higher effective factor endowment, which consequently affects factor demand and price. Within this multi-sector modelling framework, changes in productivity of specific factors/sectors affect demand and price for other factors/sectors through different transmission channels. The higher the factor productivity, the lower is its effective price. Consequently, producers substitute other factors/intermediate inputs by the cheaper factor. Changes in factor productivity entails also lower production cost and, hence, lower price. Consumers gain and their demand increases, which consequently boosts production.

[13] In this general equilibrium framework, the causal relationship between factor demand and factor rents works in two directions. Excess demand for a production factor pushes its average rent to rise in order to clear the market. Simultaneously, producers substitute this factor, which became relatively more expensive, for other factors according the elasticity of substitution at the fourth level of the CES production function.

Table 7: Agricultural Production, Systematic Sensitivity Analysis

	Minimum	Maximum	%	Mean	SD
W. Wheat	26.41	26.41	0.01	26.41	0.0003
W. Cereals	1.13	1.13	0.05	1.13	0.0001
Winter Sugar Beet	3.19	3.19	0.06	3.19	0.0003
W. Fodders	24.03	24.04	0.05	24.03	0.0015
W. Fibbers	0.15	0.16	0.07	0.15	0.0000
W. Medical Plants	0.43	0.43	0.09	0.43	0.0001
W. Vegetables	18.35	18.36	0.05	18.35	0.0015
S. Rice	12.35	12.36	0.07	12.35	0.0014
S. Other Crops	15.34	15.35	0.07	15.35	0.0016
S. Sugar Cane	5.38	5.41	0.41	5.39	0.0036
S. Cotton	4.45	4.46	0.13	4.46	0.0008
S. Fodders	3.55	3.55	0.12	3.55	0.0006
S. Oily Crops	2.28	2.28	0.20	2.28	0.0007
S. Medical Plants	0.17	0.17	0.14	0.17	0.0000
S. Vegetables	19.97	19.99	0.12	19.98	0.0038
N. Rice	0.05	0.05	1.40	0.05	0.0001
N. Other Crops	2.40	2.41	0.47	2.41	0.0017
N. Fodders	0.42	0.43	1.03	0.42	0.0007
N. Oily Crops	0.01	0.01	2.41	0.01	0.0001
N. Medical Plants	0.00	0.00	3.08	0.00	0.0000
N. Vegetables	2.98	2.99	0.26	2.98	0.0012
Fruits	10.85	10.85	0.00	10.85	0.0000
Other agri	39.74	39.74	0.00	39.74	0.0000

Source: authors' elaboration on model results

9. Systematic Sensitivity Analysis

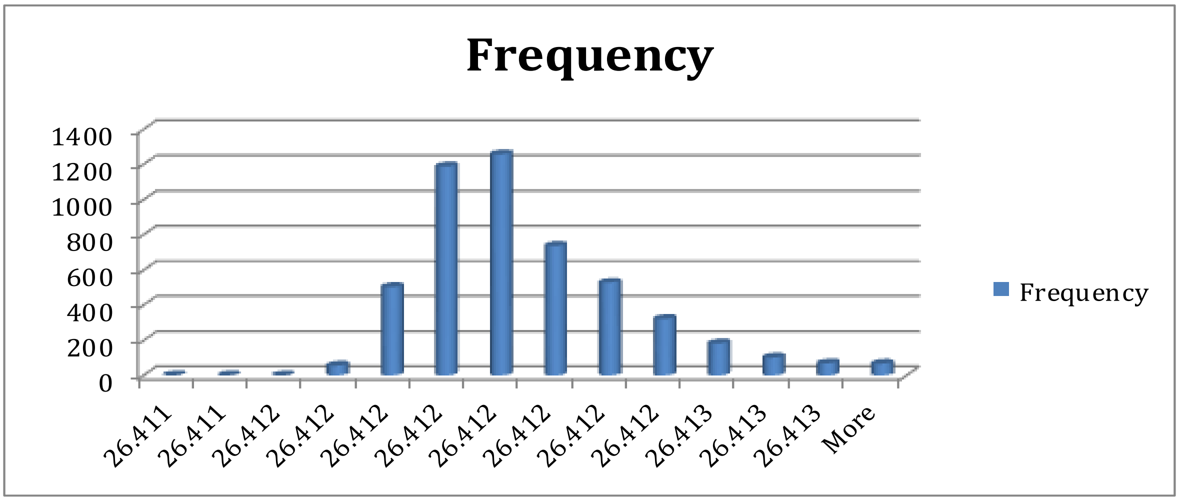
To analyse the robustness of the model, the elasticity of substitution between water and land is analysed through a systematic sensitivity analysis (SSA). SSA is performed with a standard Monte Carlo approach.[14] We assume that the elasticity of substitution between water and land for each agricultural activity follows an independent identically distributed (i.i.d.) normal distribution, $N(\mu, \sigma^2)$, where the mean is the value provided by Calzadilla et al. (2011). We simulate 5,000 Monte Carlo draws for the Irrg-Eff scenario, under which a 30 percent increase in irrigation efficiency is simulated for both Nile water-dependent and groundwater-dependent irrigation schemes.

Table 7 reports the minimum and maximum values as well as the percentage change between them, the mean and the standard deviation for the quantity produced by each

[14] For more explanation of Mont Carlo approach, see (Belgodere and Vellutini, 2011).

agricultural activity. The frequency distribution of the quantity of winter wheat produced (Figure 3) shows that 95 percent of the observations are within two standard deviations around the mean (84 percent within single standard deviation).

Figure 3: SSA Frequency Distribution, Winter Wheat Production



Source: authors' elaboration on model results

10. Conclusions and Discussion

The simulation results suggest that Egypt should be able to manage the potential reductions in the supply for Nile water with more efficient irrigation practice that secures higher productivity (30 percent) for Nile water, groundwater and irrigated land. The results however suggests more ambitious plan to boost irrigation efficiency for summer rice in order to overweight any potential shrinkages in its output and exports. Furthermore, the findings show that even doubling all non-conventional water resources is not sufficient to compensate the potential adverse impacts of Nile water losses. This highlights the critical importance of irrigation efficiency for the Egyptian economy. A Monte Carlo style SSA confirms the robustness of our findings.

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Table A1: Factor Intensity by Agricultural Activity (Percent)

	Labour	Capital	Nile-land	Nile-water	Ground-land	Ground-water	Rainfed-land	Total
Winter Wheat	13.8	56.4	20.0	3.4	1.8	0.2	4.5	100
Winter Cereals	22.2	29.8	34.6	4.6	1.3	0.0	7.5	100
Winter Sugar Beet	12.3	64.2	16.9	2.8	0.0	0.0	3.8	100
Winter Fodders	2.5	83.7	6.0	5.1	0.4	0.0	2.2	100
Winter Fibbers	14.4	59.0	18.4	3.8	0.1	0.0	4.3	100
Winter Medical Plants	10.2	68.7	15.3	2.2	0.2	0.0	3.4	100
Winter Vegetables	7.7	84.1	5.8	0.8	0.4	0.1	1.3	100
Summer Rice	13.8	54.1	6.1	20.6	0.1	0.0	5.2	100
Summer Other Crops	23.1	47.0	17.0	7.4	0.6	0.1	4.7	100
Summer Sugar Cane	11.4	70.1	2.3	13.1	0.1	0.0	3.1	100
Summer Cotton	24.7	59.0	10.9	2.7	0.0	0.0	2.6	100
Summer Fodders	4.8	77.8	9.7	2.7	2.2	0.4	2.4	100
Summer Oily Crops	15.1	62.5	15.6	2.4	1.0	0.0	3.4	100
Summer Medical Plants	12.1	64.6	14.6	5.0	0.0	0.0	3.8	100
Summer Vegetables	11.4	74.3	10.4	1.3	0.4	0.1	2.2	100
Nili Rice	11.4	54.3	13.4	0.5	17.6	0.2	2.7	100
Nili Other Crops	23.0	47.2	12.9	9.9	2.3	0.2	4.4	100
Nili Fodders	5.5	76.9	10.9	0.0	4.5	0.1	2.1	100
Nili Oily Crops	18.4	39.7	30.4	1.8	3.6	0.0	6.1	100
Nili Medical Plants	11.8	56.4	5.3	21.2	0.0	0.0	5.3	100
Nili 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 agri forestry fishing	58.0	42.0	0.0	0.0	0.0	0.0	0.0	100

Source: authors' elaboration on model results

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

	Labour	Capital	Nile-land	Nile-water	Ground-land	Ground-water	Rainfed-land
Winter Wheat	12.9	12.6	29.8	10.7	27.2	9.7	25.2
Winter Cereals	0.7	0.2	1.8	0.5	0.7	0.0	1.4
Winter Sugar Beet	1.4	1.8	3.1	1.1	0.1	0.0	2.6
Winter Fodders	2.5	20.1	9.7	17.3	7.4	2.3	13.1
Winter Fibbers	0.1	0.1	0.2	0.1	0.0	0.0	0.1
Winter Medical Plants	0.2	0.3	0.4	0.1	0.1	0.0	0.3
Winter Vegetables	5.9	15.5	7.1	2.0	5.2	2.4	5.8
Summer Rice	6.2	5.8	4.4	30.7	0.9	0.0	14.0
Summer Other Crops	11.2	5.5	13.3	12.1	5.2	2.6	13.8
Summer Sugar Cane	2.2	3.3	0.7	8.5	0.3	0.0	3.6
Summer Cotton	4.0	2.3	2.8	1.5	0.0	0.0	2.5
Summer Fodders	0.7	2.6	2.2	1.3	5.2	3.0	2.0
Summer Oily Crops	1.3	1.2	2.1	0.7	1.3	0.1	1.7
Summer Medical Plants	0.1	0.1	0.1	0.1	0.0	0.0	0.1
Summer Vegetables	8.5	13.3	12.4	3.2	5.0	2.1	10.0
Nili Rice	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Nili Other Crops	1.8	0.9	1.6	2.5	2.9	0.9	2.0
Nili Fodders	0.1	0.3	0.3	0.0	1.2	0.1	0.2
Nili Oily Crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nili Medical Plants	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nili 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 agri forestry fishing	32.8	5.7	0.0	0.0	0.0	0.0	0.0
Agr. Value Added	100	100	100	100	100	100	100

Source: authors' elaboration on model results

Table A3: Domestic Agricultural Production (Percentage change)

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

Source: authors' elaboration on model results.