Water Policy and Irrigation Efficiency in Egypt

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Preliminary Draft – Please DO NOT Circulate OR Cite

Abstract

Increasing water scarcity in many regions of the world renders the question of the efficient use of the limited resource of central importance for regional development and food security. We study the impact of different water management tools on irrigation demand seeking to answer the question of the optimal use of water. We extend the single-country CGE IFPRI model to measure the impacts of different water demand management instruments on the Egyptian economy as a whole and on agriculture in particular. The scenarios mimic the implementation of water quotas, and three different water pricing schemes in irrigation sector.

Keywords: Irrigation efficiency, water management, CGE model,

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1 Introduction

Agriculture is a vital economic sector in Egypt, employing 30% of the workforce in rural areas and providing livelihoods for 55% of the population (World Bank, 2020).[1] Yet Egypt is an arid region with increasing water scarcity.[2] Scarcity in economic terms describes the situation when the available resource or commodity fall short of meeting all needs, Gibbons (2013). According to the National Strategy for Water Resources Management until 2050, Egypt's water needs amount to 80 bm^3 and its resources are 60 bm^3. In 2020, the import of virtual water ("the water that is used in the production process of an agricultural or industrial product", Chapagain and Hoekstra (2003)) is estimated at 30 bm^3. Therefore, and apart from the virtual water, the country has a water gap of 20bm^3. This gap is even increasing due to population and economic growth.

Another important aspect is the pressure this puts on non-renewable water resources. Egypt has a water stress ratio of 1.4 indicating increasing exploitation of non-renewable fossil groundwater. Hydrologists define water stress as the ratio between total freshwater withdrawn and total renewable freshwater resources taking into account the environmental water requirements. Because the withdrawn water includes non-renewable groundwater, the upper value could exceed one, FAO AQUASTAT. Furthermore, 97% of the renewable freshwater resources of the county are flowing from neighboring countries, mainly through the transboundary Nile river.[3] A major infrastructure project on the Blue Nile which provides more than 70 % of the Nile waters to Egypt, namely the Grand Ethiopian Renaissance Dam (GERD) is expected to result in water supply shortages in Egypt, Digna et al. (2018), Goor et al. (2010). Faced with this tough reality, the country is looking into a national strategy for water management in pursuit of achieving efficiency and adaptation. The creation of economic incentives to encourage the application of water-saving technologies is at the center of Egypt's national adaptation strategy, particularly in the agricultural sector. This sector is responsible for 80% of freshwater withdrawals.

In order to control water use and incentivize the best use of the scarce resource, economics suggests that the open access feature has to be limited or removed completely to avoid a *tragedy of the commons*, Feeny et al. (1990). This requires active policy interventions to either administratively regulate the access to water or to make the allocation based on the competition for this production factor among different economic sectors the same way these sectors compete for the other factors of production, e.g. capital, land or labor. What complicates things, however, is the fact that water is not quite the same as capital and labor. Water cannot be simply substituted by other factors in production. Particularly in agriculture water cannot be replaced below a specific level. This is not just a technical limitation as in the case of capital and labor but it is a natural biophysical constraint. Moreover, the implementation of such policies would inevitably have distributional effects which might be heterogeneous across income

[1]https://www.worldbank.org/en/results/2020/04/01/modernizing-irrigation-improved-water-security-for-farmers-in-egypt

[2]Precipitation rate (long-term average) is 51 mm/yr, FAO.

[3]FAO. 2016. AQUASTAT Country Profile – Egypt.

groups and regions.

The literature on water management offers many tools to deal with that. This includes volumetric water pricing, water caps or quotas, area-based pricing, crop-based pricing, input tax, output tax, among other things. These tools differ in terms of ease of implementation and transaction costs incurred in the implementation.[4] Water management is of high relevance in countries such as Egypt that are limited in water availability and where the agricultural sector plays an important role in the economy. Thus, policies that restrict the water quantity or make irrigation water more expensive have to take into account the interlinkages of this sector to other sectors and to the economy as a whole. On one hand agriculture is intrinsically linked to the agrifood processing sectors. Moreover, food prices and regional development are also two key aspects for policy makers. All this makes the quantification of positive externalities or the social benefit difficult and thus the decision making on which policy instrument to use becomes even more complicated.

Many previous studies investigated the value of agricultural water use in Egypt. He et al. (2006) introduced water policy instruments into a partial equilibrium (PE) model of the Egyptian agricultural sector. The policy instruments included water pricing, input tax, and output tax. The simulation results show declines in water demand and welfare losses in the agricultural sector in different magnitudes depending on the policy implemented. The limitation of this work is that it does not account for the cross-sectoral reallocation of water and the economy-wide welfare effects. Strzepek and Yates (2000) use an IFPRI static model to evaluate the impact of water supply reliability resulting from the construction of the High Aswan Dam (HAD) which created a controlled water supply compared to fluctuating inflows before. The model assumes Leontief combination of land and irrigation water. Farmers choose between four different pre-specified combinations of land and water in fixed proportions, based on the generated shadow prices of water and land. Osman et al. (2016) study the impact of water supply shortages on the Egyptian agriculture. The analysis models three different land-water types; groundwater-dependent land, Nile water dependent land and rain-fed agriculture. In addition, an increase in water use efficiency is modeled exogenously.

In this paper, we study the impact of different policies aiming at improving efficiency in the use of scarce water. Concretely, we focus on the reallocation of water between and within sectors, as a consequence of such potential policy interventions. The intervention aims at removing the *open access* feature of irrigation water. We study in depth four potential interventions; water quotas, market-based pricing, volumetric water pricing and crop-based charges. We extend the single-country IFPRI model.[5] to introduce water as an explicit production factor in all sectors. Then for each of the policy instruments, we implement a policy scenario.

Our approach deviates from the above literature in two ways. First, it includes not only water use in the agricultural sector but in all economic sectors. This allows for structural shifts in the economy, i.e.

[4] For an extensive discussion of these tools see Dinar and Schwabe (2015).
[5] Lofgren et al. (2002)

an expansion of sectors with a higher value for water relative to agriculture. Second, and concerning the agricultural sector, our work treats irrigation efficiency as a substitute for irrigation water – to a specific degree – and thus explicitly depicts the substitution possibility. This will allow us not only to understand the changes within the agricultural sub-sectors but also to answer the question about which cropping activity would be able to adapt by adjusting its water intensity and which crops might witness declines in production and area cultivated.

The rest of the paper is organized as follows, section 2 gives an overview of the irrigation system in the country and describes the relevant policy instruments, section 3 describe the methods and the data including the water cost of in agriculture and introduces the scenarios. Section 4 presents the results and discusses their implications and section 5 concludes.

2 Background

2.1 Irrigation System in Egypt

Almost 99% of crop production in Egypt is irrigated (FAO). The irrigation system in Egypt is designed to deliver full requirement flood irrigation. The construction of the HAD in the 1960s decoupled the water supply downstream the HAD from upstream variations. Following that and in addition to increased cropping intensity[6] the cultivated area expanded from the historical old lands on the Nile valley and the Delta into the New Lands in the desert. These two types of land differ in terms of their soil characteristics and fertility, and therefore their water requirement, productivity, and suitability for the cultivation of specific crops. Moreover, in the new lands groundwater is used while Nile water is the exclusive source in the old land.

Some studies, e.g. Gersfelt (2007), argue that in the clayey old land water is used inefficiently which represents a loss only at the farm level but not at the basin level. The reason for that is that the water delivered and not consumed or evapotranspired is recovered downstream. This makes the adoption of water-saving at the farm level economically wasteful. In sandy new lands this is however different. Still there are multiple reasons to think that the application of water-saving technology is feasible. First, water saving reduces the losses via the transpiration especially in hot areas. Second, the quality of the recovered water via drainage is lower than the saved water, this is in addition to the cost of setting up and maintaining a drainage system, of course. If the water is recaptured via aquifers, then the cost of groundwater pumping must be weighed against the cost of saving technology. Third, the recovery premise is even more doubtful in the sandy new land.

In front of each dam from the HAD downstream to the Mediterranean, there are two canals (see Fig... in the appendix), these deliver water to distributary branches from which water is pumped into

[6]The cropping intensity is a fraction of the cultivated area that is harvested. The cropping intensity may exceed 100 percent where more than one crop cycle is permitted each year on the same area. of 1.75 the harvested area reached 6.3 million hectare, FAO.

the fields. The drainage canals complete this system, where the agricultural drainage water is mixed with Nile water and reused in the system again. The government is responsible for the construction as well as the maintenance of this infrastructure whereas the pumping is done privately. Groundwater is used for irrigation in less than 20% of total cultivated area. There are two different types of groundwater; the Nile basin aquifer which is recharged via the Nile water and the fossil aquifers in the Egyptian desert.

2.2 Water-saving technologies

As mentioned above, the ability of farmers to respond to water prices is governed by their ability to save water given the decision to cultivate a specific crop. These technologies enhance irrigation efficiency. Irrigation efficiency is measured as the ratio between the water diverted and the water consumed by the crop.[7]

In general, using the right economic tools in water management and water allocation would give rise to the optimization of water use in crops with higher value per unit of water (economic efficiency) rather than crops with high value per hectare.

Even if water saving at the farm level does not necessarily contribute to savings at the aggregate, because most of the water withdrawn beyond the water consumed is recovered in the system, e.g. via groundwater withdrawal, high local efficiency in the 'new lands' is important as excess deliveries in the 'new lands' will not return to the system. Even in the old lands and as mentioned above water-saving might be beneficial at the aggregate.

If farmers adopt the water saving technology, then the excess water withdrawn will be reduced in relation to the price of water and the cost of saving water. This implies however that water productivity increases, hence demand for water would rise as well. If wastewater is included in the water management scheme, the increasing demand might then be met by treated wastewater. Wastewater treatment might become economically more feasible at higher levels of water prices and water productivity.

The Mathematical Model:

2.3 Irrigation Policy instruments

Different water management tools differ in many ways. Most importantly is their effects on the decision of farmers. If water is costly, this decision making has two steps; first the farmer decides what crop to

[7]There two related terms. First, water use efficiency is the yield per unit of water diverted (kg/m^3); this is also known as the water use technical efficiency. Second, water use productivity which measured as the dollar value of water produced per unit of of water or economic efficiency, Dinar and Schwabe (2015).

cultivate then she chooses the water quantity to apply. Indeed, these two steps could be analytically reduced to one step where the choice variable is water quantity (irrigation efficiency) and this quantity is allocated to the crop with the highest value of the marginal product (economic efficiency), see the derivation in the appendix. The final objective of these tools is to realize efficiency. Efficiency is reached when water is allocated to the economic sectors such that the total (or social) net benefits are maximized. Total net benefits are the difference between total benefits and total cost. Yet, quantifying the social benefits and social costs is a tedious job, since information on the social preferences are usually lacking. For instance, the social value of irrigation water is arguably positive and therefore is larger than the private value (the value of irrigation to farmers), because the society might value domestic food production and regional development. However, we will focus on the direct (private) benefits and costs.

2.3.1 Water Caps(Quotas)

Quotas mean limiting the quantity of water available for use either for individual users or collectively. It is important to recognize that implementing water quotas is not possible at the farm level given the current state of the irrigation system in Egypt. The quotas could be allocated based on the irrigation branch level. Currently there is some caps put on water availability, i.e. water is released into the distributional irrigation canals according to a seasonal schedule. If this is the case then water quotas would cap the overall quantity of water available, but it would have no impact on irrigation efficiency.[8] If the cap per area is set below the level of aggregate water required for irrigation, then the common tail-end problem would emerge where farmers at the tail-end of a canal would not be served. Even worse, quotas could lead to the overuse of water for farmers upstream which would expose the downstream farming activity even more. This might result in decline in area cultivated and land abandonment. Thus, water caps are unlikely to serve efficiency if they are appointed uniformly. Improvement could be reached, however, if the restrictions would target the low-value crops, Griffin (2016). In the current study we assume that water caps as well as all other tools are applicable at the level of individual agricultural producer.

2.3.2 Water pricing

Water pricing could take many forms. Market-based pricing treats water as any other commodity or input whose price is determined by free competition. The outcome will be that water is allocated first to the user with the highest marginal value, then to the one with the second highest and so on until the demand equals supply. This requires that the property rights over water are defined the same as with other commodities such that sellers and buyers trade water freely. The resulting allocation is Pareto-efficient and described as first-best solution. In the current analysis we assume that these property rights are defined, namely according to the current level of use.

[8] For more on this see for instance Gersfelt (2007)

A second tool is cost-recovery pricing. cost-recovery pricing, farmers pay for the actual water metric quantity they divert. This price is determined administratively and not via free markets. The charges could be flat (same for different levels of water use) or stepwise variable. The natural monopoly water supplier is regulated such that price setting has the goal to recover the fixed and variable cost of delivering water to farmers.

Putting a price on water increases efficiency by encouraging the wise use of the scarce resource after a threshold. This threshold is given by the biophysical water requirement.[9] Above this, the ability of farmers to reduce water use is governed by the elasticity of demand which in turn depends on the cropping pattern (permanent vs non-permanent crops) and irrigation technology among other things, Hellegers and Perry (2004). Efficient pricing ensures that the net marginal benefits (marginal benefit minus marginal cost) are equalized across the sectors competing for the use of a specific commodity, Griffin (2016). If the volumetric price is equal to the market price then the two tools would have the same effect. The problem is that the supplier has information on his cost but she does not have information on the value of water for users.

Another pricing regime is the crop-based water price where farmers pay a price based on what they crop. This tool discourages the cultivation of water-intensive crops with low-value of water such as rice and sugarcane and therefore reduces the overall water withdrawal and water consumption. Once the farmer pays the charge, she can withdraw the desired (unlimited) level of water, which reduces the efficiency gains. This tool indeed reduces the water consumption by making the cultivation of water-intensive goods less attractive, but they do not reduce water withdrawal per crop.[10]

3 Methods and Data

3.1 Cost share of water in Agriculture

Historically, irrigation water is not charged in Egypt. However, there is a land tax, Gersfelt (2007). The main crops are wheat, maize, rice, vegetables, fruits, fodder and sugarcane, The main water-consuming crops per hectare are sugarcane and rice. Table 1 shows the main crops and their irrigation needs. The cost of irrigation water includes the cost of the canals and dams (most dams are equipped with hydropower generators), infrastructure, and canal maintenance in addition to control and management cost of domestic irrigation engineering and administrative staff. The pumping cost which is borne by water users includes the cost of machines and the energy cost (gasoline or electricity).

The cultivated area amounted to 3.97 million hectare in 2020. But with a cropping intensity of

[9]This approach assumes that there is no production if the quantity of water available for irrigation of the crops is below this water requirement. Relaxing this assumption requires the introduction of yield to water functions.

[10]Hellegers and Perry (2004) note that, it is recommended to improve ways to monitor the impact of economic instruments on water consumed instead of water applied. It is complex to measure changes in actual consumption since where excess water applied is recaptured through groundwater recharge or re-use of drainage water the concept of losses is misleading.

Table 1: Main Crops and their water use in Egypt 2020

Crop	Area 1000 ha	Share of total harvested area	Total water use 1000 CM	CM/ha
Wheat	1429.684	0.21	5 611 016	3 924
Rice	499.361	0.07	7 987 679	15 995
Maize	976.401	0.14	8 184 167	8 382
Other cereals	228.343	0.03	1 421 708	6 226
Vegetables	642.411	0.09	2 305 150	3 588
Fruits	728.99	0.1	3579941	4 910
Oil crops	314.79	0.05	474 046	1 506
Tubers	299.559	0.04	NA	NA
Pulses	71.829	0.01	53 940	751
Sugarcane	217.625	0.03	3 100 805	14 248
Sugar beets	141.235	0.02	1 808 809	12 807
Fodder	1022	0.15	4 326 666	4 234
Cotton	76.918	0.01	576 306	7 492
Others	299.854	0.04	701 954	2 341

Data source: Annual Bulletin of Irrigation and Water Resources (2019).

175% the harvested area lies above 6 million hectare, FAO. The crops differ in terms of the share of water in their cost profile. Table... shows these values for the main crops. It is worth noting the value of water is relatively low for most crops... ... ...

3.2 The Model

The IFPRI model is a single-country static modelLofgren et al. (2002). The production in the standard model consists of two nesting levels. In the upper nest output is produced by intermediates composite and the Valued Added composite in fixed proportions. In the second level water enters the intermediate composite as a fixed quantity and is used in agriculture and manufacturing. In household's consumption functions water is used as a final good. The primary factors, labor, land and capital are substituted in the second level according to a CES relation.

We extend the IFPRI model in 2 different ways. First, we use water as a production factor in industrial and agricultural sectors in addition to serving as a final commodity in household consumption. Second, we use a novel nesting approach which explicitly models irrigation efficiency as an endogenous response to the policy, see Figure ... Then, the model will be calibrated to the 2019 SAM for Egypt . The SAM comprises 69 activities and 73 commodities. This includes 14 crops, 5 livestock, and 16 food processing and processing of agricultural raw material activities in addition to manufacturing and service sectors.

The agricultural production is represented by a series of nested CES and Leontief functions. At the bottom level, the substitutability between irrigation water and water-saving technology will be made explicit. Farmers have to choose the quantity of water to use and the investment in irrigation technology they want to make based on the relative costs of water and irrigation technology. Together, irrigation water and water-saving *commodity* make up a composite good, which then enters the value-added nest alongside capital, labor, and land in a Cobb Douglas functional form. The model includes only irrigated agriculture, therefore, there would be no substitution between irrigation water and rain-fed agriculture.

3.3 The Scenarios

After the model is calibrated to the modified Egypt SAM 2019, we introduce the policy instruments described in section 2 by running scenarios as following:

- Scenario I: the quantity of water available to agriculture is capped. This cap applies unequally across different crops. That is, the water available to specific crops is capped in order to discourage the cultivation of low-value crops or water intensive-crops.
- Scenario II: market-based price is introduced by treating water as a market commodity in all different uses.
- Scenario III: volumetric price on irrigation water is introduced while the price of other uses is fixed.
- Scenario IV: crop-based pricing where the price differs according to crop to discourage water use in less value crops.

4 Results and Discussion

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5 Conclusion

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A Appendix

Table 2: Main Studies on Irrigation efficiency in Egypt

Paper	Model type	Method	Scenrios
Osman et al. (2013)	one-country static CGE model	Water and land are substituted according to a constant exogenous CES water efficiency parameter	external water supply shock from the GERD hits agricultural sector