IMPROVEMENT OF EGYPTIAN IRRIGATION WATER MANAGEMENT; A NECESSITY FROM AN ECONOMIC PERSPECTIVE

Esam BADER and Claus-Hennig HANF

Department of Agricultural Economics. Christian-Albrechts-University of Kiel, Olshausenstraße 40, 24098 Kiel, Germany.

e-mail: **ebader@agric-econ**.ni-kiel.de(E.Bader)

1 INTRODUCTION

1.1 Background

Egypt's main and almost exclusive resource of fresh water is the Nile River. The availability of the reliable water supply from Aswan High Dam is governed by the existing water sharing agreement, under which 55.5 billion cubic meters are allocated to Egypt. Most of Egypt's water use is within the agricultural sector, with 85% for agriculture, 9,5% for industry, 5,5% for potable water (Year Book 2002). The availability of adequate amount of water is the most significant factor limiting agricultural production. Considering an increasing demand for food, the limited freshwater and land resources, and an increasing competition for these resources, it is the most self-evident option for Egypt's agricultural policy to try to improve the productivity and utilisation efficiency of the available water resources.

1.2 Objectives

Taking into account the described irrigation situation in Egypt, the main objective of this paper is to present some of the concepts and economic criteria which may serve as a basis for optimising irrigation water management. The first section aims to define terms of water productivity and efficiency measurement to enhance information that is available for evaluation of efficiencies and inefficiencies respectively in the use of irrigation water. The knowledge of the reasons for these inefficiencies will help to determine in the selection of strategies to improve irrigation water management ensuring food security. Therefore, the second section aims to demonstrate how these economic criteria can be determined by applying appropriate mathematical models that can be used to calculate optimal allocation of scarce water resources to competing water consuming activities and to agricultural regions in Egypt.

1.3 Methodology

In first section of this paper is based on a literature survey reviewing recent publications about irrigation water use efficiency, in order to discuss the terms of irrigation water productivity and efficiency. Mathematical economics and the methodology of optimisation is applied in second part to outline and analyse models of optimal allocation of scarce water resources.

2 CONCEPTUAL FRAMEWORK OF IRRIGATION WATER PRODUCTIVITY AND EFFICIENCY

Achieving a high irrigation water efficiency and productivity is the ultimate goal in water planning and management in Egypt. The Government of Egypt expects that water management will have significant impact on water savings in order to free up water resources that help to meet the needs of new land reclamation projects. In this section, the most important concepts of water management regarding to potential development of water productivity and frequently used measures of irrigation efficiency will be discussed.

2.1 Potential development of water productivity in Egypt

There are three paths generally applicable for increasing agricultural production from water resources: i) to develop more supplies by increasing storage and diversion facilities, ii) to exploit more of the developed primary water supply for productive purposes through water saving practices, and iii) to produce more output per unit of water deployed, i.e. to increase water productivity (Molden et. al., 2000). The first path refers to supply side response, while paths 2 and 3 are related to responses to demand side management. These options will be discussed with respect to Egypt in some more detail.

1) To develop more supplies by increasing storage and diversion facilities is rather restricted. Surface water resources are limited to Egypt's share of the flow of the River Nile, in accordance with terms of the Nile water agreement between Egypt and Sudan. The 1959 Agreement is based on the average flow of the Nile during the period 1900-1959, which was 84 billion m^3/year in average at Aswan. Average annual evaporation and other losses from the High Dam Lake were estimated to be 10 billion m^3/year, leaving a net usable annual flow of 74 billion m^3/year. It was agreed that 18.5 billion m^3/year is allocated to Sudan and 55.5 billion m^3/year to Egypt (International Water Law, Documents). Other sources of water cannot be considered a dependable water sources, so that this path cannot be used in Egypt.

2) Water savings practice can be realised by making use of a process of recycling previously used fresh water. By re-introducing drainage water into the irrigation network, an equivalent quantity of fresh water is released for new irrigation projects. The drainage water of Upper Egypt returns directly to Nile River where it is mixed automatically with Nile water to be used for purposes downstream. The official amount of recycled agricultural drainage water was about 4.5 billion m^3 during 99/2000(Year Book 2000). The amount of drainage water reuse will be increased in future to meet the increasing demand. The main drainage reuse expansion is the El-salam canal project for reclaiming 92 thousand hectares in west Suez and 168 thousand hectares in Sinai. Nile water is mixed with drainage water in a 1:1 ratio so that salinity does not exceed 1000 part per million in addition for cultivating the suitable crop patterns (MWRI)

   In addition, about 50% of the water diverted and delivered for municipal uses is actually consumed in its initial application. The remainder returns to the stream in form of wastewater and can be reused in agriculture after treating. The amount of treated water was about 0.7billion m^3 during 99/2000(Year Book 2000). The increasing demand for domestic water due to population growth and improved living standards and the growing use of water in the industrial sector due to expansion of Egyptian industry will increase the total amount of sanitary drainage water available for reuse. Treated water could become an important irrigation source in the future.

   Moreover, fresh water savings can be obtained by improving the efficiency of both the irrigation network and irrigation technique. Reducing water losses is a promising way to make more water available for agriculture. The water lost by seepage from channels during conveyance and distribution forms a significant proportion of loss of potential use. A considerable amount of fresh water is consumed for transporting as water losses, particularly when water is transported long distances. The total losses occurring is calculated about 16.5 billion m^3/year in average from Aswan to the fields level during the period (1996-2000) before applied to crops (CAMPAS, 2000). In consequence, the amount of water losses during transporting substantially differs among regions and among months. Other reasons for differences in field losses are the design of the irrigation system, the distance between field and the source of water, weeds in irrigation networks canals, accurateness of land preparation, and agronomic practices. Most of these factors are strongly dependent from the level of knowledge and skill of the farmer.

i The third path to ameliorate the irrigation water situation is to produce more output per unit of water deployed, to increase water productivity. Water productivity can be increased by obtaining more production with the same amount of water or by reallocating water from lower to higher valued crops. Indeed, the greatest increases in the productivity of water in irrigation have not been from better irrigation water management practices, but rather from increased crop yields due to better plant varieties and agronomic practices (Molden and de Fraiture 2000). For this reason, water efficiency and productivity terms should be used in conjunction to assess water management strategies and practices to produce more production with less water (Guerrs et al. 1998).

2.2 Frequently used measures of irrigation efficiency

Generally speaking, the term "efficiency" expresses the relation between the actual input or output of a production process and the input or output that could be expected under ideal process conditions. Hence, efficiency is either defined as $E=I_i/I_a$ or as $E=O_a/O_i$ with E= measure of efficiency, I_a input actually used in the process, I_i the input necessary under ideal conditions, O_a output actually resulting from the process, O_i output expected under ideal conditions.

The definition of efficiency differs among engineering, agronomic and economic perspective. The used measures of efficiency depend on the area of interest. From engineering perspective irrigation efficiency defines the relation between the amount of water that is effectively utilised on field and the amount of water from the main water source. The agronomic perspective of irrigation efficiency relates to the production from one unit of water and measures the production value actually produced divided by the theoretically possible produce. The economic perspective describes the really produced net value of this production and relates it to the maximum net value being possible to generate. All these perspectives are important in determining optimal water use, particularly in Egypt where water is scarce. However, the potential for improving water management differ from each perspective.

2.2.1 Irrigation (Hydraulic) Efficiency

Classical irrigation efficiency (E_C) is defined as the volume of water used beneficially divided by the volume of water diverted (Keller et al., 1996). Irrigation efficiency is affected by all levels of distribution and associated losses, from the main supply source to main canals (conveyance efficiency), secondary canals (distribution efficiency), tertiary canals (tertiary efficiency) to the farm (farm efficiency) and being applied to crops (field efficiency). Although the classical irrigation efficiency concept is normally appropriate for irrigation system design and management, it could lead to erroneous conclusions and serious mismanagement of scarce water resources if it is applied for water accounting systems at regional or state wide scale. This is because the classical approach ignores the potential reuses of irrigation return flows.

To overcome the limitations of the classical irrigation efficiency concept, a new concept has been proposed, called effective efficiency (E_E). (E_E) is defined as the beneficially used water divided by the amount of freshwater consumed for the process including the losses during conveying and applying the water. The volume of water that becomes usable surface runoff or deep percolation is subtracted from the total volume delivered in the new model (Keller et al., 1996). This concept is necessary to correctly evaluate the net water losses within the Nile river basin or groundwater system in Egypt.

In Egypt, the classical irrigation efficiency (E_C) was 65-70% over all irrigation system sector during the period from (91-99), while the effective efficiency (E_E) was 75-80% because of reusing of agricultural drainage water (MWRI). The (E_E) on Egypt's irrigated agriculture differs from region to region. The agricultural drainage water in upper and middle Egypt returns to the river or recharges aquifers and can be directly reused without any problem. In contrast, in northern part drainage water have a high salinity level. Further, the Damietta and Rosetta branches are contaminated by industrial drainage into the Mediterranean Sea. Where drainage water with high salinity level and fresh water with low quality is used for irrigation, the soil tend to degrade and thus excess irrigation water has to be applied for leaching requirement to maintain a favourable soil salinity level for crop production. Therefore, it becomes a problem in the concept of effective efficiency (E_E) tend to overestimate the available water resources where the use of recycling water exhibit negative externalities (i.e., salinity in northern part). For this reason, it would be better to define the production per unit of water and its value from an economic point of view of water management when comparing the water use efficiency. Considering the salinity problem there is not much real water saving to be made through irrigation efficiency at the macro system, but the only option available in the short run is the economic criterion in Egypt's water management. However, irrigation efficiency can be not ignored because it clearly points up the water losses within the system. Therefore, farmers must be more educated about irrigation and to avoid losses and to enhance applied irrigation technology.

2.2.2 Agronomic (Technical) Efficiency

Agronomic efficiency focuses on water productivity by the crop. Water productivity (WP) can be expressed as the yield (in kilograms) produced per cubic meter of water consumed by crops. More generally, it can be expressed as the economic value of production per unit of water consumed (Molden 1999). Crop production depends on a number of inputs other than water input; therefore, partial water productivity (WP) is most commonly measured as crop output per cubic meter of water. The agronomic efficiency involves economic components including output per unit of water but it does not capture differences in the value of water in alternative uses or the costs of other inputs. A more appropriate measure to the decision maker could be the economic return per unit water used, which represents the net return attained from the production per unit of water used.

2.2.3 Net value per unit of water.

A rather simple measure of efficiency V is sometimes used that take care of the total water losses W_L from water source to point of application. V is determined as:

$$V = Y\ (p\text{-}c) - Y\ (p\text{-}c)\ W_L$$
$$V = Y^*\ (p\text{-}c)^*\ (1\text{-}\ W_L)$$

Where, (V) value per unit of water, (Y) yield per unit of water, (P) market price per unit of yield, (C) average production costs per unit of yield, (W_L) inefficiency of water use factor considering the share of water losses from the source of water to the field per m^3.

The value of water losses must be taken into consideration in calculation profitability in crop production. Allocation and management policy should primarily pay attention to water losses value. This means that it is essential to develop information on withdrawals, losses and returns. This concept may be advantageously used under conditions of water movement in Egypt. The relative water losses measured in monetary terms should determine the agricultural water distribution. The most productive activities will thus compete for the lowest water losses. This concept presupposes a set of basic assumptions which reflects Egyptian agricultural conditions:

- Isolation: There is only one source of irrigation water (Lake Nasser) and all agricultural regions should satisfy their water requirement from it through canal.
- Land characteristics: The Nile extends about 1,532 km. from the southern Egyptian borders to the Mediterranean Sea in the north.
- Transportation: It is assumed that there is no transport infrastructures such as pipes and that water are transported to farmers using open canals.
- Transportation requirements: Water can be made available in dependence of the irrigation requirements of the crops with respect to time and region.

2.2.4 Virtual Water

Virtual water is a very new concept. Virtual water represents the amount of water needed to raise a certain quantity of food. In other words, one tonne of grain has embedded tonnes of "virtual water" because this amount of water is used to raise one tonne of grain (Allan 1999). The "virtual water" concept is one of the most discussed concepts. It can contribute to a change in water management because it makes very obvious that the water embodied in the crops imported and exported in international trade should be recognized. Virtual water can be used to analyse the flows of resources from one economic sector to another. It converts all water flows in crop production.

The idea behind this measure is that Egypt could aim at importing products that require a lot of water in their production (water-intensive products) and producing and exporting products that require less water (water-extensive products). Egypt’s water use would be minimised by importing commodities that have embedded a lot of water from other countries. The thereby saved water resources can be used for purposes with higher economic returns. Since this water is virtually embedded in the commodity, it is called virtual water. The problem with this concept is at one side foreign exchange, because Egypt does not have sufficient exports to pay for imports. Furthermore and probably more severe is a conceptual weakness of concepts. The concept is only valid when water cost would be the only cost in agricultural production.

2.2.5 Economic Efficiency

Economic efficiency (EE) of water allocation is achieved when the marginal benefit from the use of the water resource is equal across all users. The definition of economic efficiency presupposes that as well technical as allocative efficiency is attained. A farm is technically efficient in its water use when it produces the maximum level of crop production for a given volume of water with the assumption that technology and other inputs are fixed. Technical efficiency can be defined as given when a selected level of crop production is accomplished at the lowest possible irrigation water requirement. A farm is allocative efficient when water resources are allocated in a way that allows the maximum possible net benefit from their use. It occurs when price of output equals marginal cost of input. Allocative efficiency can play an important role to increase the return to water.

A farm is economically efficient (EE) if the farm is both technically and allocatively efficient. EE is a criterion describing the conditions that must be satisfied to guarantee that water resources are being used to generate the highest possible net return, while the irrigation efficiency (hydraulic) only refers to the relation of the fraction of water beneficially used over total water applied. Any improvement of this type of efficiency increases the beneficially used fraction of water, while enhancing economic efficiency considers both physical measures and allocation of water to the highest valued uses. Economic efficiency can be expressed in terms of the maximum revenue, profit or added value that can be generated from a unite of water or a unit of land, and its general approach compared to technical efficiency allowing an analysis of private and social costs and benefits. Net private benefits are defined as the market value of all outputs minus the individual cost of all inputs. In opposite to that net social returns values all inputs and outputs at social prices.

Economic efficiency should be used to assess irrigation water strategies when examining private and social efficiency as well. Simple reflections about the efficiency criterion demonstrate the advantage of the usage of economic parameters against the pure technical ones in irrigation water management. It can be argued as follows: economic efficiency includes the impacts of prices and incentives for farmers to move to high net return crops, whereas the hydraulic efficiency is only determined by the percentage of water used beneficially, but do not consider whether the water can be utilised in a more beneficial way. The definition of technical irrigation efficiency that is included in the concept of economic efficiency implies that the beneficially used share of irrigation water is as large as possible and that it is used with maximum possible value.

A further advantage of economic efficiency over the presently used technical term of efficiency is visualised if private and social optimality have to be considered as well. In order to determine a difference between social and private optimum, the calculations and measurements have to be performed with the private and social prices as well. In case those social prices are applied in the calculation, the Pareto optimality EE refers to the maximization of overall social net return from different irrigation water projects by equating the shadow prices of water in all competing uses. These economic criteria are appropriate parameters that can be used in determining optimal allocation of scarce water to competing water consuming activities and regions in Egypt by using appropriate mathematical models.

From the environmental viewpoint, the concept of economic efficiency can be also defined in a way that it adequately includes environmental impacts resulting from irrigation at farm level and regional level. Therefore, EE should include factors involving technical efficiency, opportunity cost of water, and externality costs generated by the irrigated agriculture.

3 NORMATIVE ANALYSIS OF IRRIGATION WATER USE IN EGYPT

3.1 Goals and framework of modelling

The objective of this section is to elaborate the types of model that is elaborate suited to make the right choices about optimal use and optimal allocation of water among potential users on the basis of a partial equilibrium model incorporating the environmental impacts in the economic assessment of water. Insight into the marginal value of alternative water uses is important for making the right choices about optimal use and allocation of water as a scarce resource. Economic analysis of irrigation water use have to consider the value generated by production activities and the costs to carry through these activities including the opportunity costs for alternative water uses and costs for the economic externalities arising.

The scope of costs and benefits is different when describing efficient use of water resources at the farm level viewed from the farmer's standpoint or from a social perspective. The major reasons for the difference between social and private benefits, and social and private costs in Egypt's agriculture are: i) The irrigation water is delivered to farmers without charging the true costs, hence, the volume of water used by farmers will differ from the socially optimal volume. ii) The rent of agricultural land does not reflect the marginal value of production. iii) Many markets of agricultural products are characterised through market failure due to imperfect competition and imperfect information. iv) Prices are biased due to food subsidies and other governmental decisions. Furthermore, environmental degradation is not internalised adequately.

An appropriate modelling framework for water planning will depend upon the particular management problem. A very multilateral model is necessary to include all possible productive uses of water, all possible production regions and the externalities that occur by the proposed activities. Furthermore, the model should be suited to represent the farm decision-making structure and also the viewpoint of a central "social planner". Approximately these demands can be satisfied by the application of two slightly different models. A static linear programming model is formulated to calculate the economic shadow prices. A dynamic framework is required that explicitly accounts for decline or improvement in land and water quality over a long time period that result from water use. Outlined below are the main distinguishing features of static and dynamic models.

3.2 The Static Models

The objective of the static models is to maximize either the social or private returns. The results from social model are compared with those from the private model. The comparison is made in order to analyse policy implications and to generate policy options, which can serve to stimulate farmers to consider the social economic value of water.

3.2.1 National Optimum

The national goal of maximising the net social benefits generated with the Nile River water can be described in a simultaneous model that includes all agricultural regions simultaneously. The detailed analysis is necessary because existing differences in the economic values of water from one region to another. The objective function (Z) is the net social return from all crops (j), to be maximised subject to the total irrigation water available. The amount of water allocated to each region (W_{ij}) is the decision variable. For the sake of simplicity, all other constraints besides the water constraint are here neglected. The mathematical model is then as follows:

$$\mathrm{Max} Z = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y_{ij}(W_{ij}, X_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(W_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(X_{ij})$$

Subject to: $\sum_{i=1}^{n}\sum_{j=1}^{r} W_{ij} \le W$

Thereby is, (Z) the total net social return from all crops, (P_{ij}) price of crop j in region i, (Y_{ij}) crop production function for each region, (X_{ij}) non – irrigation inputs including labour and capital for agricultural production, ($C_{ij}(W_{ij})$) cost functions of water for each region, this costs include operation and maintenance costs of irrigation and drainage system, (C_{ij} (X_{ij})) cost functions for non-irrigation inputs, (W_{ij}) irrigation water requirements of the crop j in region i computed at source of water (Aswan), (W) Total amount of water. The constraint indicates that the total amount of water used in all competing uses equals the amount available. The lagrangean for this problem is:

$$L = \sum_{i}^{n}\sum_{j}^{r} P_{ij} Y_{ij}(W_{ij}, X_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(W_{ij}) - \sum_{i}^{n}\sum_{j}^{r} C_{ij}(X_{ij}) + \lambda(W - \sum_{i=1}^{n}\sum_{j=1}^{r} W_{ij})$$

Assuming that all functions are increasing and concave and all variables are positively valued guarantees the optimality of first-order conditions. These conditions for this optimisation problem can be determined via partial differentiation of lagrangean function with respect to the decision variable as follows:

$$\partial(L)/\partial(W_{ij}) = P_{ij}\,\partial Y_{ij}(W_{ij})/\partial(W_{ij}) - \partial C_{ij}(W_{ij})/\partial(W_{ij}) - \lambda = 0$$

The equation is the maximum principle, which requires that decision maker equate the marginal return with operation and maintenance costs of irrigation and drainage system and opportunity cost of water λ. The equation requires that the shadow price λ of irrigation water measured at Aswan to each user is the same in all regions at the optimal allocation of irrigation water. This value must be considered when making the optimal allocation decisions of scarce irrigation water resources to each user in all region of Egypt.

3.3 Farm Optimum

The farmers objective function is describe as maximising net return from their farm activities subject to their resource endowments, the availability and prices of inputs, and their expectation regarding crop return. The most important difference between the national model and the farm models are the following:

i The national model is a simultaneous model enclosing all agricultural regions simultaneously, whereas the farm models have to be calculated for all regions separately.

ii The farm model has no restriction on water use. The optimal water demand is satisfied by equating marginal costs of water use to its marginal benefits.

iii The farm model employ private prices and costs whereas the national model use social prices and costs.

This maximisation problem for any farmer (j) in any region (i) can be formulated as follows:

$$\mathrm{Max}Z=\sum_{i}^{n} P_i^* \; Y_i(W_i, X_i) - \sum_{i}^{n} C_i^*(X_i) - \sum_{i}^{n} C_i^*(W_i) \quad \text{for } j=1,\ldots r$$

The farmer cost level of diverting irrigation water for use in their farm activities is described by the irrigation cost function (C_i^* (W_i)) which is the cost of irrigation (lifting water from a below–grade tertiary canal) and, for the maintenance of the private canals (mesqas) and ditches that are attached to their fields, for which farmers are responsible. And ($C_i^*(X_i)$) cost function of non-irrigation inputs. The first order condition for maximisation of net returns, regard to the diverted water (W_i), is as follows:

$$\partial(Z)/\partial(W_i) = P_i \, \partial Y_i(W_i)/\partial(W_i) - \partial C_i(W_i)/\partial(W_i) = 0$$

This equation requires that farmer will chose the amount of irrigation water that equates the farm marginal return of irrigation water in crop production with the marginal cost of irrigation. To gain further more information, $MP_i= MC_i/P_i$, the right hand side of this equation must be positive since both the inverse of price and irrigation cost must be positive and non-zero. This equation indicates that the profit maximisation will be found in the rising part of the production function. Thus a profit maximising strategy will use less water per unit of land than a yield maximising strategy. From above, it is indicated that if farmers receive prices, which do not reflect the true value of crops or if the marginal cost of water is less than the true marginal cost of delivery, the volume of water used will differ from the socially optimum.

3.4 The dynamic models

Water scarcity is forcing policy maker to exploit unconventional water resources to meet growing demand from competing uses. However, because of water resource has social costs, the decision-maker need a framework for explicitly incorporating environmental impacts of irrigation water into system of water planning and management. The national water management may be improved through a dynamic economic model. The following dynamic model allows for changes in environmental impacts of irrigation water use and can determine optimal dynamic strategies on national level.

3.4.1 National Optimum

In a dynamic setting the objective of the social planner is to maximise the present value of the net economic return from water use over a fixed time horizon subject to quality and quantity of water. In the case of incorporating the environmental impacts resulting from the use of water in crop production, the problem can be formally stated as:

$$\text{Max } V = \sum_0^T \beta^t \left[\sum_i^n \sum_j^r P_{ij} Y_{ij}(W_{ij}, X_{ij}, E_{ij}) - \left(\sum_i^n \sum_j^r C_{wij}(W_{ij}) + \sum_i^n \sum_j^r C_{Xij}(X_{ij}) \right) \right] \quad (1)$$

Subject to:

$$E_{ij(t)} = g(W_{ij_{Nile(t-1,t)}}, W_{ij_{draining(t-1,t)}}, W_{ij_{mixed(t-1,t)}}, E_{ij(t-1)}) \quad \text{for } t = 0, T-1 \quad (2)$$

$$\sum_{i=1}^n \sum_{j=1}^r W_{ij} \leq W \quad (3)$$

Where V is the net present value of cumulative net return over the planning horizon, T denotes the period and the interval (0,T) is planning horizon, $\beta^t = 1/(1+r)^t$ is the discounted factor for the given interest r, P is the output price, Y is the period production function, which is a function of the non-irrigation inputs (X), irrigation water (W)(control variables), Et is environmental characteristics for example land quality (State variable), which result from the use of irrigation water in period t and previous period(t-1) and changes over time, as a function of water quantity and quality and the primary state of production environment, g is the rate of change in the environmental quality parameter which is a function of water quality along the Nile River in Egypt. The current value Hamiltonian is maximised along these optimal paths, as follow:

$$H = \sum_i^n \sum_j^r P_{ij} Y_{ij}(W_{ij}, X_{ij}, E_{ij}) - \left(\sum_i^n \sum_j^r C_{wij}(W_{ij}) + \sum_i^n \sum_j^r C_{wij}(X_{ij}) \right) + \beta \left[\left(\lambda_1 g(E_{ij}) \right) + \left(\lambda_2 (\Sigma W - \Sigma W_{ij}) \right) \right] \quad (4)$$

The Hamiltonion function is the net return obtained from an existing level of control and state variables. The equations of motion (λ_1, λ_2) represent the change in accumulated quality and quantity of water. The costate variable λ_1 represents the marginal external cost or/and return of environmental impacts, it change as affected by state and control variables, and λ_2 represents the opportunity cost of water. The dynamic optimisation problem presented in this section differs to the static maximisation in the static model in that the future externalities, income and or costs, from current period decisions are explicitly included in the current period return. An optimal solution to the above problem must satisfy the following conditions:

$$\partial H / \partial W = \sum_i^n \sum_j^r P_{ij} Y'_{ij} - \sum_i^n \sum_j^r C'_{wij} + \beta \lambda_1 \partial g(.) / \partial w - \lambda_2 = 0 \quad (5)$$

Equation (5) is the maximum principle, the standard condition for maximisation with respect to irrigation water applied, which requires that decision maker equate the marginal return product plus the marginal value gained by reducing the negative impacts with cost of water and the marginal damage caused by negative impact. The full economic cost of providing water consists of the full supply costs: Operation and maintenance expenditure as well as capital expenditure for replacement and investments in the existing irrigation and drainage infrastructure C_{wi}, the opportunity costs (shadow prices) λ_2 from alternative water uses and the economic externalities λ_1 arising from changes in economic activities.

Positive externalities impose benefits and occur for example when surface irrigation is both meeting the needs of crops, fish production and recharging groundwater, and water discharge to wetland and Mediterranean sea. Negative externalities impose costs caused by irrigation, drainage, reusing of drainage water. Intensification of Egypt's agriculture can lead to groundwater pollution related to the increased use of pesticides and fertilisers, salinization, and water logging. Opportunity cost of water λ_2 are resulting because increases of water quantities on existing cropping patterns enhance the economic returns, or changes in cropping pattern to more water consuming crops is profitable, e.g. expanding rice areas all over the Delta for alleviating of salinity problems, and finally additional water can be profitably used for reclaiming new lands. The value of λ_2 will be zero if the water supply is not scarce and positive when the water demand exceeds the available supply.

To gain further insight into the difference between static and dynamic solutions rearrange (5) and obtain

$$Y' = \left[C'_{wij} + \lambda_2 - \beta\lambda_1 \partial g(.) / \partial w\right] / P = 0 \qquad (6)$$

As in the static case, this condition states that optimal irrigation water volume occurs when the marginal product of irrigation water used equals the ratio of water cost to output price, but now water cost is decreased by the value of its future return effect, because this depend on the value of multiplier λ_1. This will result in higher quantity water used than in the static model. Due to the return effect of the current volume of water used on future profits, a higher level of optimal water volume occurs than when only current profits are maximized. Therefore, including the inter-temporal effects of externalities into the decision-making framework will result in a greater level of optimal water use and a higher economic return than static models.

Also, from the equation, if the prices of water will reflect the cost of supply, opportunity cost and economic externalities in the long term, farmers will be motivated to select social optimal levels of irrigation water. But in practice, the economic value of water different from water pricing, which can be used as a policy instrument for demand management and cost recovery. The price does often not reflect the value and cost of water because of social and political goals.

3.4.2 Farm Optimum

The dynamic model of national level is characterised by two facts: First, the way of water utilisation in one period influences the environmental state of next period. By this is a dynamic effect given. The second features of the model is that the quality of water is an endogenous control variable. Of course, the Egyptian farmers reuse water themselves from branch drain canals whenever a shortage occurs in tertiary canal. The Egyptian farmer, upon feeling that fresh water is becoming scar, especially during summer periods, directly moves his pump to the drainage canal to irrigate his field, however, farmers do not and must not consider the environmental impacts over time. If farmers neglect the environmental effects, the dynamic connection between the periods gets lost and the maximisation model falls back to the static one described in previous section. Hence, we have omitted to formulate such a model because it would be too artificially.

3.5 Farm and national optimisation

The difference in the farm optimum and national optimum demonstrates that farm decisions of water management are not socially optimal. Farmer's volume of water use will either exceed the socially optimum volume because the cost of water is less than the true marginal cost, or the water is less profitably used in social term. Two components of the true cost of water use are not included in the farm model: The cost of operation and maintenance of irrigation and drainage system and the opportunity cost of water. These costs should be added to the cost of irrigation at the farm level to achieve the socially optimal volume of water per unit of area in the short run. In the long run, the true costs of water include beside operation and maintenance expenditure and the opportunity cost of water in next alternative use, also external costs due to environmental effects. These costs should also be added to the cost of farm level in order to achieve the socially optimum level. When prices of crops are not reflecting off farm environmental effects, or the agricultural policy distort prices and costs, farmer will prefer short term return of water use and the water use is higher than socially wanted, resulting in degradation of environment.

The relevant economic issues must be considered when designing water policies with the goal to maximise social benefits. Allocation and management policy should focus on water losses. This means that it is essential to develop information on losses and returns. Economic efficiency of water use provides information for policies that may encourage farmers to choose the optimal cropping pattern and improve water resources use. They must choose crops that generate the highest net return in competitive market. Regional decisions on the allocation of water can be more or less efficient, depending on the economic value of water in its alternative uses.

4 CONCLUSION

This paper has presented a framework for interpreting the concept of water use efficiencies. The effective efficiency in Egypt is rather high because of the recycling of irrigation water. However, economic efficiency should be used to assess irrigation water strategies when examining both private and social efficiency.

The irrigation water resources management can benefit from application of economic analysis and methodology of optimisation. Modelling can test alternatives of water use in order to help policy maker and farmer to improve the use of water resources. The social net return from water will be maximised when the shadow value of water is the same in all regions and competing uses. Farmer will not consider the economic value of water in the absence of water charge. Accounting for the economic value of water in the price paid by farmers would help to improve efficiency of water use. Water management can be improved by incorporating the future effects of water use into economic models of water management.

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