THE POLICY IMPLICATIONS OF USING WATER MORE THAN ONCE – THE CASE OF IRRIGATION IN EGYPT

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ABSTRACT

When water is scarce and agricultural production is dependent on irrigation, the question naturally arises how to allocate water most efficiently from society's point of view. Standard volumetric water pricing targets the amount of water the farmer applies to his field. However, what matters from a social efficiency point of view is often not how much water is applied to the field but rather how much water is consumed by the crops and evaporation, as a substantial amount of the water losses due to drainage and percolation tends to be recycled in a basin and become available for additional application cycles.

One example of this ability to use water more than once can be found in the Egyptian agricultural sector. Egyptian agriculture is traditionally centred around the Nile, and in the Nile Valley virtually all water losses are recovered by the basin water system. So far Egyptian farmers have not had to pay for their irrigation water, but water scarcity is expected to be a growing problem in Egypt due to population growth and reclamation of desert land for agricultural production. Efficient allocation of irrigation water is consequently becoming an important issue from an economic efficiency point of view, and the fact that water losses are at least partially recoverable has implications for the socially optimal choice of policy instrument to regulate the farmers' use of irrigation water.

Based on results from a theoretical model I have recently developed on the optimality of policy instruments for regulating farmers' use of irrigation water, the present paper will explore the empirical implications of different direct and indirect water allocation policy instruments ranging from water pricing to land taxation. The theoretical analysis will be incorporated into a modified version of the ORANI-G CGE model and the IFPRI 1997 SAM for Egypt, where the use of water in agriculture has been introduced.

The aim of the analysis is to compare the production and welfare implications of the theoretical first best instrument of combined volumetric water taxes and return flow credits with the theoretically second best instruments of standard volumetric water taxes or crop-specific land taxes. Simulation results for production and welfare implications are reported for the two kinds of water tax policy instruments, but a satisfactory implementation of crop-specific land taxes have not yet been found. It is nonetheless expected that crop-specific land taxes will perform relatively well from an efficiency point of view.

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1. INTRODUCTION AND BACKGROUND.

One of the special features of water is the fact that use of water typically does not imply complete physical consumption of the water applied in a given production or consumption activity. Furthermore, the non-consumed fraction of water applied is often returned to the water system and hence it becomes available for another application cycle. As the fraction of water applied, which is physically consumed, will often vary across activities, this in turn has implications for how scarce water resources should be allocated across competing uses.

The basic point is that if the non-consumed water flows return to the system and are reusable, then what matters from a social efficiency point of view is not how much water is applied in a given production or consumption activity, but how much water is physically consumed in the course of this activity, as the non-consumed part of water applied may be used again for another production or consumption activity. The implication of this phenomenon for economic policy is that in order to achieve the most optimal allocation of water, the policy instruments used for allocating this resource should not merely target the amount of water applied for a given activity but rather also take account of the reusable water return flows.

The use of irrigation water for crop production is a prominent example of the possibility of using water more than once. Depending on the particular irrigation technology used, the non-consumed fraction of water applied may easily be as high as 40% or more. This in turn suggests that taking account of return flows from irrigated agriculture may be very important when assessing a country's water resources, to the extent that these return flows are recoverable. In Egypt crop production is almost completely dependent on irrigation water from the Nile River and the associated aquifers. In the so-called Old Lands in the Nile Valley and Delta, farmers typically employ surface irrigation techniques, which have an irrigation efficiency of 60% (Bader 2004), where irrigation efficiency is defined as the ratio between the amount of water consumed by the crops and evapotranspiration and the amount of water applied to the field. While return flows from the Nile Delta are often not recoverable and / or reusable, return flows from the Nile Valley are virtually fully recoverable suggesting that the "same" irrigation water will often be used multiple times on its way from the High Aswan Dam to the Mediterranean Sea. Taking account of the recoverable return flows may consequently be an important consideration in Egypt when choosing policy instruments for efficient allocation of irrigation water in the case of water scarcity.

Water scarcity has not previously been a national issue in Egypt, but increasing population size and the Egyptian government's plans to reclaim dessert land for agricultural cultivation means increasing demands on Egypt's fixed water resources. Water scarcity in Egypt is consequently foreseeable in a not too distant future. Given that the agricultural sector accounts for 83% of water diversions in Egypt (Mohamed 2001), efficient allocation of irrigation water would appear to be important for the Egyptian economy. But what policy instruments will assure the most efficient allocation of irrigation water when return flows from irrigated agriculture are at least partially recoverable? And what difference does it make to use policy instruments which take account of these recoverable return flows?

The present paper will seek to answer these questions through theoretical and empirical analysis of three types of tax policy instruments: Pricing of water applied and crediting of return flows, only pricing of water applied, and finally crop-specific land taxation. As the analysis will show, pricing water applied and crediting of return flows is the only one of these three policy instruments, which always yields a first-best allocation of irrigation water. However, as this theoretical first-best instrument would be virtually impossible to implement in a real-world setting, policy makers will have to use second-best instruments like only pricing water applied or crop-specific land taxes for allocating irrigation water. Determining the efficiency and welfare properties of these policy instruments is consequently important from a real-world policy point of view.

The paper is organized as follows: Section two will present the results from a theoretical model on the relative efficiency of these three tax policy schemes. The tax policy instruments will subsequently be incorporated into a national CGE model in which their impact on welfare and production patterns can be assessed. However, as it has not yet been possible to achieve a satisfactory implementation of crop-specific land taxes in the CGE model, simulation results will only be reported for the two water tax policy instruments. Section three presents the CGE model and data, while section four outlines the design of the CGE policy scenarios. Section 5 presents the results of the CGE analysis, section 6 discusses key model assumptions, and section 7 concludes.

2. THEORETICAL IMPLICATIONS OF USING WATER MORE THAN ONCE.

The issue of allocating irrigation water efficiently in the presence of the recoverable return flows basically amounts to solving two externality problems simultaneously.

The first externality relates to farmers' initial appropriation of irrigation water in a setting where the allocation of the scarce irrigation water is not governed by the market mechanism. A classic example of this type of externality is the so-called head-end-tail-end problem, where irrigators at the head of an irrigation canal may have virtually unlimited access to irrigation water, while irrigators at the tail end of the canal may only receive a small fraction of the water needed to cover their irrigation needs.

The second type of externality relates to the recoverability of return flows. This externality arises when return flows from upstream irrigation activities are recovered by the river basin system, as these return flows affect the amount of water available for other irrigators downstream.

Inefficiencies arising from externalities can be ameliorated through different types of policy interventions including taxes and quotas. As mentioned in the introduction the present analysis of irrigation water externalities will focus on three types of tax policy instruments: Taxing amount of water applied and crediting amount of return flows, only taxing of water applied, and finally crop-specific land taxation. The aim of the theoretical analysis is to ascertain to what extend the different tax policy instruments are able to ensure an efficient allocation of irrigation water in a general situation, where both the water appropriation and the recoverable return flows externalities are present. This is done by formulating the water allocation problem from the point of view of the social planner and from the point of view of the individual farmer under the three different policy scenarios and then comparing the first order conditions of the social planner's problem and the farmer's problems.

2.1. THEORETICAL FRAMEWORK

The theoretical model has been formulated as a linear programming problem in line with the agricultural sector model tradition. This implies the use of Leontief production technology in terms of fixed coefficients for input per land unit, including the input of water per land unit. The model is static and deterministic and thus disregards any dynamic aspects as well as issues arising due to uncertainty. Irrigation water is the only source of water in the model implying that crop production is 100 per cent dependent on irrigation. The analysis focuses on the quantities of water applied, consumed, and recycled. The quality of the water, on the other hand, and the changes it undergoes in the production process are not taken into account, and leaching requirements are not considered either. Water provision costs are also not taken into consideration, meaning that the only cost to society of using water is the opportunity cost of this resource.

Both the social planner's problem and the farmer's problem are formulated as maximizing producer surplus subject to relevant constraints, including a constraint on the amount of land available to each farmer. The key difference between the social planner's and the farmer's problem is the way in which water enters these two optimization problems. Water enters the social planner's problem as a constraint on the total amount of water, which can be taken out of the system. In the farmer's problem, on the other hand, there is no constraint on water usage. In stead taxes are introduced on the use of water or land in order to induce the farmer to limit his use of water so that aggregate water usage does not exceed the total amount of water, which can be taken out of the system.

The farmer's water use is specified in terms of water applied, which is the amount of water he applies to his field. However, as mentioned in the introduction, only a fraction of this water is consumed – or evapotranspired - by the crops.[1] The rest of the water – here termed return flows - either ends up in the drains or percolates into the ground. Water from the drains is often not discarded but may be returned to the initial water source (e.g. a river) or pumped back into the irrigation canals, while percolating water may recharge aquifers. A fraction of

[1] In this paper the term "crop water consumption" is equated with crop evapotranspiration. Evapotranspiration is defined as the "the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration" (FAO 1998 chapter 1 p 1). The reason for combining the two concepts evaporation and transpiration in the single concept evapotranspiration is that the two processes take place simultaneously and are not easy to distinguish from one another. When the crop is small water is primarily lost due to soil evaporation, whereas transpiration is the main source of water loss once the crop is well developed and covers most of the soil (FAO 1998 chapter 1 p 2).

the return flows can thus typically be recovered for yet another diversion cycle. What matters from society's point of view is thus not how much water the farmer applies to his field, but rather how much of this water is consumed by the crops or irretrievably lost through drains or percolation. The water constraint in the social planner's problem is consequently formulated as a constraint on water consumed or irretrievably lost rather than a constraint on water applied. The water constraint can be written in the following way:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(e_i + (1-\beta)(d_{ij} - e_i))X_{ij} \leq \overline{W} \qquad (1)$$

Where:

- i : Index of crops, $i = 1,...,I$.
- j : Index of farmers, $j = 1,...,J$.
- X_{ij} : Size of area cultivated with crop i by farmer j. X_{ij} is measured in feddan.[2]
- $\overline{W}$: The total amount of water which can be taken out of the system, measured in cubic meters.
- e_i : Amount of water evapotranspired (or "consumed") per area unit by crop i. e_i is measured in cubic meters/feddan.
- d_{ij} : Amount of water applied per area unit for production of crop i by farmer j. d_{ij} is measured in cubic meters/feddan. The amount of water applied is assumed to be partially determined by the amount of water consumed in accordance with the following equation: $d_{ij} = \frac{1}{\gamma_{ij}} e_i \Leftrightarrow e_i = \gamma_{ij} d_{ij}$
- γ_{ij} : Field irrigation efficiency for farmer j for crop i, measured as the share of water applied, which is consumed by the crops. $0 \leq \gamma_{ij} \leq 1$.
- β : Fraction of water losses (i.e. the difference between water applied and water consumed), which are recovered by the river basin system. $0 \leq \beta \leq 1$.

[2] Feddan is the Egyptian measure of area size, corresponding to 0.420 hectares or 1.037 acres (World Bank 1993).

The first term on the LHS of equation (1) captures the amount of water evapotranspired by crop i, while the second term captures the amount of the return flows, which are not recovered.

The first key features to note in this formulation of the national water constraint is the fact that the amount of water consumed by a given crop is assumed to be independent of farmer-specific characteristics. Water applied, on the other hand, will depend on farmer-specific characteristics, as the field irrigation efficiency coefficient is assumed to depend on these characteristics. The assumption that water consumed is independent of farmer-specific characteristics will prove important for the efficiency properties of crop-specific land taxes.[3] The reason for this is that the social planner is assumed to be able to observe the farmer's choice of crops but not the farmer-specific irrigation coefficient. The social planner is consequently able to tailor the tax policy instruments to take account of crop choice but not field irrigation efficiency. While field irrigation efficiency is assumed to be a non-observable farmer-specific characteristic, it is not assumed to be a choice variable for the farmer, as Egyptian farmers may in reality have rather limited choice of irrigation technology due to technical, financial, and legislative constraints.[4]

The fraction of return flows, which are recoverable (i.e. β), will typically depend upon the location of production, as the degree of recoverability may change from one region to the other depending in part on the drainage and percolation characteristics of the regions. In order

[3] According to FAO evapotranspiration for a given crop (ET_c) may be calculated by multiplying reference crop evapotranspiration (ET_o) by a crop-specific coefficient (K_c). The reference crop evapotranspiration ET_o refers to the evapotranspiration of a hypothetical grass reference crop with certain characteristics including abundant availability of water. When water is abundantly available, ET_o only depends on climatic parameters and not soil factors (FAO 1998 chapter 1 p 6 and 8). This is the reason for assuming that crop water consumption is independent of farmer-specific characteristics. This in turn carries with it the implicit assumption that crops can only be produced when there is sufficient water to meet their optimal water requirements. This unrealistic assumption has been relaxed within the theoretical framework in Gersfelt (2006).

[4] However Egyptian farmers do have a choice regarding the degree of land preparation they undertake and this will also affect the irrigation efficiency.

to keep the model simple, the present model is specified for a given region, within which drainage and percolation characteristics are assumed to be uniform across farms.

2.2 RESULTS OF THEORETICAL ANALYSIS.

The individual farmer's problem is formulated for each of the three policy schemes: (1) A uniform tax on water applied and a uniform credit on return flows, (2) a uniform tax on water applied, and (3) crop-specific taxes on land. The first order conditions from the farmer's problems are then compared to the first order conditions for the social planner's in order to determine the optimal level of each of the tax policy instruments, and whether the instruments can be in fact be implemented to yield a first-best outcome.

With respect to the scenario with a uniform tax on water applied and a uniform credit on return flows, the analysis shows that this policy scheme can achieve a first best allocation of irrigation water when these are set at the following rates:

$$T_D = \lambda_2 \text{ and } T_R = \beta\lambda_2$$

Where:

- T_D : Tax on water applied, measured in LE/cubic meter.
- T_R : Credit for return flows, measured in LE/cubic meter.
- λ_2 : The social shadow price of water consumed or irretrievably lost.

Furthermore, additional analysis shows that setting the water diversion tax and return flow credit at these rates in fact amounts to taxing water consumed or irretrievably lost by T_D .

The second instrument analyzed is a uniform tax on water applied and the theoretical analysis shows that this tax should optimally be set at the following rate:

$$T_D = \lambda_2(1-\beta(1-\gamma_{ij}))$$

The expression $1-\beta(1-\gamma_{ij})$ is the fraction of water applied, which is not returned to the system (i.e. the fraction of water applied, which is either consumed or irretrievably lost). Comparing this result to the result for the first best instrument of taxing water applied and crediting return flows, we see that in the case of only taxing water applied the tax rate on water applied should be lower than the social shadow price of water consumed or lost in order to compensate for the fact that a fraction of the return flows are recoverable.

The tax on water diversions is supposed to be uniform since the government is assumed not to be able to verify neither what crops the water is used for nor the farmer-specific irrigation efficiency. However, setting the tax at the optimal rate will not result in a first-best allocation of water, if return flows are at least partially recoverable (i.e. if $\beta > 0$) and field irrigation efficiency coefficients differ across crops and / or farmers, as the single tax rate would not be able to accommodate differing fractions of recoverable return flows. If, on the other hand, return flows are not at all recoverable (i.e. if $\beta = 0$), then a uniform tax set at the rate $T_D = \lambda_2$ will be able to achieve a first-best allocation of irrigation water as in this case the externality of recoverable return flows disappears. This is an example of the familiar principle that in order to achieve a first best solution you typically need one policy instrument for each imperfection you need to correct. When return flows are at least partially recoverable the uniform tax on water applied has to address two externality problems. The outcome is a second-best allocation of irrigation water, as the water applied tax is not able to adequately handle the recoverability of return flows.

The third policy instrument, which is analyzed, is crop-specific land taxes, and the theoretical analysis shows that the optimal rates for these taxes are:

$$T_{Li} = \lambda_2(1-\beta(1-\gamma_{ij})d_{ij}$$

Where:

- T_{Li} : Crop specific land tax, measured in LE/feddan.

Although this policy scheme allows for tax rates to differ across crops, a first-best allocation of water is not possible if irrigation efficiency differs across farmers and return flows are not fully recoverable (i.e. if $0 \le \beta < 1$), as it would require the social planner to have knowledge of the non-observable field irrigation efficiency coefficients. However, if return flows are fully recoverable (i.e. if $\beta = 1$), then crop-specific land taxes set at the rate $T_{Li} = \lambda_2 e_i$ would ensure a first best allocation of irrigation water in this model. The important point here is that crop-water consumption - e_i - is assumed to be independent of farmer-specific characteristics since this implies that the social planner only has to be able to observe the farmers choice of crops. It should be noted, however, that the result of crop-specific land taxes producing first-best allocations when return flows are fully recoverable does not hold in a more elaborate version of the model, where each crop can be grown using different water-yield techniques, as the crop-specific land taxes cannot ensure optimal choices of water-yield techniques (cf. Gersfelt (2006)).

The conclusion of the theoretical analysis is consequently that only the policy scheme of taxing water applied and crediting return flows is able to ensure a first-best allocation of irrigation water regardless of the values assumed by the irrigation efficiency coefficient and return flow recoverability coefficient. The efficiency properties of the two other policy schemes – the single uniform tax on water applied and the crop-specific land taxes – depends on the values of the irrigation efficiency and the return flow recoverability coefficients and consequently the efficiency of these two policy instruments cannot be ranked theoretically. It is therefore necessary to undertake an empirical investigation of these policy instruments. This is done in a national CGE model of Egypt.

3. MODELING AND DATA WORK FOR CGE ANALYSIS.

The investigation of the empirical properties of the three tax policy instruments is carried out in a national CGE model of Egypt. The CGE policy simulations are undertaken in a modified version of the ORANI-G model using IFPRI's 1997 disaggregated SAM for Egypt and data on crop water consumption requirements, irrigation efficiency, and recoverability of return flows in Egyptian agriculture.[5]

3.1 INCORPORATING WATER INTO THE ORANI-G MODEL

The version of the ORANI-G model used in this CGE analysis is the multi-household version of the ORANI-G model without margins and regional extensions.[6] Following the approach taken in Robinson et al (2002), water is introduced into the model by adding a land-water nest under the original primary factor land (cf. diagram 1 below).[7]

Dry land and water are combined using a Leontief production function to produce "wet" land, which is subsequently combined with labor and capital in the primary factor nest. In the present formulation of the model, a given crop can only be produced with one combination of land and water. This is obviously an overly restrictive assumption, as crops can be produced with sub-optimal amounts of water. The assumption has been relaxed in the theoretical model

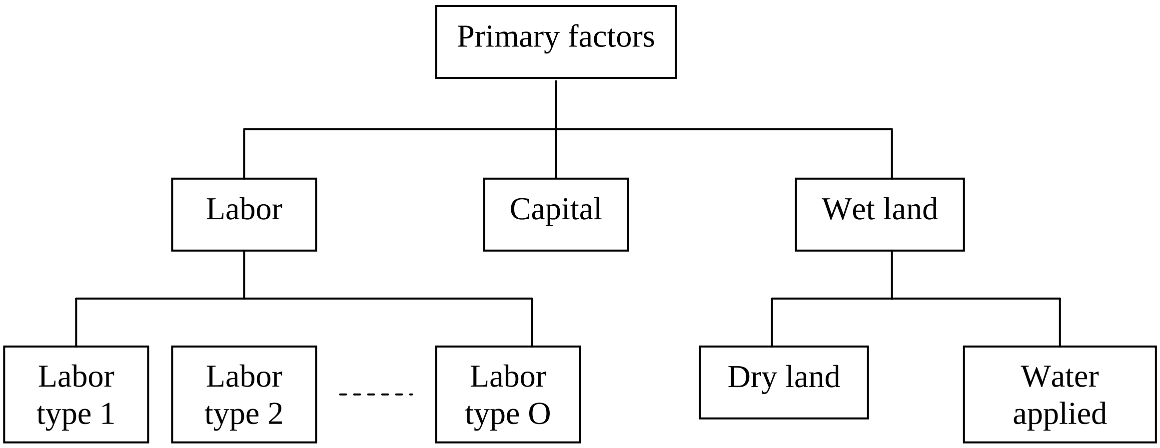
[5] The ORANI-G model is documented in Horridge (2005). Information about IFPRI's 1997 disaggregated SAM for Egypt can be found in Löfgren and El-Said (1999). Data on crop water consumption requirements, irrigation efficiency, and recoverability of return flows are gathered from Robinson et al (2002), Bader (2004), and Mohamed (2001).

[6] Information about the multiple household version of ORANIG03 can be found at the following website: http://www.monash.edu.au/policy/oranig.htm

[7] However, the model by Robinson et al includes four different land-water technology combinations for each crop, while the present model only allows for one land-water technology for each crop (cf. below).

presented in Gersfelt (2006), and the plan is to also relax this assumption in the empirical CGE analysis at a later date.

DIAGRAM 1: Structure of primary factor nest in the model



Source: Adapted from diagram in Horridge (2005) p 18.

The water variable, which enters the production function, is water applied as this is the variable the farmer is assumed to control directly. The two water tax policy schemes - taxing water applied and crediting return flows vs. only taxing water applied - will be implemented by levying taxes on the water applied variable. The national water constraint, on the other hand, is specified in terms of water consumed or irretrievably lost, as this is the amount of water, which is actually taken out of the system in the course of production. For modeling purposes, the amount of water consumed or irretrievably lost can be calculated based on information about the amount of water applied for the production of a given crop, cf. diagram 2 below.

DIAGRAM 2: Calculating water consumed or irretrievably lost

WATER DIVERTED = WATER CONSUMED + NON-RECOVERABLE RETURN FLOWS + RECOVERABLE RETURN FLOWS

$$d_{ij}X_{ij} = e_i X_{ij} + (1-\beta)(d_{ij} - e_i)X_{ij} + \beta(d_{ij} - e_i)X_{ij}$$

$$= \gamma_{ij} d_{ij} X_{ij} + (1-\beta)(1-\gamma_{ij})d_{ij}X_{ij} + \beta(1-\gamma_{ij})d_{ij}X_{ij}$$

$$= (1-\beta(1-\gamma_{ij}))d_{ij}X_{ij} + \beta(1-\gamma_{ij})d_{ij}X_{ij}$$

Proportion of water diverted which is consumed or irretrievably lost

Proportion of water diverted which is subsequently recovered

NOTE: For definition of the variables used in diagram see theoretical framework in section 2.1

A land constraint is also introduced into the model. Both the water constraint and the land constraint are formulated in physical quantities. As will be discussed in the data section, the starting point of the analysis is a hypothetical equilibrium in which both the land and water constraint is assumed to bind, implying that land and water rents are strictly positive. The simulations are designed so as to not drive land or water rents to zero, and the physical land and water constraints are consequently assumed to bind at all times. Future work on the model includes the introduction of a complementarity statement, which will allow either the land or the water constraint to be non-binding.

3.2 DATA WORK.

Data work for the present analysis has encompassed preparation of various data sets relating to water and land use in agriculture as well as modifications to the SAM and model parameters.

The modifications to the SAM encompass disaggregation of various SAM accounts to fit the data needs of the ORANI-G model. After the basic database for the ORANI-G model had been constructed, some of the activity and commodity accounts where aggregated in part to avoid problems of having several industries producing seemingly the same products in a long run simulation without industry fixed factors.[8] The ten households in the database were also aggregated to one single household. The parameter values for the various elasticities etc. were primarily taken from the standard Australian ORANI-G database and an ORANI-G model for Iran.[9] The elasticity values for household demand were chosen so as to turn the Klein-Rubin (or Stone-Geary) demand function into a simple Cobb-Douglas function, as focus in the present analysis is on production rather than consumption.

The SAM does not contain any information on water but merely the value of land used in production of the different crops. As agriculture is basically 100 per cent dependent on irrigation in Egypt, these land values must be the combined value of "dry" land and irrigation water needed for producing the crops in question. The SAM values for land input into crop production are thus assumed to include the value of the water used in production of these crops. The base year of the SAM is 1997, and water scarcity has most likely not been an issue in Egypt at this point in time. However, as a complementarity statement on the water constraint has not yet been incorporated in the model, the data on land and water use has been prepared under the assumption that the water constraint is indeed binding and that part of the land value in the SAM can thus be attributed to strictly positive water rents.

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[8] The problem of having several industries producing seemingly the same products in a long simulation without industry fixed factors arises because seasons have not yet been introduced in the model (which would make the industries summer and winter vegetables use inputs from different seasons) and because relevant agronomic constraints have not yet been introduced in the model (short berseem is a crop that precedes cotton and is as such not a perfect substitute for long berseem)

[9] Information about the standard Australian ORANI-G database and the Iranian ORANI-G database can be found at the following websites: http://www.monash.edu.au/policy/oranig.htm and http://www.monash.edu.au/policy/archivep.htm. Löfgren and El-Said (1999) do list a number of Egypt specific elasticities etc., but these have not yet been incorporated into the model.

The specification of the land and water constraint requires data on the physical amounts of land and water used for the production of the different crops. When the crop land values in the SAM are compared with data on land use for crop production, it turns out that returns to irrigated land differs quite substantially across crops. This would at first appear to be incompatible with the assumption of the initial database representing equilibrium, but the differences in crop land values may in fact be explained by the lack of regional disaggregation of the SAM. Cropping patterns may well differ substantially across regions due to agronomic conditions and / or policy constraints, and this may in turn give rise to differences in returns to land across the different regions. However, the present analysis is carried out in aggregate model of Egypt without regional disaggregation. In order for the SAM data to constitute an initial equilibrium, data for land use in crop production has consequently been artificially created to ensure that returns to land are equal across different crops.

Apart from the lack of regional disaggregation, the model and data have also not been disaggregated to distinguish between different seasons. This implies that the results will overestimate the substitution possibilities in crop production, and that perennial crops can not be handled appropriately. Given these lacks of disaggregation, the results of the present analysis should consequently only be considered as illustrations of how the policy instruments work, not predictions about their actual impact on Egyptian agriculture in case they were to be implemented. Future work on the model and database will include regional and seasonal disaggregation in order to produce more realistic estimates of the impacts of the tax policy instruments.

4. DESIGN OF EMPIRICAL ANALYSIS FOR ILLUSTRATING THEORETICAL RESULTS.

The aim of the policy analysis is to compare production patterns and welfare levels under the three different policy schemes - taxing water applied and crediting return flows, taxing water applied, and taxing use of land using crop-specific tax rates. This is done by applying a positive shock to the supply of dry land in each policy simulation. Such an increase in the amount of dry land for crop production will increase the demand for water for crop production, but the amount of water available for consumption or irretrievable loss is assumed to be fixed. In stead the new tax policy instruments are endogenized in order to reestablish the equilibrium between demand and supply of dry land and water.

Following the theoretical framework presented in section 2.1 and 2.2, the three tax policy instruments are modeled as taxes on *quantities* of water diverted or dry land rather than *ad valorem* taxes. The three tax schemes are implemented in the following way:

- *Tax on water applied and credit for return flows*: As mentioned in section 2.2, taxing water applied and crediting return flows amounts to taxing water consumed or irretrievably lost. As shown in section 3.1, the amount of water consumed or lost in the production of a given crop can be calculated based on the amount of water applied and knowledge of the irrigation efficiency and return flow recoverability of the region. The policy scheme of taxing water applied and crediting return flows is consequently modeled as a crop-specific tax on water applied, where the crop-specific coefficient of the tax rate is the proportion of water diverted, which is either consumed by the crop in question or irretrievably lost (cf. the fraction $(1-\beta(1-\gamma_{ij}))$ in diagram 2).[10] The

[10] It should be noted that while taxing water applied and crediting return flows is comparable to taxing water consumed or irretrievably lost, the social planner would not be able to implement the latter of these schemes, as he is assumed not to be able to observe the farmer-specific irrigation efficiency. Implementing the scheme in this way is thus a short cut, which is taken for modeling convenience. However, as can be seen in section 2.2, the original policy scheme of taxing water applied and crediting return flows does not depend on region-specific information, which is why the results from taking the modeling short cut will still be valid.

policy instrument is implemented in the CGE model by exogenizing the uniform basic price of water applied (i.e. the water rent) while endogenizing the crop-specific tax on water applied. The uniform basic price on dry land (i.e. the dry land rent) is left endogenous, as dry land is assumed to be owned by the farmers, who must therefore be expected to adjust their cropping patterns in accordance with any changes in the dry land rent.

- *Tax on water applied*: Is simply implemented as a uniform tax on water applied. The policy instrument is implemented in the CGE model by exogenizing the uniform basic price of water applied (i.e. the water rent) while endogenizing the uniform tax on water applied. The uniform basic price on dry land is again left endogenous.
- *Crop-specific land taxes*: Will be implemented as crop-specific taxes on dry land, where the crop-specific coefficient of the dry land tax rate is the crop water consumption coefficient (e_i).

The differences between the three policy instruments are driven by the two key water parameters – the irrigation efficiency and the recoverability of the return flows. In the theoretical model, field irrigation efficiency is assumed to be a farmer-specific parameter, which the social planner cannot observe. In the CGE model there is no farmer-specific dimension, so irrigation efficiency simply becomes a region-specific parameter. However, the social planner is still assumed to be unable to observe this parameter, as the design of the policy instruments would otherwise be rendered meaningless.

It is the variation in the irrigation efficiency across regions or crops, which produces the fundamental difference between the two water tax policy instruments. [11] However, the present analysis is undertaken in a single-region model, and the irrigation efficiency parameter consequently does not have a regional dimension in this analysis. In order to illustrate the difference between the two water tax instruments, the irrigation efficiency parameter is assumed to be crop-specific by assuming that rice is produced with lower irrigation efficiency than other crops. The irrigation efficiency for rice has been set to 0.5, while the irrigation efficiency for all other crops is set to 0.65.

The other key water parameter is the recoverability of return flows. As outlined in section 2.2, the recoverability of return flows also plays a central role in the similarities and differences between the three policy instruments. In the extreme case of 0 per cent recoverability of return flows, the uniform tax on water diverted becomes equivalent to the first-best instrument of taxing water diverted and crediting return flows. In the other extreme case of return flows being 100 per cent recoverable, the crop-specific tax on dry land becomes equivalent to taxing water diverted and crediting return flows in this version of the model, where there is no choice between water-yield techniques. While the average return flow recoverability for Egypt lies between these two extreme cases, they do serve as useful checks on whether the policy instruments are functioning as expected in the CGE model. The policy simulations will consequently be undertaken for the following three values of the return flow recoverability coefficient: 0%, 30%, and 100%.[12]

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[11] As previously mentioned, the policy scheme of taxing water applied and crediting return flows amounts to taxing water consumed or irretrievably lost. If irrigation efficiency is not crop-specific then a tax on water consumed or irretrievably lost would be directly proportional to the tax on water applied. As tax rates are endogenous in the policy simulations, the two policy schemes would yield identical results in the single-region model. In a multi-region model, where either irrigation efficiency or return flow recoverability differs across regions, this would not be the case.

[12] The initial cropping pattern and hence also the initial water diverted requirements, is assumed to be identical in each policy simulation. This, however implies that the initial amount of water consumed or lost will differ with the return flow recoverability coefficient. As the water constraint is assumed to bind at all times, the amount of

As outlined in the beginning of this section, the policy simulations are carried out by increasing the amount of dry land and setting the tax policy instrument in question to be endogenous. The amount of dry land is increased by 5 % in each of the policy simulations. The reason for choosing a relatively small shock like this is the fact that both the land and water constraint are presently modeled as being binding at all times, which might not be a reasonable assumption if the model were subjected to a large increase in the supply of dry land.

The closure used for all three simulations is a long run closure in which aggregate employment, aggregate capital stock, and aggregate amount of water for consumption / loss is assumed to be fixed. On the expenditure side the model is closed by fixing the trade balance as a proportion of GDP, and government consumption follows aggregate household consumption. The workings of the policy instruments will be evaluated based on their impact on cropping patterns and welfare. The changes in cropping patterns will be assessed based on the changes in land allocation, and the changes in welfare are proxied by the changes in aggregate real household consumption.

5. EMPIRICAL IMPLICATIONS OF USING WATER MORE THAN ONCE: THE CGE RESULTS

The results of the policy simulations have been divided into three subsections based on the three values of the return flow recoverability coefficient. In section 5.1, the results are presented for the case in which the return flow recoverability is 30%. In section 5.2, the results are presented from the case in which return flows are not recoverable, while the results from the case in which return flows are fully recoverable are presented in section 5.3. As

water available for consumption or loss will differ in the three scenarios, and results from different policy simulations are consequently not straightforward comparable.

mentioned in the introduction, no results are reported for the crop-specific land tax instrument as a fully satisfactory implementation has not yet been achieved.

5.1 Results for simulations with return flow recoverability of 30%.

Table 5.1 shows the percentage change in the allocation of land across crop-producing industries, when return flow recoverability is 30%. The overall changes in the cropping pattern are related to the relative water intensity of the crops, as land allocation generally increases for less water intensive crops (like other winter crops, legumes, wheat, and vegetables) while there is a reduction in the amount of land allocated to the production of more water intensive crops (like sugar cane, rice, and fruits).[13] The explanation for this result is the fact that a shock, which increases the amount of dry land for agricultural production, implies an increase in demand for the fixed water resources. As the endogenous water taxes drive up the price of water for agricultural production, the farmer will tend to adjust his cropping pattern accordingly by allocating more land to the relatively less water intensive crops. However, as mentioned in section 3.2, given the lack of regional and seasonal data disaggregation and hence the lack of restrictions on substitutability between crops, the results should not be considered predictions of possible policy outcomes but rather simple illustrations of the difference between the way the policy instruments work.

[13] It should be noted that the changes in allocation of land for the production of different crops is not solely driven by the relative water intensity of the crops. Whether or not the crop is traded internationally also explain part of the land allocation pattern, as the domestic demand for commodities, which are not traded internationally (e.g. sugar cane and other winter crop), will tend to dampen the increase or decrease in the production of such commodities.

TABLE 5.1: Percentage change in allocation of land across crop-producing industries when return flow recoverability is 30 %

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Wheat	12.4958	12.4522	
Maize	0.9850	1.1594	
Rice	-21.5825	-22.4356	
Legumes	24.2770	23.9112	
Sugar cane	-12.3206	-12.0451	
Other winter crops	13.8012	13.5665	
Other summer crops	1.1521	1.2817	
Fruit	-15.0273	-14.5357	
Vegetables	13.5216	13.4771	
Cotton	-3.9776	-3.7180	
Berseem	2.3124	2.3365	

When return flows are partially recoverable, differences in irrigation efficiency across crops will matter from an efficient water allocation point of view. The reason is that differences in irrigation efficiency will result in different proportions of water applied ending up as return flows. When return flow recoverability is less than 100 per cent, a fraction of the return flows will be irretrievably lost. For a given crop, the amount of water which is irretrievably lost in the course of production will consequently increase as irrigation efficiency decreases.

As outlined in section 4, the irrigation efficiency for rice is assumed to be lower than the irrigation efficiency for other crops. Given that return flows in the present scenario are partially recoverable, the first-best instrument of taxing water applied and crediting for return flows is the only one of the instruments, which can adequately deal with this difference in irrigation efficiency across crops. Compared with the allocation of land under the first-best instrument, a uniform tax on water applied should result in a smaller amount of land being used for rice production, as this instrument does not capture the fact that a proportion of the higher return flows from rice production are indeed recoverable.[14] Looking at the changes in the amount of land used for rice production, we see that this prediction is realized in the

[14] In a sence the uniform tax on water applied treats all return flows as being irretrievably lost although the optimal tax rate for this instrument is lowered to take account of the average return

results, as a uniform tax will result in a larger reduction in the amount of land being used for rice production (-22.43%) than will taxing water applied and crediting return flows (-21.58%).

Table 5.2 shows the welfare impact of the policy instruments, where the change in welfare is proxied by the change in real household consumption. When return flows are at least partially recoverable, a uniform tax on water applied is a second-best instrument, and we would therefore expect welfare to be smaller in the case of a uniform tax on water applied than in the theoretical first-best case of a tax on water applied and credit for return flows. As seen in table 5.2, this prediction is realized in the welfare results from the simulations, as real household consumption increases by 0.1967 per cent in the scenario of a uniform tax on water applied, while it increases by 0.1975 per cent in the scenario with a tax on water applied and credit for return flows.

TABLE 5.2: Percentage change in welfare when return flow recoverability is 30%

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Real household consumption	0.1975	0.1967	

However, while this difference in overall welfare between applying the first-best instrument of taxing water applied and crediting return flows and applying the second best instrument of a uniform tax on water applied is quite small, it can not simply be interpreted as implying that is makes no difference whether first-best or second-best instruments are used to allocate irrigation water. As mentioned previously, the lack of regional and seasonal disaggregation implies excessive substitutability between crops. In a more disaggregated model the differences between the policy instruments may thus be more pronounced. Furthermore, the welfare results also show that the basic shock of increasing dry land supply by a mere 5% only results in minor impacts on welfare. A larger shock to the supply of dry land would have a greater impact on aggregate welfare which would in turn make the differences between the policy instruments more pronounced.[15]

5.2 RESULTS FOR SIMULATIONS WITH RETURN FLOW RECOVERABILITY OF 0%.

When no portion of return flows are recoverable, the second-best instrument of a uniform tax on water applied should be equivalent to the first-best instrument of a tax on water applied and credit on return flows. The percentage changes in cropping patterns for the policy instruments, when return flow recoverability is 0 per cent, are presented in table 5.3. Comparing these changes in cropping patterns for the two water tax instruments we see that they are indeed identical, and the policy instruments are consequently behaving as expected.

TABLE 5.3: Percentage change in allocation of land across crop-producing industries when return flow recoverability is 0 %

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Wheat	12.2731	12.2731	
Maize	1.3203	1.3203	
Rice	-21.7699	-21.7699	
Legumes	23.2583	23.2583	
Sugar cane	-11.6880	-11.6880	
Other winter crops	13.1917	13.1917	
Other summer crops	1.4081	1.4081	
Fruit	-13.9581	-13.9581	
Vegetables	13.2668	13.2668	
Cotton	-3.4370	-3.4370	
Berseem	2.3706	2.3706	

[15] It should be noted that a scenario with a substantially larger increase in Egyptian agricultural land would not be unrealistic compared with the Egyptian government's land reclamation plans. Estimates on how much land the Egyptian government plan to reclaim varies somewhat from source to source. However, according to Hellegers and Perry, The Land Master Plan of 1986 estimated Egypt's additional reclaimable lands at 3.4 million feddan (Hellegers and Perry 2004 p 64). According to preliminary estimates from the 1990 agricultural census, Egypt's agricultural holdings then amounted to 7.5 million feddans (of which 5.4 million feddans are old lands and 1.9 million feddans are new lands). This corresponds to only 3 % of the total land area. The land reclamation plans are thus very ambitious as they aim to increase agricultural land by up to 45%. However, so far progress in land reclamation has been much slower than planned, which has resulted in a widening gap between food self-sufficiency and food demand (Mohamed 2001 p 10).

Table 5.4 presents the percentage changes in welfare for the policy instruments when return flow recoverability is 0 per cent. Again we see that the policy instruments produce identical results in this case, and the policy instruments are thus producing the expected results.

TABLE 5.4: Percentage change in welfare when return flow recoverability is 0%

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Real household consumption	0.2064	0.2064	

5.3 RESULTS FOR SIMULATIONS WITH RETURN FLOW RECOVERABILITY OF 100%

When return flows are 100 per cent recoverable, the second-best instrument of crop-specific land taxes should be equivalent to the first-best instrument of tax on water applied and credit on return flows. A uniform tax on water applied, on the other hand, should produce a second-best allocation of water and land, as this policy instrument does not capture the recoverability of the return flows. Looking at the changes in land allocation presented in table 5.5, we see that the two water tax policy instruments do indeed produce different allocations of crop land.

The result to note in particular is that a uniform tax on water applied results in a land allocation to rice production, which is substantially smaller than that under the first best instrument of a tax on water applied and credit on return flows. The difference in the amount of land allocated to rice production under the two policy schemes is due to the lower irrigation efficiency for rice and the implication this has for return flows, as explained in section 5.1. Comparing the results from table 5.5 with the results from table 5.1 we see that for the two water tax policy instruments this difference in irrigation efficiency matters more the higher the return flow recoverability is, as the first-best instrument captures the fact that return flows are recoverable while the second-best instrument of a uniform tax on water applied treats all return flows as irretrievable losses.

TABLE 5.5: Percentage change in allocation of land across crop-producing industries when return flow recoverability is 100 %

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Wheat	13.2491	13.1852	
Maize	-0.4381	0.4452	
Rice	-19.7795	-25.1353	
Legumes	28.4201	26.7641	
Sugar cane	-14.6490	-13.4954	
Other winter crops	16.3629	15.2265	
Other summer crops	0.0664	0.7205	
Fruit	-19.1218	-16.9330	
Vegetables	14.3847	14.3436	
Cotton	-6.1423	-4.9171	
Berseem	2.0446	2.1724	

Turning to the welfare results we also see that when return flows are 100 per cent recoverable a uniform tax on water results in a smaller increase in welfare (0.1537 per cent) than would the first best policy instruments (0.1649 per cent). Furthermore, the difference between the welfare results of the two policy instruments is significantly larger in the case of return flows being 100 per cent recoverable than in the case of 30 per cent return flow recoverability. Once again this is in accordance with the predictions from the theoretical model, as the difference between the two water tax instruments increases with the degree of return flow recoverability. However, the difference in aggregate welfare effects between the two models is still small in absolute terms.

TABLE 5.6: Percentage change in welfare when return flow recoverability is 100%

	Tax on water applied and credit for return flows	Uniform tax on water applied	Crop-specific land tax
Real household consumption	0.1649	0.1537	

6. DISCUSSION.

The theoretical and the empirical framework which are presented in this paper obviously rest on a number of simplifying assumptions. Before turning to the conclusion of the analysis, the implication of some of the key assumption should be considered.

One of the important simplifications is the fact that the present model only considers the quantity of water, not the quality. In reality water quality obviously cannot be ignored, nor can it be separated from analysis of water quantities as a large decrease in water quality may render the water effectively useless. However, as discussed in Gersfelt (2006), water quality may to some extent be incorporated into the present theoretical framework by adjusting the return flow recoverability coefficient so that it reflects the decrease in water quality that an application cycle would induce.

Another simplifying feature in the present model is the absence of the spatial and temporal dimension as recoverable return flows are implicitly assumed to available immediately at any desired location. While recovering return flows from drains may be instant, recovering return flows from percolation would normally take some time. From a temporal point of view, the solution to the model should thus be thought of as a kind of steady state solution in which return flows from the current period would be of the same magnitude as the return flows in the previous period, which by now would have resurfaced and be available for recycling.

With respect to the lack of spatial dimension, return flows, which are recovered by a river, will generally only be available for downstream users, while return flows, which are recovered by aquifers, may also be available to upstream farmers if the aquifer stretches over the upstream area. In Egypt some of the recoverable return flows end up in the Nile River, while others end up in aquifers under the Nile Valley and Delta. The spatial allocation of the return flows is consequently an important issue, which the model does not explicitly address. However, in a multi-region model the return flow recoverability coefficient may be adjusted to implicitly reflect the spatial dimension, as the recoverability coefficient in downstream regions could be reduced to capture the fact that these return flows are not available to upstream farmers. The estimation and interpretation of the return flow recoverability coefficient is thus very important for the properties of the model.

7. CONCLUSION.

One of the special features of water is the fact that the use of water often generates reusable return flows and this in turn has implications for the efficiency of the water allocation and the policy instruments that can be used to implement an efficient water allocation. The purpose of the present analysis has been analyze what policy instruments will assure the most efficient allocation of irrigation water, when return flows from irrigated agriculture are at least partially recoverable, and what difference it makes to use policy instruments, which do take account of these recoverable return flows.

The issue of allocating irrigation water efficiently in the presence of recoverable return flows amounted to solving two externality problems simultaneously - the externality problem related to the allocation of water applied between different irrigators and the externality related to recoverability of return flows from irrigation. The results from the theoretical model showed that a scheme of taxing water applied and crediting return flows would result in a first-best allocation of irrigation water in the presence of the two externalities regardless of the extent to which return flows are recoverable. When return flows are partially recoverable the other two policy instruments - taxing water applied uniformly or applying crop-specific taxes to land - would only result in second-best allocations of irrigation water and land. The reason for this is that the policy instrument of taxing water applied cannot accommodate differing fractions of return flows being recoverable, while the policy instrument of crop-specific land taxes cannot capture differing fractions of return flows being non-recoverable.

In order to ascertain how well the second-best instrument would perform under different return flow recoverability parameters and what difference using first-best as opposed to second-best instruments would make, the policy instruments were subsequently implemented in a national CGE model of Egypt. A policy experiment of increasing the amount of dry land for agricultural production by 5% was implemented to illustrate the different tax instruments impact on cropping patterns and welfare, and results were reported for the two types of water tax instruments. The results on cropping patterns showed that the water tax instruments behaved as predicted by the theoretical insights and that the differences in cropping pattern results between the two instruments increased as the degree of return flow recoverability increased. The results on changes in welfare confirmed that the scheme of taxing water applied and crediting return flows would result in higher aggregate welfare than the scheme of taxing water applied uniformly. However, the aggregate welfare effects of increasing dry land for agriculture by 5% were small, and the differences between the welfare impacts under the different policy schemes were thus minute in absolute terms.

While the results of the analysis do illustrate how the policy instruments work in principle, they should not be considered predictions of how they would work in reality if they were to be implemented in Egypt. The lack of regional and seasonal disaggregation in the present model means that the real-world restrictions on substitution between different kinds of crop production are not captured in the analysis. Furthermore, the assumption of the national water constraint being binding in the base year also needs to be relaxed. Future work consequently entails a seasonal and regional disaggregation of the model as well as the introduction of complementarity constraints to allow either land or water constraints to be non-binding. Such developments of the model will certainly lead to different cropping pattern responses, and they may also lead to larger welfare impacts as variation in the key water parameters across regions will make the averaging properties of the second-best policy instruments more pronounced.

As mentioned in the introduction, the first-best policy instrument of taxing water applied and crediting return flows will be virtually impossible to implement in a real world setting. In reality policy makers will therefore have to use second-best policy instruments for allocating irrigation water. The second-best instrument of a uniform tax on water applied amounts to introducing a volumetric water pricing scheme. In the absence of recoverable return flows, using this policy instrument will ceteris paribus lead to a first-best allocation of land and water, which also explains the popularity volumetric water pricing in the water allocation literature. However, as the present analysis showed, volumetric water pricing will only result in a second-best allocation of land and water when return flows are at least partially recoverable. Furthermore, volumetric water pricing is often very difficult and expensive to implement in developing countries, as it requires establishment of an irrigation infrastructure with the ability to meter the amount of water applied by each individual farmer. In most of the so-called “Old Lands” in Egypt volumetric water pricing is currently not possible.

Implementation of crop-specific land taxes, on the other hand, only requires information about the amount of land each farmer uses for cultivation of the different crops. It will consequently often be easier and cheaper for the state to implement crop-specific land taxes than to tax water applied. Furthermore, the present theoretical analysis suggests that when the degree of return flow recoverability is high, crop-specific land taxes are also likely to produce a more efficient outcome than taxing water applied. Once the model and dataset has been further developed and disaggregated, the present type of analysis will be able to yield an estimate of the efficiency implications of using crop-specific land taxes in stead of volumetric water pricing and hence answer the question which of these policy instruments would be most appropriate for allocating irrigation water in Egypt.

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