DEVELOPING COUNTRY AGRICULTURE AND INTERNATIONAL TRADE: IMPACT AND FUTURE CHALLENGES

BY

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CONTENTS.

PREFACE.

The present PhD thesis entitled “Developing Country Agriculture and International Trade: Impact and Future Challenges” is the result of my PhD studies from September 2003 to January 2007. During this period I have had the privilege of being affiliated with two research institutes in Copenhagen – the Institute of Food and Resource Economics (FOI), my daily work place, and the Department of Economics at the University of Copenhagen, where I have been enrolled as a PhD student. Financial support for this PhD project from the Danish Council for Development Research (Forskningsrådet for Udviklingsforskning (RUF)) is gratefully acknowledged.

In the course of my PhD studies I have been fortunate to be surrounded by inspiring and supportive people. First I would like to thank my supervisor Professor Finn Tarp for his support and encouragement throughout the process as well as for his facilitation of contact and co-operation with other researchers in his extensive network. I would also like to thank my co-supervisor Søren Frandsen, director general of FOI, for encouraging me to embark on this PhD project and supporting my adjustments and expansions to the project along the way. Special thanks go to Professor Philip Abbott, whom I had the privilege of consulting on core parts of my research; I have learned a lot from his insights on economic modeling and empirical analysis, and I also benefited greatly from our collaboration during my visit to Purdue in September 2006, where we worked on the empirical analysis for chapter 4 of this thesis.

Furthermore, I would like to thank my co-author on chapter 5 Hans Grinsted Jensen for facilitating my entry into the world of CGE analysis and my colleague Lars-Bo Jacobsen for technical support on my CGE modeling. Thanks also to Ahmed Shawky Mohamed, Martin Hvidt, Sherman Robinson, Moataz El-Said, and Wally Tyner for information and materials on various aspects of the Egyptian economy and irrigation system and to Glyn Wittwer and Ken Pearson for advice on CGE modeling. I would also like to thank my colleagues and my fellow PhD students at FOI for their support and encouragement throughout the process. In addition I have benefited greatly from participation in GTAP conferences and the GTAP short course, as well as from participation in the ORANI-G short course and the DERG PhD courses.

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SUMMARY

Studies of factor markets in developing country agriculture have traditionally focused on the labor, capital, and land markets. There is, however, a fourth factor of production, which is highly important for agricultural production in many developing countries. This production factor is irrigation water. The main focus of the present PhD thesis is to analyze the policy implications of water scarcity and allocation of irrigation water using the Egyptian agricultural sector and irrigation system as a case study. The thesis consists of six chapters. The first four constitute an integrated unit, with analyses in later parts building on the results from the previous chapters. The last two chapters are more self-contained.

Chapter 1 is a survey of the irrigation economics literature, emphasizing two central types of externalities in irrigation economics and the policies, which might address these externalities. The first type of externality is the well-known problem of allocating a scarce resource between competing users, when there is no mechanism to ensure an efficient allocation. When farmers' appropriation of scarce irrigation water is not efficiently regulated, farmers with access to irrigation water will tend to acquire larger amounts of water than what is socially optimal. They consequently impose a negative externality on other farmers, who will not be able to obtain the socially optimal amount of water for their crops. Potential policy solutions for alleviating this type of externality include volumetric and non-volumetric taxes, quotas, establishing a water market, and user-based allocations. The second type of irrigation externality arises from the fact that some of the water applied to the fields end up in drains or aquifers beneath the fields. These water flows – referred to as return flows – are often recoverable and reusable and they therefore constitute a positive externality. Possibilities considered in the literature for regulating this type of externality include water markets and water pricing, but more research is required on the issue of how to most efficiently handle recoverable return flows. This topic will therefore be explored in the present PhD thesis.

Water is likely to become a scarce resource in Egypt due to the growing population and the government's plan to reclaim large amounts of desert land for agricultural cultivation. **Chapter 2** contains an institutional account of the Egyptian irrigation system. The institutional set-up of the irrigation system is important because agriculture is the major water user in Egypt. There are large differences between the traditional irrigation system in the so-

called Old Lands and the irrigation system in the New Lands. In the traditional system, it is not yet possible meter individual farmers' water appropriation, but large-scale renovations of the irrigation infrastructure imply that it may be possible in the future. Farmers use the flood irrigation technique, which has a low degree of field irrigation efficiency and hence results in substantial return flows from irrigation. However these return flows typically end up in drains or shallow aquifers from which they are readily recoverable. In the New Lands, on the other hand, return flows tend to be non-recoverable. Farmers are therefore required by law to use the modern and more efficient sprinkler and drip irrigation techniques, and water can in principle be metered at the point of delivery.

Chapter 2 demonstrates how both of the irrigation externalities identified in chapter 1 are present in Egypt. As water is becoming scarce in Egypt, the question is how an efficient allocation of irrigation water can be achieved in the presence of these two externalities. **Chapter 3** presents a theoretical model for analyzing the efficiency properties of different tax and quota instruments, which can be used to regulate farmer water use in the presence of the two externalities. The model is formulated as a linear programming model in line with the agricultural sector model tradition. The model analysis identifies a set of policies, which can be used to achieve a first-best allocation of water and land in the presence of the two externalities. However, as the first-best policies are not implementable in a real-world setting, it is necessary to turn to second-best instruments. The relative efficiency properties of the second-best instruments depend on the values of various water parameters, and can therefore not be determined based on the theoretical analysis.

In order to rank the second-best policy instruments, the theoretical analysis from chapter 3 is implemented empirically in a non-linear programming model in **chapter 4**, which is joint work with Philip Abbott. Based on data for 1997, water is made scarce by increasing the amount of land available for cultivation. The efficiency implications of the different second-best tax policy instruments are then determined by comparing the social welfare of the land and water allocations produced under the different policy regimes. The results show that although the resulting cropping pattern changes from one policy instrument to the other, there are only minor differences in social welfare under the different policy schemes.

The future of Egyptian agriculture is not merely shaped by domestic agricultural policies, but also by the international agricultural trading environment. The EU is one of Egypt's most important trading partners and the EU's Common Agricultural Policy (CAP) has undergone substantial changes in recent years, as the EU has been enlarged with ten new member states and the CAP is being reformed in accordance with the so-called Mid-term Review. **Chapter 5** investigates the implications of these developments in the EU for the African regions, including North Africa. The study is co-authored by Hans Grinsted Jensen. The analysis is undertaken in the multi-country CGE model known as GTAP. The results suggest that although the enlargement of the EU and the reform of the CAP have significant implications for EU agricultural production and trade, the effects on the African regions will typically be neglible.

Chapter 6 of the thesis focuses on the relationship between international trade and the national water balance in Egypt. The analysis is carried out in a national CGE model of Egypt, based on a modified version of the so-called ORANI-G model and IFPRI's 1997 SAM of Egypt. The study analyzes the impact of the national water constraint on Egyptian international trade and demonstrates how the onset of water scarcity has significant implications for especially exports from the water-intensive and trade-exposed rice sector. The study also investigates the impact of rising international cereal prices on the food-import-dependent Egyptian economy.

Summing up, as water becomes more scarce it is important not only to treat water as a general economic good, but to focus on the special characteristics of this good such as the difficulties in regulating access to water in many places and the fact that water will often be used more than once due to presence of recoverable return flows. In order to maximize the economic value of each drop, it is important that water regulating policies be designed with these issues in mind. The analyses show that achieving a high degree of efficiency, when allocating irrigation water in the presence of the water appropriation and recoverable return flows externalities, does not necessarily require the ability to meter individual farmer water diversions. A properly specified set of non-volumetric water policies like crop-specific land taxes will typically also yield a high degree of efficiency in water and land allocation, even if the resulting allocation is not be first-best. Many developing countries may thus be able to achieve a more efficient allocation of water and land resources without having to devote substantial amounts of government funds or development aid to implement volumetric metering in their irrigation infrastructure. Furthermore, it is also important to consider the implications of water scarcity when analyzing international agricultural trade issues, as the water constraint has implications for the agricultural supply response. This is especially the case for the trade-exposed, water-intensive crop sectors.

INTRODUCTION.

Agriculture is an important sector in many developing countries. This is the case not only in terms of agriculture's contribution to GDP, but also in terms of the amount of people employed in the agriculture and the sector's contribution to export earnings. The rural factor markets are of key importance for the functioning of the agricultural sector, and the rural labor, capital, and land markets have consequently been studied extensively in the development literature.

There is, however, a fourth factor of production, which is also highly important for agricultural production. No crops can be produced without water, and in many developing countries rainfall has to be supplemented with – or fully replaced by – irrigation water. As long as irrigation water is in plentiful supply and all farmers have access to the right amount of water at the right time, irrigation need only affect production through the costs of pumping the water and maintaining the irrigation system. However, when water supplies become scarce, the allocation of irrigation water starts to have noticeable effects on agricultural production.

Irrigation is practiced on all continents, but the importance of irrigation for the agricultural sector obviously differs across countries and regions depending on the proportion of agricultural water needs that has to be met through irrigation. Some of the driest regions are found in North Africa and the Middle East, and irrigation is thus of paramount importance to the agricultural sectors in these countries.

Egypt is the largest and most populous economy in the North African region. Despite the fact that the vast majority of Egyptian land is desert with agricultural land constituting less than 5% of the total land area, the Egyptian agricultural sector is highly important for the Egyptian economy. In 2002 agriculture thus accounted for 16.5% of GDP and 27.5% of total employment (World Development Indicators 2006). Due to very sparse and erratic rainfall, crop production in Egypt is virtually 100% dependent on irrigation. Irrigation water is taken from the Nile, and so far the government has provided it to farmers free of charge. However, population growth and expansion of the agricultural areas implies that water scarcity is likely to materialize in the near future. It will consequently be important to identify efficient mechanisms for regulating Egyptian farmers' use of the scarce irrigation water resources.

Water as a production factor is characterized by several features, which make the issues of efficient utilization of this resource different from those pertaining to other production factors. Property rights in water are often not clearly defined, and the allocation of water is rarely governed by a market mechanism. There is consequenlty ample scope for competing water users to impose externalities on each other. The probability of externalities arising from irrigation activities is further heightened by the fact that water is normally not fully consumed in the course of the irrigation activities. Substantial fractions of water may thus be either lost or they may be returned to the irrigation system, where they can be recovered and reused by other irrigators.

The first four chapters of this Ph.D. thesis focus on the issue of externalities in irrigation and the policy instruments, which could be used order to efficiently address these externalities. The analysis is guided by the realities of the Egyptian irrigation sector. **Chapter 1** is a literature survey of the two central types of externalities in irrigation economics and the associated policy solutions. The first type of externality is the well-known problem of allocating a scarce resource between competing uses, when there is no mechanism to ensure an efficient allocation of this resource. The second type of irrigation externality arises from the above-mentioned fact that some of the water applied to the fields end up in drains or aquifers beneath the fields. This water – referred to as return flows – is often reusable by other farmers and it therefore constitutes a positive externality.

Chapter 2 contains an institutional account of the Egyptian irrigation system. The chapter outlines the large differences between the traditional irrigation system in the so-called Old Lands and the more modern irrigation system in the New Lands and demonstrates how both of the irrigation externalities identified in chapter 1 are present in Egypt. As water is becoming scarce in Egypt the question arises as to how an efficient allocation of water can be achieved in the presence of these two externalities.

This question is investigated in **chapter 3,** which presents a theoretical model for analyzing the efficiency properties of different tax and quota instruments, which can be used to regulate farmer's use of water in the presence of the two externalities. The model is formulated as a linear programming model in line with the agricultural sector model tradition. The underlying hypothesis is that the simultaneous presence of the two externalities will challenge the conventional theoretical notion that a first-best allocation of water can be achieved by simply placing a uniform price on farmers' water diversions. Furthermore, the simultaneous presence of the two externalities may also make the indirect water policy instruments of land or output taxes more efficient. The efficiency properties of these non-volumetric policy instruments are important. Metering individual farmers' water diversions is not possible in many developing countries, implying that these countries will not be able to use volumetric water pricing policies without investing heavily in their irrigation infrastructure.

Not all of the policy instruments investigated in chapter 3 can be ranked theoretically in terms of their efficiency properties. Furthermore, even in the cases where it is possible to rank the policy instruments, the theoretical model cannot attest to the significance of the differences in the efficiency of the policy instruments. In order to rank the remaining policy instruments and determine "what difference the difference makes", **chapter 4** presents an empirical implementation of the theoretical analysis in a regional non-linear programming model of Egypt. The analysis in chapter 4 is joint work with Philip Abbott. Based on data for 1997, water is made scarce by increasing the amount of land available for cultivation in Egypt. The efficiency implications of the different policy instruments are subsequently determined by comparing the social welfare of the land and water allocations produced under the different policy regimes. It is expected that the effects of the policy instruments will differ across the regions of Egypt, as these differ substantially in their irrigation and hydrological characteristics.

The future of Egyptian agriculture is not merely shaped by domestic agricultural policies, but also by the international agricultural trading environment. Changing absolute and relative prices on the international markets can have significant implications for the national trade balance and the structure of domestic agricultural production. Agricultural trade is important for the Egyptian economy, as Egypt has to cover a significant proportion of its grain demands through imports. The agricultural sector is also a significant indirect source of export earnings for Egypt, as the sector delivers inputs to the cotton and textile industries. Changing conditions in international agricultural commodity markets may thus have important implications for the Egyptian economy, and the onset of water scarcity may on the other hand have important implications of Egyptian international trade.

The EU is one of Egypt's most important trading partners. The EU's Common Agricultural Policy (CAP) has undergone substantial changes in recent years, as the EU has been enlarged with ten new member states and the CAP is being reformed in accordance with the so-called Mid-term Review. **Chapter 5** investigates the implications of these developments in the EU for the African regions, including North Africa. The chapter is co-authored by Hans Grinsted Jensen. The analysis is undertaken in the multi-country CGE model known as GTAP and focuses on the impact on the EU's trade with Africa and the resulting changes in the African production structure and welfare.

Chapter 6 of the thesis analyzes the relationship between international trade and the national water balance in Egypt. The analysis is carried out in a national CGE model of Egypt, based on a modified version of the so-called ORANI-G model and the International Food Policy Research Institute (IFPRI)'s 1997 SAM of Egypt. The study analyzes the impact of the national water constraint on Egyptian international trade in order to determine to what extent the onset of water scarcity will affect Egyptian international trade in agricultural commodities. Furthermore, the study also investigates the impact of rising cereal import prices on the Egyptian economy.

CHAPTER 1

EXTERNALITIES IN IRRIGATION ECONOMICS
- A LITERATURE REVIEW.

1. INTRODUCTION.

In developing countries, factors of agricultural production are rarely allocated by means of perfectly functioning markets. This is a well-known fact in development economics, and the workings of labor, land, and credit markets have therefore been studied extensively in formalized theoretical and empirical models.

However, land, labor, and capital are not the only factors of agricultural production. Water is a necessary ingredient for all crop production. If the required amounts of water are not delivered by precipitation, farmers must irrigate their crops. The allocation of irrigation water is rarely governed by market mechanisms, and farmers' use of irrigation water may consequently result in substantial externalities being imposed on other farmers and on the rest of society.

The purpose of the present chapter is to review the literature on selected externalities arising from farmers' irrigation activities. The chapter will give a brief presentation of the general theory of externalities before presenting the different types of externalities arising from irrigation activities and the policy options for alleviating the inefficiencies they cause. As the literature review will show, the policy implications of water appropriation externalities have been studied in great depth, while the policy implications of so-called return flow externalities have not yet been fully explored.

2. THE THEORY OF EXTERNALITIES.

The theoretical starting point for the study of externalities is the benchmark of the perfectly competitive market economy. In a market (or private ownership) economy, consumers own a variety of assets as well as the firms, and both consumers and firms can trade freely in the market selling their respective assets and outputs and buying other assets, goods, and inputs. The perfectly competitive market economy is a special case of the market economy, which is characterized by every relevant good being traded at publicly known prices and all agents acting as price takers (Mas-Colell et al 1995). The perfectly competitive economy consequently rests on the strong assumption of market completeness. When this assumption is violated several different types of imperfections may be present, including externalities.

It is difficult to produce a precise definition of the concept of externalities. In their classical book “The Theory of Environmental Policy”, Baumol and Oates define externalities as being present “whenever some individual’s (say A’s) *utility* or *production* relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, governments) without particular attention to the effects on A’s welfare” (Baumol and Oates 1988 p 17). Furthermore, they debate whether the fulfillment of a second requirement is necessary for a relationship to qualify as an externality: “The decision maker, whose activity affects others’ utility levels or enter their production functions, does not receive (pay) in compensation for this activity an amount equal in value to the resulting benefits (or costs) to others” (Baumol and Oates 1988 p 17-18). This additional condition is needed in order for the externality to necessarily result in inefficiencies and resource misallocation. However, Baumol and Oates nonetheless opt for defining an externality as being present whenever the first condition holds.

Mas-Colell et al define an externality as being present “whenever the well-being of a consumer or the production possibilities of a firm are directly affected by the actions of another agent in the economy” (Mas-Colell et al 1995 p 352). The keyword in this definition is *directly*, as this entails that the impact on consumer well-being or production possibilities is not mediated by prices. This in turn suggests that the existence of externalities is closely linked with the absence of markets for these commodities. If markets did exist for these commodities, then each agent would be able to decide for himself how much to consume of the externality-producing good, provided that this good exhibits the characteristics of being *private* (or *depletable*, or *rivalrous*) and *allocable*.[1] If, on the other hand, the externality-producing good exhibits *public* good characteristics, then existence of a market for such a good would still not allow each agent to decide for himself how much to consume of the good, and the externality problem would consequently not be solved simply by establishing a

[1] An externality is depletable when the consumption of the externality by one agent leads to a reduction in the amount of the externality consumed by other agents. This in turn implies that depletable externalities have the characteristics of private commodities. Non-depletable externalities, on the other hand, share the characteristics of public goods. A depletable externality is *allocable* when it is possible to control the allocation of it (which is not the case with e.g. acid rain). Analytically non-allocable depletable externalities are similar to non-depletable externalities (Mas-Colell et al 1995 and Baumol and Oates 1988).

market for this type of good.[2] While externalities with public goods features are clearly important for e.g. environmental economics, the present analysis will primarily focus on externalities exhibiting private good characteristics, as this is the kind of externality most relevant to the selected issues in irrigation economics.

The reason, why markets do not exist for the externality-producing goods, is typically related to problems of defining or enforcing property rights for this good. In the case of property rights not being well-defined, it may for instance be unclear whether the externality-producer has the right to generate the externalities or whether the persons experiencing the externality have a right to an externality-free environment. Alternatively, the property rights may not be enforceable due to e.g. problems of measuring the level of the externality. In either case it will not be possible to establish a market for the externality-producing good without first addressing these property right problems.

When a market does not exist for the externality-producing good, the assumption of market completeness underlying the perfectly competitive economy is violated. The consequence of this violation is that the competitive equilibrium in the economy will not be Pareto efficient. Compared with the socially optimal outcome, the competitive equilibrium will generally entail either an over- or an undersupply of the externality-producing good (depending on whether it is a negative or a positive externality), as well as an inefficient allocation of resources across agents.

The inefficiencies resulting from the presence of externalities may be alleviated through a wide variety of policy measures. The suggested solutions to externality problems have generally centered around three different approaches: taxes, quotas, and bargaining. In the first two cases, the state is directly involved in determining the equilibrium outcome. In the third case, the role of the state is "merely" to assign, and enforce property rights over the externality-producing good. It should be noted, though, that each of the three cases presupposes the ability to measure the amount of the externality-generating good, which may often be difficult and costly.

[2] A public good is defined as "a commodity for which the use of a unit of the good by one agent does not preclude its use by other agents" (Mas-Colell et al 1995 p 359). A public good thus has the characteristics of being non-depletable or non-rivalrous in consumption. Public goods also may or may not be non-excludable, meaning that it may not be possible to exclude an individual from enjoying the benefits of the public good. Private goods, on the other hand, are always excludable.

Pigouvian taxation (subsidization) implies that a tax (subsidy) be imposed on the externality-generating good and that the tax (subsidy) rate be equal to the marginal social cost (benefit) produced by the externality, as this forces the externality-producing agent to take account of the effects his actions have on others in a socially optimal manner. Pigouvian taxation ensures an efficient allocation of the externality-producing good across the externality-generating agents, as each agent is faced with the same price on the externality producing good. However, unless the state has full information on each externality-producer's marginal benefit from generating the externality, it will not be able to control the total amount of the externality being generated.

Quotas, on the other hand, offer the state direct control over the amount of externality being produced. However, unless the state has information on each externality-producers marginal benefit from producing the externality, it will generally not be able to allocate the quotas efficiently across the externality producers. The problem of allocating the quotas efficiently may, however, be solved by establishing a competitive market for tradable externality permits, in which the externality producers can then buy and sell quotas for the externality-producing good.

The use of taxes or quotas to alleviate the inefficiencies from a given externality requires the state to posses a substantial amount of information on the costs to society and the benefits to the producers of this externality. However, in the case of depletable externalities, it may be possible to achieve a socially optimal outcome through decentralized bargaining between the agents, who generate the externality, and the agents, who are affected by it. [3] In order for decentralized bargaining to be an option, it must be possible to establish well-defined and enforceable property rights over the externality. Furthermore, in order for bargaining to lead to a socially optimal outcome, all affected parties must be able to participate in the market and all agents must act as price-takers. However, in reality bargaining is typically only possible between small numbers of individuals (Baumol and Oates 1988). It may consequently not be possible to include all affected parties in the bargaining process, and if the bargaining process only includes a small number of agents some of these may not behave as price-takers. As the

[3] In the case of a non-depletable externality, a market-based solution will not be able to achieve an efficient outcome for the same reasons as market-based solutions do not work for public goods (cf. Mas-Colell et al 1995).

irrigation externalities being analyzed would normally involve a large number of agents, the decentralized bargaining approach will not be considered explicitly in the following analyses.

3. EXTERNALITIES IN IRRIGATION.

Water is a necessary input into agricultural production, and in many developing countries the water needs for crop production are covered partly or fully by irrigation. The use of irrigation can generate a number of benefits for the agricultural sector. First of all, irrigation allows for an expansion in the cultivatable area beyond that which is possible under rain-fed agriculture. Secondly, irrigation also allows for increases in yields due to prevention of crop water stress and due to the combined effect of using irrigation with high yielding crop varieties, fertilizers, and pesticides (cf. "green revolution" technology) (Turner et al 2004).

Although irrigation water is an important input in agricultural production in developing countries, there is often no market for irrigation water. Sometimes the state will have formulated a set of water allocation policies to compensate for the missing water market, but these water allocation policies are not necessarily designed to ensure an efficient allocation of irrigation water across users. If the right quantities of water were always available at the right time, in the right place, and in the right quality, there would be no need for a market or any other type of allocation mechanism. However, if some kind of water scarcity prevails – whether this is a global, local, or seasonal phenomenon – the lack of mechanisms for allocating water efficiently between competing uses will result in inefficient usage of the water resources and externalities amongst the water users. The present chapter will focus on two types of externalities amongst farmers: The externalities arising from the farmers' initial diversion of water for irrigation and the externalities arising from the subsequent return flows from the farmers' irrigation activities. These two types of externalities focus primarily on quantities of water rather than quality, although the latter will also be considered briefly. The use of water for non-agricultural purposes is not considered.

4. EXTERNALITIES OF WATER DIVERSIONS.

The externalities associated with appropriation of irrigation water are well appreciated in the literature. This type of externality occurs when some farmers withdraw more water from the irrigation system than what is optimal from society's point of view. When water is scarce, a farmer's excessive diversion of irrigation water results in negative externalities for other irrigators, who are left with less than the socially optimal water supply. One example of this problem in irrigation is the head-end-tail-end problem, where farmers at the head of the irrigation system are able to appropriate so much water that they may in fact reduce yields due to waterlogging, while farmers in the tail of the irrigation system may not be receive sufficient water supplies and hence end up suffering drought damage to their crop (Perry et al 1997).

4.1. CAUSE OF THE WATER DIVERSION EXTERNALITY: PROPERTY RIGHTS IN WATER.

The water diversion externality can typically be attributed to ill-defined property rights over irrigation water. Property rights in water can take several different forms. In a recent FAO report on water resources in agriculture, Turner et al (2004) operates with four types of property right regimes: private, common, state, and open-access. Private property rights entail that a private individual owns the resource, has the right to the use of this resource and the benefits from it, as well as the right to sell it. Common property rights, on the other hand, entail that the resource is owned by a group of individuals, who manage the resource. Group members have specific rights and duties in relation to the resource and non-group members are excluded from using it. State property rights entail that the resource is owned by the state, but the state may grant individuals permission to use the resource. Finally there is the open-access property rights regime, in which no property rights are assigned to the resource and use of it is neither subject to regulation nor exclusion. All potential users hence have open access to the resource and full autonomy in its use (Turner et al 2004).

The efficiency implications of these different types of property rights may be assessed according to whether they fulfill the following four criteria (Turner et al 2004 p 42-43):

- Universality – implies “full specification of ownership and entitlement to the resource”.
- Exclusivity – implies “accrual of all benefits and costs exclusively to the entitled individual”.
- Transferability – implies “exchange of property rights in voluntary transactions”.
- Enforceability – implies “penalties that prevent individuals from encroaching or taking property rights without prior agreement”.

A system of private property rights often meets these four criteria. In this case, private property rights result in efficient resource management. However, in a number of situations the criteria of exclusivity will be violated.[4] This in turn results in externalities for third parties and inefficiencies in the resource management. A system of common property rights can also lead to an efficient allocation of resources to the extent that the four criteria are met at the group level, and to the extent that the group is able to manage the resource efficiently within the group. State property rights, on the other hand, are not considered to meet the criteria of universality, exclusivity, and transferability. Although a state property right regime may meet the criteria of enforceability, government failure tends to imply an inefficient management of state property resources.[5] Finally there is the open access regime, which does not meet any of the four criteria. This in turn implies a high degree of inefficiency in resource utilization under an open access regime and no incentives to conserve the resource. Furthermore, the characteristics of open-access regimes may also arise in the case of common property rights or state property rights, if resource use under these regimes is poorly managed or unregulated (Turner et al 2004).

In the case with private property rights to water, a market for irrigation water may easily be established. If the exclusivity criteria holds and all agents act as price-takers, the resulting allocation of water diversions across farmers would be efficient. However, when property rights in irrigation water resemble open access, inefficiencies in the allocation of irrigation water are to be expected, and users may inflict significant negative externalities on each other through their appropriation of irrigation water. As discussed in the theoretical section, inefficiencies from externalities may be alleviated through a variety of policy instruments ranging from taxes over quotas to the establishment of some sort of bargaining/market mechanism. All these instruments imply the assignment or modification of the property rights in the water resource, whether this be done explicitly or implicitly (Turner et al 2004). The inefficiencies of the water diversion externality are thus alleviated by explicitly or implicitly addressing the underlying cause of the externality.

Johansson et al (2002) list a total of five general methods for pricing and allocating water: volumetric pricing, non-volumetric pricing, quotas, market-based mechanisms, and user-

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[4] The exclusivity criterion is also violated in the case of public goods. Some water related services do have public goods characteristics (e.g. navigation on the high seas) (Hellegers and Perry 2004). However, as the primary interest in the present analysis is on the cases, where consumption is rivalrous, this issue will not be explored here.

[5] Perry lists a number of instances of government failure, which can affect the public sectors management of water resources: "rent seeking", "the divorce of incentives from performance", "capture of public agencies and funds by politically powerful interests and their clients", and "administrative operations, 'by the book', rather than management in terms of objectives and results" (Perry et al 1997 p 7).

based allocations. The following sections will consider each of these methods in turn. In the case of the two first options, the literature generally uses the term “pricing” rather than taxing. A volumetric water pricing scheme could for instance be implemented by a water user organization (cf. Tsur and Dinar 1997), in which case it may seem more appropriate to refer to the water charge as a price rather than a tax. However, the distinction between the notion of prices and taxes will not be pursued here, and both volumetric and non-volumetric water pricing will consequently be categorized as tax policy instruments in the present analysis.

4.2. ALLEVIATING THE WATER DIVERSION EXTERNALITY: VOLUMETRIC TAXES.

Volumetric pricing implies placing a tax on the amount of water the farmer diverts for irrigating his fields. This can be done using a single tax rate on water diversions. However, a volumetric pricing scheme can also take more sophisticated forms such as tiered pricing, where the water tax rate varies according to the amount of water diverted, or two-part tariff pricing, where the farmer pays a constant marginal price per unit of irrigation water purchased as well as a fixed annual or admission charge for the right to purchase water (Tsur and Dinar 1997). Tiered pricing can be used in cases, where there are periodical variations in water demand (e.g. seasonally or daily) and water supply is insufficient to meet this demand at all times. Two-part tariff pricing, on the other hand, can be used to take account of long run fixed costs in water provisions, as the fixed admission charge can cover these costs (Tsur and Dinar 1995).

Hellegers and Perry (2004) make a distinction between volumetric pricing and market-pricing. In their terminology, volumetric charging implies that the farmer is charged for the actual amount of water delivered, but he cannot necessarily demand as much water as he would like to at the agreed price. Market pricing, on the other hand, entails that the farmer can demand as much water, as he would like, at the set price. Both types of policy instruments provide the farmer with price-incentives to reduce his use of water, but in Hellegers and Perry’s terminology volumetric charging is in effect a combination of price and rationing. Such a combination of policy instruments is likely to be important in a real world setting. However, in the present analysis the term volumetric pricing will not include any rationing of farmers’ demand unless explicitly stated, as this would confuse the discussion of whether pricing instruments can solve water scarcity problems.

In order to implement a volumetric water pricing scheme, the water authorities need to collect information about how much water each farmer is diverting for his fields. The most obvious way to obtain this information is to incorporate water meters into the irrigation infrastructure, in order to directly measure the size of each farmer's water diversions. However, installing water meters may be very costly, and the existing irrigation infrastructure may not be well suited for a metering system. Metering may for instance be practically infeasible if irrigation water is delivered in open canals, as farmers may well be able to pump the water from these canals without it being metered. According to Johansson (2000), volumetric water pricing is feasible under the "demand and closed pipe systems", whereas it is very difficult to implement under the rotation system and almost impossible to implement under the continuous flow system. If the water flow is reasonably constant, volumetric pricing can also be implemented in a more indirect way by charging the farmer for the amount of time water is delivered to him (Johansson 2000). However, in many cases water flow per time unit may vary significantly depending in part on the farmer's location in the overall irrigation system, and this would in turn translate into different water prices for different farmers.

Implementing a volumetric water pricing system in reality is not simply a matter of getting the technology in place for metering farmer water diversions. A regulatory framework must also be established with procedures for measurement of the amount of water delivered as well as procedures for partial deliveries, missed deliveries, excess deliveries, late deliveries, polluted deliveries, etc. Furthermore, apart from the sophisticated water delivery system, an administrative bureaucracy must be established, which can collect data on water deliveries to the farmers and carry out the billing (Perry 2001). Perry stresses that in order for water pricing to have the desired effect on farmer behavior, the delivery-billing process must not simply be an ex post scheme that relates payment to whatever quantity of water ended up being delivered. Rather "it must involve an ex ante, two-sided process of demand from the user and agreement by the supplier if pricing is to have the desired impact on demand" (Perry 2001 p 4).

Once the technical, legal and regulatory ability to implement a volumetric water pricing scheme has been established, the next challenge is to determine the right price to charge for the irrigation water deliveries. Marginal cost pricing is a special case of volumetric water pricing, which entails that the price of water is set equal to the marginal cost of supplying the last unit of water (Johansson et al 2002). The marginal cost of supplying irrigation water includes water delivery costs and policy implementation costs as well as the scarcity value of water. It is the latter of these elements, which captures the water diversion externality. In the absence of implementation costs, marginal cost pricing can achieve a first-best allocation of irrigation water.[6] However, as outlined in the previous paragraph, implementation costs for a volumetric water pricing scheme are likely to be substantial and this lowers the efficiency gains from using volumetric water pricing. Moreover, even in the absence of implementation costs, it would still be difficult to include all the relevant marginal costs and benefits when determining the right price to charge for the water. Marginal cost of water provision will, for instance, typically vary across months and years. Furthermore, prices should reflect any differences in the marginal costs of supplying different users, and they should also reflect any differences in the quality of the water supplied (Johansson 2000).

The efficiency assessment of volumetric pricing schemes can also be given a time dimension according to whether or not they can handle the long run fixed costs of water delivery in an efficient manner. In the absence of implementation costs, simple marginal cost pricing and tiered pricing can achieve short-run first-best efficiency, while two part tariff pricing can achieve long-run first-best efficiency, as the latter pricing scheme can take account of long run fixed costs in an efficient manner (Tsur and Dinar 1995).

Determining the right price to charge for water under a volumetric pricing scheme is thus difficult, and once implementation costs are taken into consideration it is only possible to achieve second-best outcomes. Moreover, the need to volumetrically measure farmers' water use implies higher implementation costs for a marginal cost pricing scheme than for some of the other water pricing schemes (Johansson 2000). However, doubts have also been raised in the literature concerning the effectiveness of water pricing as a means to affect farmers' use of water. Several studies suggest that the demand for water is inelastic below a threshold price. In order to reduce demand for water, water prices would consequently have to be increased substantially, which may not be politically feasible (de Fraiture and Perry 2002).

[6] According to Johansson et al (2002), marginal cost pricing can achieve a first-best allocation of water in the absence of implementation costs and scarcity. While this is correct, it seems important to emphasize that marginal cost pricing can also result in a first-best allocation of water in the presence of water delivery costs *and* water scarcity. In this case the price of water would initially be set equal to the marginal delivery cost of water, and if water scarcity still prevailed at this non-zero price, then the price would be raised further in order to cover the remaining scarcity value of water.

De Fraiture and Perry offer two explanations as to why demand for water may be inelastic below a threshold price. The first explanation centers on the technological aspects of field irrigation efficiency, which is defined as the fraction of water applied to the field, which is beneficially used by the crops.[7] Citing Gardner they state that when farmers are faced with higher irrigation water prices, they can respond in four different ways: demand less water and leave land fallow, reduce the amount of water used to grow a given crop and accept a reduction in the crop yield, switch to less water intensive crops, and / or invest in more efficient irrigation technology (de Fraiture and Perry 2002).[8] Based on a model, which captures the farmer's choice of cropping pattern, water application level, choice of irrigation technology and level of labor input in its operation, de Fraiture and Perry conclude that in cases where irrigation efficiency is low and can be improved relatively cheaply, the farmer will be able to cut down on his water diversions without substantial losses in profit.[9] However, in cases where irrigation efficiency is already high, additional improvements in irrigation efficiency may come at a high cost. In this case farmers' profit will decrease as water prices are raised, but their water demand will not be reduced until the price has reached a certain threshold level. This in turn leads to an inelastic demand for water at lower water prices.

De Fraiture and Perry's other explanation for why the demand for water may be inelastic below a threshold price relates to the impact of existing rationing practices. In many places farmers do not have completely open access to irrigation water. Instead irrigation water is

[7] The notion of field irrigation efficiency is explored in more detail in chapter 2 and 3. The basic point of field irrigation efficiency is that only a fraction of the water applied to a field ends up being consumed by the crops. The rest of the water either ends up in the drains or percolates into the ground (cf. also section 5 in the present chapter). Field irrigation efficiency is determined partly by the irrigation technology employed and partly by the soil type (Caswell and Zilberman 1986).

[8] It is important to consider the time horizon when evaluating farmers' response to changing water prices. In a real world setting, irrigation water demand is likely to be rather unresponsive to price changes in the very short run. Once the growing season is underway, crop changes and major efficiency improvements are no longer possible. At this point the farmer's only options for lowering his water demand are thus to water-stress the crop or undertake minor efficiency improvements, if he is not to completely abandon the crop. However, between seasons and over the longer run, farmers can change crops and undertake major adjustments of irrigation efficiency and management practices. Water demand is therefore likely to be much more responsive to price changes in the median and long run (Spulber and Sabbaghi 1994).

[9] There are three main types of irrigation technology: Surface (or gravity) irrigation, sprinkler irrigation, and drip irrigation. Surface irrigation is generally the least capital intensive and typically also the least efficient of the three techniques, while drip irrigation is the most capital intensive and typically also the most efficient of the three techniques. Within the class of gravity techniques, simply flooding the field requires the least amount of labor but also results in low irrigation efficiency. Irrigation efficiency can be raised by using additional labor to construct field bunds. Constructing furrows is another even more efficient and also more labor intensive solution (de Fraiture and Perry 2002). De Fraiture and Perry thus highlight the fact that irrigation efficiency can be improved not only by investing in more efficient irrigation technologies, but also by substituting labor for water in order to operate the existing irrigation technology more efficiently.

allocated to farmers by irrigation managers, and this implies that farmers may already be subject to irrigation water rationing. If the farmer's demand for water has been truncated by such a rationing scheme, then the productive value of his last unit of water will be strictly positive even if the price of water is zero. When the price of water is subsequently increased, it will initially lower the farmer's scarcity rent on water as well as his profits without affecting his demand for water. Only when the price of water exceeds the marginal productive value of water for the farmer will he lower his water diversions (de Fraiture and Perry 2002).

If the demand for water is inelastic, curbing water demand may require very large increases in the price of water. As pricing water is often a politically sensitive topic increasing water prices substantially may not be politically feasible. Based on her study of Maharashtra in India, Ray thus concludes that "significant price increases could be politically infeasible, and feasible price increases could be economically insignificant" (Ray 2005 p 3663).

However, inelastic water demand is not the only factor, which can undermine the use of volumetric pricing to allocate water efficiently. In order to determine whether water pricing is in fact an effective means to increase the efficiency of irrigation, Ray investigates the implicit assumptions behind this notion. She argues that, in order for water pricing to induce higher efficiency in irrigation, water costs must account for a significant part of the overall crop budget and a significant fraction of crop net revenues. If this is not the case, the net effect of an increase in water prices will most likely be too small to noticeably change farmer's demand for water. Furthermore, farmers must be irrigating wastefully or growing low-water-productivity crops because water is too cheap, and farm level inefficiencies should be significant compared to overall system inefficiencies. If farmers are over-irrigating because their water-deliveries are unpredictable or growing low-water-productivity crops because local food or fodder markets are thin, then water pricing may not have the expected effect. Moreover, if farm level inefficiencies are minor compared to water conveyance and distribution inefficiencies, larger water savings may be achieved from raising water conveyance and distribution efficiency than from raising farm level efficiency. Finally, there must in fact be a volumetric link between the farmer's payment and the amount of water he receives, and any changes to infrastructure or administration, which may be required to implement volumetric pricing, must not be prohibitively expensive (Ray 2005). If – as will often be the case – some of these assumptions are not met, water pricing may not result in higher irrigation efficiency and water savings.[10]

Summing up, it may be concluded that while volumetric water pricing appears to be an obvious solution to the water diversion externality problem from a theoretical point of view, implementing this type of policy in reality is often associated with substantial difficulties. The literature has focused particularly on the high cost of upgrading the irrigation infrastructure to allow for metering of individual farmer water diversions. However, the political feasibility of volumetric water pricing has also frequently been questioned, partly on the grounds that in many places water is considered a basic human right rather than on economic good, and partly because any existing water prices would typically have to be increased substantially – sometimes by several hundred percent – in order to curb water demand sufficiently. However, while the introduction of high water prices would very likely meet with strong political opposition, from an economic point of view the need to increase water prices substantially only underscores the fact that water is currently severely under-priced in many locations.

A closely related point is the concern about the effect of high water prices on farm incomes. However, while it is true that high water prices by themselves would reduce farmer income, they also generate tax revenue, which could be used in various ways to benefit the very same farmers. One possibility would thus be to return tax revenue in excess of water delivery costs to the farmers using a distribution key which is not directly related to the farmer's actual use of water. In this way volumetric water pricing could be used to achieve a more efficient allocation of irrigation water without reducing the average farmer's income by more than the water delivery costs. Of course the issue of covering the implementation costs for a volumetric water pricing scheme still persists, and farmers may also be required to cover part or all of these costs.

The question of how to use the tax revenue generated by water pricing is fundamentally a question about how property rights to water are implicitly assigned through the design of the water policy instruments. By transferring tax revenue in excess of water delivery costs back to the farmers, the farming community is implicitly granted property rights to the irrigation

[10] However, as section 5 will show, increasing irrigation efficiency may not be necessary in order to achieve socially efficient water usage at the basin level. Higher irrigation efficiency also need not lead to water savings. Whether this will be the case depends on the recoverability of the return flows.

water and the scarcity rents from this resource. Such a strategy would also counteract the problem that the value of prevailing usefructuary water rights – be these formal or informal – has been capitalized into the value of irrigated land in existing irrigation systems. The introduction of volumetric water pricing in these settings will, ceteris paribus, result in capital losses, and water users consequently perceive such policies as expropriation of their rights (Dinar et al 1997). While water users should pay for water delivery costs, the issue of the implicit property rights inherent in different water policy schemes deserves more attention in the literature than it is currently granted, as it is crucial for determining the impact on farmers' income.[11]

4.3. ALLEVIATING THE WATER DIVERSION EXTERNALITY: NON-VOLUMETRIC TAXES.

Given the difficulties of implementing volumetric water pricing, non-volumetric water pricing methods are more widely used. Non-volumetric water pricing methods include output pricing, area pricing, other input pricing, and so-called betterment levy pricing based on land values (Johansson et al 2002 and Tsur and Dinar 1997). The present analysis will focus on area and output pricing.[12] In a global survey of farmers covering 12.2 million hectares of land, Bos and Wolters found that in 60% of the cases farmers were charged for irrigation water through per unit area charges. In 25% of the cases volumetric water pricing was used, while a combination of area and volumetric methods was used in less than 15% (Tsur and Dinar 1997).

The area pricing methods charge for the use of irrigation water by placing taxes on the irrigated area. According to Johansson et al (2002), the method is best suited to continuous flow irrigation. The simplest form an area pricing scheme can take is a uniform per area charge. However, such a scheme can only influence the farmer's use of water through his decision of how large an area to irrigate. Area pricing schemes are consequently often

[11] On the related issue of the distributional properties of different water pricing instruments, Tsur and Dinar conclude that when farmers are "per hectare" identical water pricing must entail some sort of quantity regulation, if it is to affect the distribution of income. The example they give of a policy mechanism, which could achieve a more egalitarian income profile, is a tiered water pricing method combined with water quotas, which are equal across farmers rather than proportional to farm size. Implicit in their analysis is the notion that revenue raised from water pricing is not channeled back to the farmers. In their analysis normal price measures, which do not have any quota features (i.e. volumetric, per area, output, or input pricing), consequently do not have any impact on income inequality. Instead income inequality is determined solely by the land distribution profile (Tsur and Dinar 1995). Johansson (2000), on the other hand, states that water pricing policies may be the most effective means to redistribute income between *heterogeneous* water users and sectors.

[12] The implications of using taxes on other inputs to affect farmers' use of water have been studied by He (2004). Using agricultural sector models for Egypt and Morocco, she analyses the effect of using taxes on fertilizers, pesticides, and energy, as well as taxes on output compared to the effect of using volumetric water pricing.

designed to depend on factors such as choice of crop, extent of crop irrigated, irrigation method used, and season (Johansson 2000). These more sophisticated area pricing schemes can affect not only farmer's choice of how much land to irrigate, but also his choice of crops, and thus indirectly lower his demand for water. However, once the decision on cropping pattern has been made, area pricing can no longer affect the farmer's use of water, as the marginal price of applying more water to the same area is zero. Area pricing can consequently not be used to induce farmers to water-stress their crops, nor can it induce them to improve irrigation efficiency beyond the type of irrigation method that the area charge may depend on. According to Tsur and Dinar (1995), area pricing does not achieve a measure of efficiency, whereas Johansson et al (2002) refer to area pricing as being potentially second-best. However, it is not clear whether Tsur and Dinar's conclusion is directed at uniform rather than crop-specific per area charges. The present analysis will follow Johansson et al and refer to area pricing as a second-best water policy instrument.

While volumetric water pricing is quite difficult and costly to implement, area pricing is one of easiest water pricing policies to implement. In the case of the simple uniform area charge, the only information required is farm size data, provided that all land is irrigated or that farmers are also charged for non-irrigated land (which does happen in some schemes). In the case of crop-specific area charges, the only data required is land-by-crop data, which may also be obtained relatively easily. Although area pricing is theoretically less efficient than volumetric water pricing, the low implementation costs may thus well make this type of water policy more socially beneficial (Tsur and Dinar 1997).[13] Furthermore, area pricing also generates a relatively predictable revenue stream for covering water delivery costs (Hellegers and Perry 2004). These cost recovery aspects as well as the low implementation costs are important reasons behind the widespread use of this policy instrument.

The output pricing method charges for the use irrigation water by placing taxes on the amount of crop output produced by the farmer. By differentiating these crop taxes according to the water needs of the crops, the output pricing method can affect the farmer's choice of cropping pattern. Moreover, output pricing may also affect the amount of water the farmer applies to a

[13] If area charges are to depend on irrigation method, data is obviously also needed on farm irrigation technology. While this type of information may not be that costly to obtain, making the area pricing scheme depend on more production features will generally tend to increase the policy implementation costs. The increase in efficiency from differentiating the policy instrument thus has to be compared with the increase in implementation costs.

given crop, as a crop-specific output tax lowers the farmer's return per output unit. However, whether this will lead the farmer to conserve on the use of water for producing a given crop depends on the substitutability or complementarity between the free water and the other costly inputs. Furthermore, output pricing will generally not induce the farmer to improve his irrigation efficiency. Nonetheless, output pricing can achieve a second-best outcome according to both Johansson et al (2002) and Tsur and Dinar (1995).

In order to implement an output pricing scheme, data on output level for each water user is required. The cost of measuring these output levels will depend on the crop marketing channels. If the crop is marketed through a central state trading enterprise measuring, measuring the level of output may be relatively inexpensive resulting in low implementation costs. If, on the other hand, the crop is marketed through local, informal markets or used for home consumption, then the costs of implementing an output pricing scheme can be very high. According to Tsur and Dinar, "the measurement of output can be as formidable as that of water" and examples of output pricing as a means for pricing water are also rare (Tsur and Dinar 1997 p 245).

4.4. ALLEVIATING THE WATER DIVERSION EXTERNALITY: QUOTA INSTRUMENTS.

The price mechanism is not the only means for reducing farmers' use of water. Instead this goal can be achieved through rationing by imposing quotas on farmers' irrigation water.[14] The water quota can be defined in terms of a fixed amount of water or it can be specified according to a formula such as a fraction of the available supply (Hellegers and Perry 2004).

Irrigation water quota systems can take different forms. A simple water quota scheme entails all farmers receiving the same amount and schedule of water delivery per hectare. In more complex quota schemes, farmers may be allotted a total seasonal water quota and accounts of water deliveries are then kept for each farm. The simple quota scheme can be implemented without being able to measure water deliveries at the individual farm level, while the more complex system requires that water supplies can be measured at farm level. When the simple quota scheme is implemented without the ability to measure water deliveries at the farm level, the quota might for instance be defined in terms of the amount of time in which water is

[14] As in the case of non-volumetric water pricing, the farmer's use of water can also be indirectly affected through quantitative restrictions on land use or output volumes. These instruments will be further investigated in chapter 3.

delivered to the farm. The Warabandi system in India is an example of the simple quota system, while the more complex type of quota scheme can be found in the Murray Darling basin in Australia (Hellegers and Perry 2004).

Objections to volumetric water pricing are often based on concerns for its detrimental effect on farm incomes. The use of water quotas can mitigate these concerns, if quotas are assigned to farmers free of charge. When the farmers are each granted a specific quota, they have incentives to conserve on water by either switching to less water intensive crops, water-stressing their crops, or improving their irrigation efficiency. However, if the state is to assign the socially optimal quotas to each farmer, it would have to collect very detailed information about each farm, which would probably be prohibitively expensive. If, on the other hand, the quotas are made tradable, a first-best allocation of water would be possible under a water quota scheme (Johansson et al 2002). However, as it is difficult to distinguish a tradable quota scheme from an actual water market, the term quota will in the present analysis refer to non-tradable quotas unless otherwise stated.

Implementation costs also need to be considered in order to evaluate real-world efficiency implications of a water quota policy scheme. While the simple quota system can probably be implemented at low costs, the implementation costs for the complex quota scheme would be high, as this scheme requires the ability to measure water deliveries at the individual farm level. Furthermore, if quotas are assigned to farmers free of charge, the quota scheme will not generate any revenue to cover water supply costs or policy implementation costs.

4.5. ALLEVIATING THE WATER DIVERSION EXTERNALITY: WATER MARKETS.

The use of volumetric and non-volumetric pricing instruments as well as quota instruments for allocating irrigation water all imply the involvement of the state or another centralized water authority in the allocation of irrigation water between different farmers. However, irrigation water may also be allocated in a more decentralized manner through various types of water markets.[15]

[15] While the issue of water markets and tradable water rights has received much attention in economic literature in recent year, the aim here is only to give a brief introduction to the topic, as this type of water allocation instrument is not included in the subsequent theoretical and empirical analyses. For more detailed analysis on these issues see for instance Easter et al 1999 and Rosegrant and Binswanger 1994.

The spectrum of water markets range from informal to formal and both types of markets may exist simultaneously. Under informal water trading, farmers are typically selling excess ground or surface water for a period of time like a crop season to a neighboring farmer or town. Informal water sales may also take the form of selling or exchanging turns in a rotational irrigation system or selling of water by a tube well owner to nearby farmers. Informal water markets are often established as a response to a scarcity situation and when the state fails to respond quickly enough to changing water demands (Johansson 2000 and Perry et al 1997).

Unlike informal markets, the operation of formal water markets requires the establishment of well-defined transferable water rights or permits, which grants the holder permission to use or sell a specified amount of water (Johansson 2000). Furthermore, formal water markets also require a clear and comprehensive set of rules for trading the water rights, a judicial body to oversee the trading activities and resolve disputes, and a well-developed conveyance and distribution system for transporting water to all market participants (Tsur and Dinar 1997). While informal markets are typically local in nature involving water trading between similar water users, formal markets may cover a much larger area and they may entail inter-sectoral transfers of water (Perry et al 1997).

The potential for establishing actual markets for water has received great attention in the economic literature. One of the basic premises of modern economics is that markets - under certain conditions - can achieve first-best efficiency, provided there are no implementation costs. However, these “certain conditions” include perfect competition, full information, complete certainty, no increasing returns, and no externalities, and they are frequently violated in cases involving water. As water is expensive to transport, water markets are often localized with only a limited number of participants, some of whom may be in a position to influence market outcomes. Furthermore, water supply is often uncertain, and water supply systems may also exhibit increasing returns to scale like other public utilities. Finally, water resources are often shared by many agents, who may be inflicting various types of externalities upon each other. Although water markets may achieve first-best allocations in theory, they are consequently not likely to achieve first-best outcomes in a real-world setting (Tsur and Dinar 1997).

The implementation costs associated with establishing water markets depend to some extent on the type of water market. A significant part of the implementation costs for water markets are related to the assignment and enforcement of water rights. For local markets, where water rights are defined in terms of e.g. turns in a rotational irrigation system, the market may be able to operate without water metering at the individual farmer level. However, for non-localized trading in water, metering at the individual farmer level would be necessary. Establishing the necessary infrastructure for such a water market may consequently be very costly. Meanwhile potential efficiency gains would also tend to be larger in the large water markets than in small, localized markets. Consequently, there appears to be a trade-off between efficiency gains and implementation costs with respect to market size.

Another element of implementation costs is the collection of information. Compared to the tax and quota policy instruments, markets have the advantage of internalizing the costs of collecting information once water rights have been established. Furthermore, markets also eliminate incentives for corruption, which may plague the other water allocation mechanisms. Unlike standard volumetric water pricing, water markets also do not entail expropriation of what farmers perceive to be their rights to irrigation water, but rather formalization and securing of these rights. Finally, water markets may also be more flexible than the centrally controlled water allocation mechanisms. Johansson et al (2002) and Tsur and Dinar (1997) consequently conclude, that even though water markets will only result in second-best outcomes in real-world settings, they may still be more efficient than volumetric water pricing. However, water markets are not well suited for generating income for recovery of water delivery costs (Hellegers and Perry 2004).

4.6. ALLEVIATING THE WATER DIVERSION EXTERNALITY: USER-BASED ALLOCATIONS.

The final water allocation method to be considered here is so-called user-based allocations. As the name suggests, user-based allocation mechanisms entails that the water users allocate the water amongst themselves. User-based allocation mechanisms consequently require collective action institutions that have the authority to make decision on water rights (Dinar et al 1997).

User-based allocation mechanisms can employ a wide variety of rules for allocating water, and it is therefore not possible to make generalizations about the efficiency properties of this type of mechanism. However, according to Dinar et al, user-based allocation mechanisms will have only limited effect on water demand, if the user organization does not actively advance efficient use of water. On the other hand, social norms can induce water conservation, especially if they are supported by rules against excess consumption, monitoring of compliance, and sanctions against wasting water. If members of the user organization monitor each other's use of water and trust, that if they themselves save water others will save water as well, then user-based allocation can result in high water use efficiency (Dinar et al 1997).

Like in the case of the other water allocation mechanisms, social efficiency requires that water delivery costs be recovered. However, whether user-based organizations are effective at recovering these costs depends on the set-up of the organization and the same goes for the implementation costs. Although user-based water allocation mechanisms can be found in many places it is consequently difficult to offer a general evaluation of this allocation mechanism.

5. EXTERNALITIES OF RETURN FLOWS.

While the externalities of water appropriation are well appreciated in the literature, the presence and importance of the externalities related to so-called recoverable return flows and the ensuing recycling of water have not yet been as widely acknowledged. According to Perry et al, "[o]ne of the most important, yet least appreciated, facts about water is that in a basin, a substantial amount of it is recycled" (Perry et al 1997 p 10). In irrigated agriculture, the recycling of water stems from the fact that not all water applied to a field ends up being consumed (/ evapotranspired) by the crops.[16] The part of the applied water, which is not consumed, either returns to the basin water system or ends up in sinks like saline aquifers or the sea (Hellegers and Perry 2004). While these latter types of return flows imply a non-recoverable loss of fresh water, the former types of irrigation return flows are recoverable. After returning to the basin system, the recoverable return flows thus become available for yet another diversion cycle "at another time, another place, and at another quality" (Perry et al. 1997 p 10).[17]

[16] In this study 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" (Allen et al 1998 p 1). The concept of evapotranspiration is further examined in chapter 3.

[17] The term "return flow" is in the present analysis used as referring to the entire amount of water applied, which is not evapotranspired, regardless of whether these water flows are recoverable or not.

5.1 CAUSE OF THE RETURN FLOW EXTERNALITY: RECOVERABILITY AND REUSE.

The concept that a significant share of water applied to a field may be reused implies the existence of important externalities from use of water in agricultural production. The externality arises from the fact that while the part of applied water, which is actually consumed, is exclusive in its use, the non-consumed part of water applied is only exclusive within a narrow time- and location specific context, but not within a broader basin-wide perspective (Turner et al 2004). Comparing this notion with the property rights systems presented in section 4.1 suggests that pure forms of private property rights or common property rights in irrigation water will be difficult to establish. The reason is that the exclusivity criteria will generally not be met, as benefits from the return flows may well accrue to others than the individual or the group otherwise holding the property rights to the applied irrigation water.

Whether recoverable return flows generate positive or negative externalities depends on the time, place, and quality at which the water becomes available for another diversion cycle. If the return flows end up being stored in an aquifer from which they can readily be pumped when needed, then initial application of excess water may turn out to be beneficial for all users of the aquifer. Xie et al (1993) thus reports that there are places, where water use efficiency is kept low intentionally and canals are intentionally unlined in order to increase seepage and recharge the aquifers for conjunctive operations during low runoff years. On the other hand, if the water is originally diverted during the dry season and becomes available again during the rainy season, then the recovered return flows may be less useful than the original water diverted, if they cannot be stored until the next dry season.

In terms of location, return flows may “resurface” beyond the area of agricultural production in which case they are typically no longer useful for irrigation purposes. Such return flows may though still be fully useable for industries or household or be environmentally beneficial. Furthermore, the quality of the return flow will generally also be different from the quality of the water originally diverted, as salt levels will be higher and residues of fertilizers and pesticides may be present. This kind of pollution would normally be considered a negative externality, although Perry et al (1997) claims that some farmers may in fact be pleased to receive irrigation water already containing fertilizers.

As the preceding discussion has shown, the fact that a substantial fraction of water applied to a field is not consumed by the crops does not necessarily imply significant inefficiencies in utilization of water resources at the basin level, as the apparent water losses may be recoverable. This in turn implies that the scope for real water savings at the basin level may be much more limited than the degree of field irrigation efficiency would appear to suggest. As outlined earlier, field irrigation efficiency is defined as the fraction of water applied to the field, which is consumed (or evapotranspired) by the crops. Low field irrigation efficiency implies that a larger fraction of water applied to the field ends up as return flows. However, if these return flows are recoverable, low field irrigation efficiency need not imply high non-recoverable water losses.

In order to adequately account for the recycling of return flows, it may consequently be more appropriate to look at the irrigation efficiency for the entire basin rather than the irrigation efficiency for the individual fields. Molden and de Fraiture site Egypt as an example of how low field irrigation efficiency can be combined with high basin efficiency. While field irrigation efficiency in Egypt is typically between 40% and 50%, at the basin level irrigation efficiency is close to 80%, and much of the remaining 20% of the water is beneficially used in other sectors or for environmental purposes. Molden and de Fraiture (n.d.) therefore conclude that it will not be possible to achieve much real water saving by improving irrigation efficiency in Egypt.

The implications of recoverable return flows for basin efficiency have been further explored by Keller, Keller, and Seckler. Central to their work is the notion of “effective efficiency”, which they define as the amount of beneficially used water divided by the amount of freshwater consumed in the course of conveyance and application of the water. In their terminology, freshwater is effectively consumed when it is either lost due to evapotranspiration, flows to a sink, or its quality is degraded. The amount of freshwater consumed during conveyance and application of the water can consequently be defined as the amount of water diverted minus the amount of reusable return flows. The concept of effective efficiency is compared to the classical notion of irrigation efficiency, which is defined as the amount of beneficially used water divided by the amount of water diverted (Keller et al 1996). The key difference between these two irrigation efficiency concepts is the fact that while the classic irrigation efficiency concept treats return flows as lost, the effective irrigation efficiency concept treats them as being (potentially) reusable.

Keller, Keller, and Seckler then develop two models for exploring and simulating the effective efficiency of integrated water resource systems (IWS) like river basins. The first model represents a so-called idealized IWS in which there is no rainfall, water is pure (i.e. there is no salt or pollution), there is no non-beneficial evapotranspiration (i.e. the only evaporation result from crop evapotranspiration), and no water is otherwise lost from the system (i.e. return flows are fully recoverable) (Keller et al 1996). Under these idealized conditions the initial supply of freshwater to the system may be fully consumed by crops after a sufficiently high number of use cycles. Given the idealized model conditions, the effective efficiency for each water use cycle is 100%, while the classical efficiency for each cycle is much lower, as this efficiency measure does not take account of the possibility for reusing return flows. However, when the two efficiency measures are evaluated cumulatively (i.e. when they are computed after a given number of use cycles by dividing initial amount of water applied with cumulative crop evapotranspiration), the value of the classical efficiency measure eventually converges to the value of the effective efficiency measure of 100%.

The other model in Keller, Keller, and Seckler represents a more realistic IWS, in which salt concentration, non-beneficial evaporation, and less than full recoverability of return flows are introduced. With salt in the model, the water requirement for crop production includes not only crop evapotranspiration but also water for leaching purposes in order to maintain adequate soil salinity levels. As providing the necessary amount of water for leaching is equivalent to reducing the amount of water applied, which is available for crop evapotranspiration, the denominators of both the classical and the effective efficiency measures are reduced by the fraction of water applied, which must percolate below crop root zone in order to satisfy the leaching requirement (Keller et al 1996). With the leaching requirement and non-beneficial evapotranspiration in the model, effective efficiency and classical efficiency is generally lower for each use cycle than in the idealized model. Furthermore, as the concentration of salt in the drainage water increases for each cycle, it is no longer possible to recycle drainage water indefinitely (at least not without mixing the drainage water with new freshwater). While the cumulative classical efficiency is still increasing, cumulative effective efficiency is now decreasing. Per definition the two cumulative efficiency measures coincide for the last use cycle, as the drainage water from this cycle is discarded due to salinity.

One of the main points of Keller, Keller, and Seckler's models is to highlight the fact that classical irrigation efficiency for a single water use cycle generally underestimates the efficiency of the entire river basin, as it does not account for the repeated reuse of drainage water. Rather than simply focusing on the field irrigation efficiency in a single water use cycle, they suggest that most of the important policy questions in the field of water resources relate to the degree of closure of the water systems. A water system is defined as open, when usable water is leaving the system, and closed, when no usable water is leaving the system (meaning that either the total initial water supply has been consumed through beneficial and non-beneficial evapotranspiration or the remaining water has so high concentration of salts and pollutants as to be rendered unusable). As a water system closes, users become more interdependent, and it becomes increasingly difficult to conserve water. In the realistic IWS model, water conservation strategies include reducing salinity, increasing classical irrigation efficiency of the final use cycle and increasing the irrigated area proportionally, reusing the drainage water from the final use cycle for yet another cycle before it is discarded, and reducing non-beneficial evaporation (Keller et al 1996).

While the concept of water system (or basin) efficiency is important, it also has its limitations from an economic point of view, as it only relates to the physical quantities of water and consequently does not address the issue of whether water is being used in the most productive way. While improving physical efficiency is about conserving water through increases in the fraction of water beneficially used to water applied, increasing economic efficiency is about maximizing the economic value of water use through physical measures and reallocation of water between water users (Cai et al 2001). The differences in the value of water in alternative uses can be captured by the concept of water productivity. Water productivity can thus be increased either by increasing the amount of a given output per input unit of water or by reallocating water from lower to higher value production either within the agricultural sector or between sectors (Molden and de Fraiture n.d.). Efficient reallocation of water between users within a given sector or between sectors requires the existence of suitable water policy schemes or water market institutions, which can take account of the various interdependencies and externalities in the water sector. The attainable level of water productivity is thus closely tied to the policies and mechanisms, which serve to allocate water between competing users.

5.2 POLICY IMPLICATIONS OF RECOVERABLE RETURN FLOW EXTERNALITIES.

When irrigation efficiency is low and the degree of return flow recoverability is high, recoverable return flows will have a substantial impact on the national water balance. In order for scarce water resources to be allocated efficiently, the mechanism chosen for allocating irrigation water must take account of these recoverable return flows. The externalities from recoverable return flows could in principle be addressed through volumetric or non-volumetric taxes, quotas, water markets, or user-based allocations. The literature has tended to focus on two of these policy options – water markets and volumetric pricing.

When water is allocated through water markets, one way of addressing externalities from recoverable return flows is to change the specification of water rights from the right to divert a certain amount of water to the right to consume a certain amount of water. Rosegrant and Binswanger report that water rights in most of the western states in the US are based on consumptive use. Third-parties rights to the return flows are thus protected, but as consumptive use and return flows are difficult to measure, the system implies significant increases in the transaction costs of trading water (Rosegrant and Binswanger 1994). In the Murray-Darling Basin in Australia, on the other hand, irrigators implicitly hold the right to their return flows, as they can trade their water rights without considering the impact on downstream water users (Heaney et al 2005).

Montginoul and Renault also consider the prospects of using water markets to address the externalities from recoverable return flows in their study of rice-based irrigation in Sri Lanka. Although defining water rights in terms of consumptive rights rather than withdrawal rights would make it possible to prevent third parties from being affected by water transactions, they conclude that such a system would be difficult to implement within the Kirindi Oya irrigation system, as it would require the ability to individualize water deliveries at farmer or plot level. Another market-based possibility for taking account of recoverable return flows would be a regulatory approach in which the state determines whether sufficient conditions are met for allowing a water transaction to take place. The laws and regulations underlying this approach might be based on the “no injury” rule or a compensation principle (Montginoul and Renault 2003). However, while both the restricted water-right approach and the regulatory approach address the issue of third party effects from return flows, they primarily appear to be concerned with preservation of existing recoverable return flows. It is not given that these return flows are socially optimal, and it is not clear whether the described market mechanisms can implement an allocation of irrigation water, which is also efficient with respect to recoverable return flows.

Montginoul and Renault also explore the possibility of using volumetric water-pricing to address the recoverable return flow externality. Their water allocation mechanism consists of pricing water diversions by setting one price for the irrigators, who generate return flows, and another price for the third parties, who use the return flows. Their analysis shows that in the presence of recoverable return flows, the price on water diversion for irrigators should be lower and the amount of water diverted for irrigation should be higher than in the case, where return flows are not taken into account. Furthermore, the third parties, who benefit from the return flows, should also pay a non-zero price for this water, which should equal the gap between the marginal cost of supplying the water and the lower water price paid by the irrigators. However, Montginoul and Renault stress that although the water-pricing approach may be theoretically appealing, it would also be difficult to implement, both in terms of estimating water demand curves and in terms of identifying all the beneficiaries and collecting water charges from them (Montginoul and Renault 2003).

Another strand of the literature on recoverable return flows explores the issue of optimal conjunctive use of surface and ground water. Chakravorty and Umetsu analyze the effect of internalizing the recoverable return flow externality by joint optimization of surface and ground water use at the basin level. In their theoretical model, farmers lie in a continuum and are assumed to be homogenous in every respect, save for the distance they are located from the water source. The latter matters, because the model takes account of water losses from the water conveyance system. These losses along with the return flows from the fields are partially recoverable, as a fraction of these water flows recharge aquifers and is available for pumping. Irrigation efficiency is determined by the level of on-farm technology, which is assumed to be fixed over space (Chakravorty and Umetsu 2003).

The main result from their theoretical model is that within a certain distance from the water source all farmers will use surface water, whereas all farmers, who are located beyond this cut-off point, will use ground water. Moreover, investments in the efficiency of the conveyance system will decrease with distance from the water source. The optimal price of surface water will be increasing with distance from the water source, as the use of surface water entails conveyance losses. The optimal price of groundwater, on the other hand, will be constant across space, as groundwater is assumed to be equally accessible from all locations and the use of ground water does not result in conveyance losses. Furthermore, the prices for surface and ground water, which reflect the true social costs of the water, will be lower than the private costs of supplying the water for a given location, as the socially optimal prices will take account of the recoverable return flows.

Chakravorty and Umetsu are primarily concerned with the recoverable return flow externality and its implication for conjunctive use of surface and ground water. They consequently do not explicitly consider externalities in allocation of water diversions. In a numerical simulation of their model, farmers along the canal are thus implicitly assumed to have property rights to the canal water and to be compensated for the value of the water being reused downstream. The results from the simulation shows that joint optimization of surface and ground water use produce a relatively larger increase in benefits when field irrigation efficiency is low, as low irrigation efficiency ceteris paribus results in a larger amount of return flows. However, total net benefits are still larger under more efficient modern irrigation technology regardless of whether the use of surface and ground water is optimized jointly (Chakravorty and Umetsu 2003).

As mentioned earlier, choice of irrigation technology at the farm is kept exogenous in Chakravorty and Umetsu's 2003 analysis. However, Umetsu and Chakravorty have endogenized the level of on-farm technology in one of their other analysis. Using a very similar model they have shown that higher prices of water generally induce higher investment in on-farm technology for water conservation and lead to lower quasi-rents from land (Umetsu and Chakravorty 1998).

6. Conclusions.

The present survey has focused on two types of externalities, which may arise from farmers' irrigation activities when these are not effectively regulated by the government or the market mechanism. The first type of externality is related to the allocation of scarce water diversions among farmers, while the second type stems from recoverability of the return flows from irrigation.

The implications of the externality related to the allocation of water diversions between farmers are generally well-understood. The policy options for alleviating this type of externality have been studied extensively, ranging from volumetric pricing over non-volumetric pricing to quotas, water markets, and user-based allocations. The implications of recoverable return flows, on the other hand, have not been as widely recognized and although some studies have explored the possibilities of using volumetric water pricing or market mechanisms to address this externality, more research is needed in this area.

Rather than merely studying the recoverable return flow externality in isolation, it is important to also study it in conjunction with the irrigation water diversion externality, as the two externalities have different implications for the importance of field irrigation efficiency. If water is scarce and individual farmer water appropriations cannot be controlled, mandating investments in irrigation technologies with higher field irrigation efficiency may appear to generate real water savings by reducing the amount of water, which needs to be applied to the field. However, if return flows from the field are fully recoverable, increasing the field irrigation efficiency will not result in real water savings, and the investments in modern irrigation technology will not be socially optimal.[18] In these cases, physical efficiency of water use may consequently be high despite inefficient water application technology. However, even if physical efficiency is approaching 100%, economic efficiency may still be improved by reallocating water from low- to high-value activities (Keller et al 1996). Within the agricultural sector this can be done by adjusting the cropping pattern.

In order to investigate the policy implications of having recoverable return flows in conjunction with the water diversion externality, chapter 3 will present a theoretical model where both externalities are present. The analysis will focus on the efficiency implications of using different policy instruments to address the two types of externalities simultaneously. As the present survey has demonstrated, volumetric water pricing and market based solutions are likely to have high implementation costs, as the use of these policy instruments will often necessitate extensive investments in irrigation infrastructure in order to be able to meter individual farmers' water diversions. Non-volumetric water pricing methods like area taxation and output taxation, on the other hand, do not impose expensive demands on the irrigation

[18] While higher field irrigation efficiency will not result in real water savings in terms of water quantities, it will reduce water delivery costs as the amount of water, which needs to be diverted or pumped, will be smaller. Higher field irrigation efficiency may also affect water quality which tends to deteriorate in the course of a diversion cycle. However, increasing the field irrigation efficiency and hence reducing the amount of return flows will also tend to make the return flows more saline, if the same amounts of salts now have to be contained in a smaller amount of water. The effect of higher field irrigation efficiency on water quality is thus not readily determinable.

infrastructure. Furthermore, area and output pricing may conceptually be more targeted towards the amount of water consumed by the crops than the amount of water applied to the field. In the cases where return flows are fully recoverable, water consumed will be the relevant variable from a social efficiency point of view, and the non-volumetric policy instruments may consequently be more efficient than a simple volumetric water tax, which targets water applied. In addition to analyzing the efficiency implications of using volumetric water taxes, the analysis in chapter 3 will consequently also explore the efficiency implications of using area and output taxation in a situation where both the water diversion and return flow externalities are present.

CHAPTER 2

INSTITUTIONAL ACCOUNT OF THE EGYPTIAN IRRIGATION SYSTEM.

1. INTRODUCTION – AGRICULTURE IN EGYPT

The Egyptian economy has undergone significant structural changes since the 1950s, but agriculture remains a key sector in the Egyptian economy. In 2002 agriculture thus accounted for 16.5% of GDP and 27.5% of total employment (World Development Indicators 2006).

There are three growing seasons in Egypt - winter, summer, and Nili - and Egyptian agriculture is consequently characterized by a high cropping intensity, which in 2002 averaged 176%.[1] The main winter crops are wheat and berseem (i.e. clover), while minor winter crops include pulses, barley and sugar beet. The main summer crops are maize, rice and cotton (FAO 2005).

The Egyptian government started intervening in the agricultural sector in 1952 with redistributive land reforms. By 1980, the government was controlling a large part of the activities in the sector through regulation of land tenure, area restrictions on crop production, forced crop deliveries, administered prices, and regulation of agricultural imports and exports. However, in the late 1980s and early 1990s a more market-oriented strategy was introduced and government control over the agricultural sector was gradually liberalized. The liberalization included increasing farm-gate prices, removing farm input subsidies, removing constraints on exports of agricultural products and imports of farm inputs, and liberalizing land purchase and leasing prices as well as selling government land to private investors (Nassar and Mansour 2003).

Although Egypt is a large country, only a small fraction of the land is cultivable. According to preliminary estimates from the 1990 agricultural census, Egypt's agricultural holdings then amounted to 7.5 million feddans, which corresponds to only 3 % of the total land area (World Bank 1993).[2]

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[1] According to FAO (2005), the winter growing season lasts from November to May, while the summer season lasts from April/May to October and the Nili season runs from July/August to October.
[2] A "feddan" is the Egyptian area measurement unit. One feddan corresponds to 0.420 hectares (or 1.037 acres) (World Bank 1993).

FIGURE 1: MAP OF EGYPT

Source: Courtesy of the University of Texas Libraries, the University of Texas at Austin[3]

Egyptian agriculture has traditionally been located in the Nile Delta and along the Nile Valley. These agricultural areas are referred to as the Old Lands, and they have the most fertile soils (composed of alluvial silt and clay loam). However, the Egyptian government has also expanded the amount of cultivable land by "reclaiming" parts of the desert. These so-called New Lands are located outside the Nile Valley, and they are considerably less productive than the Old Lands (as the New Land soils are sandy and calcareous and poor in

[3] http://www.lib.utexas.edu/maps/africa/egypt_admin_1997.pdf

organic matter) (Bader 2004). Land holdings in the Old Lands tend to be very small and some are also be highly fragmented, while landholdings in the New Lands vary much more in size, ranging from small family farms to large-scale agricultural enterprises (Bader 2004 and Meyer 1998).

2. IRRIGATION IN EGYPTIAN AGRICULTURE

Egypt is characterized by an arid climate with very limited rainfall making irrigation a prerequisite for crop production. The Nile supplies more than 95% of Egypt's annual renewable water resources, and the timing and extent of the Egyptian agricultural production has consequently always been connected to the flows of the Nile.

The Nile Delta has been under cultivation for more than 5000 years (Abu-Zeid and Rady 1992). Initially the irrigation system was intimately related to the natural flow of the Nile characterized by the summer Nile Flood, which reaches Egypt in late July and recedes in late October. Over time the irrigation system developed, and in the 19th century the desire to expand summer agricultural production lead to the introduction of perennial irrigation through construction of two barrages north of Cairo at the start of the Nile Delta. In 1902 the Aswan Dam was then built with a storage capacity of 1 billion cubic meters (BCM) of water. The Aswan Dam proved so successful that it was subsequently raised in 1912 and again in 1934 increasing the total storage capacity to 5 BCM. However, complete control of the Nile flows was not achieved until the construction of the Aswan High Dam south of Aswan, which was completed in 1971. Lake Nasser in front of the High Dam has a storage capacity of 164 BCM, which in effect implies full control over the Nile flow in the Nile Valley and the Delta (Robinson et al 2002).[4]

The benefits of building dams to control the flow of the Nile can be appreciated by noting that 80% of the total annual discharge into Lake Nasser occurs between August and October, while the remaining 20% is spread out over the rest of the year. Furthermore, Nile flows also vary significantly from year to year, thus making the ability to store water from one year to the next desirable (Hvidt 1998). The construction of the High Aswan Dam consequently increased the amount of controlled water and its reliability greatly. The initial anticipation

[4] For comparison, the average annual Nile flow amounts to 84 BCM. Reservoir losses due to evaporation and seepage amount to 10 BCM, leaving a net annual water availability of 74 BCM. According to the Nile Waters Agreement of 1959 between Egypt and Sudan, Egypt is allotted 55.5 BCM of the net annual water available, while Sudan is allotted 18.5 BCM (Robinson et al 2002).

was that the extra amounts of water, which were harnessed by the construction of the High Aswan Dam, could be used for large expansions of the irrigated area. However, the existing farmers in the Old Lands responded by rapidly increasing their cropping intensity and hence also their irrigation water consumption. In 2000, the overall cropping intensity had thus reached almost 180%, implying cultivation of almost two crops per feddan annually. (Bader 2004 and Hellegers and Perry 2004)

The Egyptian irrigation system has generally been characterized by water abundance, and this is reflected in the structure, management, and technical properties of the irrigation system. Very little consideration was therefore given to the efficiency aspects of the irrigation system. However, in 1988 the water deposits in Lake Nasser reservoir reached a critical minimum of 6.8 BCM following the 1979-1988 drought period, and this brought about the first recognition of the need for rationalization and reductions in water use. The drought spell was subsequently broken, but Egypt is now facing more fundamental challenges to its national water balance (Hvidt 1998 and Hvidt 2000).

The Egyptian population, which in 2004 reached 68.7 million people, is currently growing at an annual rate of 1.7% (World Bank 2005). The growing economy and the demands for rising income can in-and-of-itself be expected to increase the demand for water. However, in addition to this, the need to accommodate and feed the growing Egyptian population led the Egyptian government to adopt a strategy of reclaiming vast amounts of low-quality desert land (Hvidt 1998). The Land Master Plan of 1986 estimated Egypt's additional reclaimable lands at 3.4 million feddan (Hellegers and Perry 2004). According to the Integrated Water Resources Management Plan from 2005, the irrigated areas are forecasted to increase from 7.985 million feddan in 1997 to approximately 11.026 million feddan in 2017 (Ministry of Water Resources and Irrigation 2005). The land reclamation plans thus remain very ambitious as they still aim to increase agricultural land by 38% compared to the 1997 level. However, progress in land reclamation has generally been much slower than planned and this has resulted in a widening gap between food self-sufficiency and food demand (Mohamed 2001).

The agricultural sector (including fisheries) currently uses approximately 86% of available water supplies (excluding recycling), while industry and domestic uses account for 8% and 6% respectively (Ministry of Water Resources and Irrigation 2005). The increasing population and the accompanying expansion of the agricultural area will hence lead to significant increases in the demand for water. With Egypt's supply of water being more or less fixed in the medium term, water scarcity may consequently become a serious problem in a not too distant future. The following two sections will outline the institutional features of the demand for and supply of irrigation water in Egypt in order to provide a more detailed assessment of the water scarcity and managements problems facing the Egyptian agricultural sector.

3. MANAGING THE DEMAND FOR IRRIGATION WATER

The Egyptian irrigation system is enormous and highly complex consisting of "the Aswan High Dam, eight main barrages (diversion barrages), approximately 30,000 km of public canals, 17,000 km public drains, 80,000 km private canals (mesqas) and farm drains, 450,000 private water lifting devices (sakias[5] or pumps), 22,000 public water control structures, and 670 large public pumping stations for irrigation" (Hvidt 1998 p 10). It is a surface-gravity irrigation system meaning that all canals are open and the water mainly flows by gravity.

In order to understand the workings of the irrigation system, it is necessary to have rudimentary knowledge of the typology of the water delivery canals. These are classified according to the order of the canals beginning with the Nile (order 0). The *principal canals* (1^{st} order) receive water directly from the Nile and pass it on to the *main canals* (2^{nd} order). Direct irrigation from principal and main canals is prohibited. The main canals convey the water to the *branch canals* (3^{rd} order), which convey it to the *distributary canals* (4^{th} order). Mesqas (private ditches) receive water from the branch canals or the distributary canals and distributes this either directly to the fields or into marwas, which are private off-takes from the mesqas conveying water to fields located away from the mesqa (Hvidt 1998).[6]

A similar hierarchy exists for the drainage system. The drainage system is comprised of open drains, sub-surface drains, and pumping stations with sub-surface drains covering more than 65% of the cultivated area. In Upper Egypt and the southern Delta drainage water is returned to the Nile or the main irrigation canals, whereas drainage water in the rest of the Delta is either pumped back into the irrigation canals or into the northern lakes or the Mediterranean Sea (FAO 2005).

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[5] Traditional animal powered device (Hellegers and Perry 2004)

[6] It should be noted that other sources refer to the mesqas as the tertiary canals (cf. e.g. Hellegers and Perry 2004 and FAO 2005)

The Ministry of Public Works and Water Resources (MPWWR) is responsible for the entire irrigation and drainage system above mesqa level. The mesqas on the other hand are owned by the landowners, and they are responsible for the maintenance of the mesqa and field drains. However, water rights are tied to the land rather than the landowner, thus making sales of water rights impossible (Hvidt 1998).

3.1 THE TRADITIONAL EGYPTIAN IRRIGATION SYSTEM IN THE OLD LANDS

As outlined above, the Old Lands in Egypt have clayey soils. Water is generally applied to the field using so-called surface irrigation techniques. Surface irrigation techniques are characterized by water being applied to the field by gravity flow either by flooding the entire field (basin irrigation), feeding the water into small channels (furrows), or feeding the water to strips of land (borders) (Brouwer et al 1988). Surface irrigation techniques are characterized by a rather low field irrigation efficiency compared to modern irrigation techniques like sprinkler or drip irrigation. As outlined in chapter 1, field irrigation efficiency is defined as the fraction of water applied to the field, which is beneficially used (/ evapotranspired) by the crops. The remaining water, which is not evaporated or transpired by the crops, either ends up in the drains or percolates into the ground. According to Caswell and Zilberman, the field irrigation efficiency is determined partly by the method of water application (i.e. the irrigation technology used) and partly by the soil type. Estimates of application efficiency for the different irrigation technologies vary, but according to FAO indicative field application efficiency values are 60% for surface irrigation, 75% for sprinkler irrigation, and 90% for drip irrigation (Brouwer et al 1989 annex I).[7] However, the use of surface irrigation techniques in the Old Lands does not imply low overall water use efficiency for these areas. As mentioned above, drainage water from a large part of the Old Lands is either returned to the Nile or the main irrigation canals, and water, which percolates into the ground in the Old Lands, recharges the Nile aquifer from where it can be recovered.

In the traditional irrigation system in the Old Lands, irrigation water is delivered to the farmer below field level, and farmers therefore have to lift their irrigation water up to field level. This is done by using a pump, which the farmer either owns himself or hires when he wants to irrigate. Having to lift the irrigation water implies that farmers incur pumping costs, which in

[7] It should be noted that these values for field application efficiency do not take account of differences in the water-holding capacity of different soil types.

principle should give them incentives to conserve water. However, over time low cost pumps have become available, which have lowered the cost of pumping and reduced the time it takes to pump a given amount of water. Apart from the pumping costs, farmers do not pay directly for their irrigation water, but they do pay land taxes, which cover part of costs of the irrigation system. Before the liberalization of the agricultural policies, the farmers were also taxed indirectly through the mandatory sales of agricultural produce to the state at low prices. (Hvidt 1998, Abu-Zeid 1995, and Hellegers and Perry 2004)

In the traditional irrigation system, irrigation deliveries are not continuous. Instead the system operates on a rotational basis normally applied at the 3rd order branch canals. There are different types of rotations, but one of the typical rotations in Middle Egypt entails that water will be on in a given section for five days and then off for the following ten days. The system was supposedly introduced to keep water levels high in the canals, where irrigation takes place, and to restrict farmers' use of water (Hvidt 1998).

However, the rotational irrigation system suffers from a number of drawbacks. Firstly, while it is suitable for cultivation of long-rooted crops (i.e. sugar cane, maize, wheat, and berseem), it is ill-suited for cultivation of short-rooted crops (i.e. vegetables), as these require more frequent irrigation. Secondly, it is very difficult to secure an even distribution of water along the branch canals, and this results in unequal water deliveries and tail-end problems. Inadequate deliveries of water have in turn lead many farmers to "manipulate" the system in various ways to deliver larger amounts of water. In some locations, the rotation schedule is also observed "somewhat loosely" making it difficult to predict when irrigation water will be available here. This implies that farmers may have rather limited water control, which in turn leads them to adopt inefficient irrigation practices like irrigating too soon and applying too much water. Studies have thus shown that farmers have applied 50% to 250% more water than required by the crops and for the purpose of leaching. In addition to these problems of the rotation system, the structures of the irrigation system are also old and deteriorating, and farmers are also increasingly facing water pollution problems. (Hvidt 1998 and Hellegers and Perry 2004)

The rotational irrigation system in the Old Lands outlined above clearly requires a substantial amount of state involvement in the allocation of water. Prior to 1992, cropping patterns in Egypt were determined by the state. Based on information on the cropping patterns and knowledge of the water requirements of each crop, the size of planted area and the soil type, as well as the expected conveyance losses and on-farm losses, the Ministry of Agriculture and Land Reclamation was able to calculate the amount of irrigation water required for the following year. The request for irrigation water would then be sent to the Inter-Ministerial Committee on Water Planning along with the requests for water from other concerned ministries, and a day-by-day plan for releases from the Aswan High Dam would be drawn up including the allocation of these releases for each principal, main, branch and distributary canal. However, after cropping patterns were liberalized 1992 it became quite difficult to calculate the needs for irrigation water, and, according to Hvidt, it is not known precisely how the water allocation now takes place. The major liberalizations in the Egyptian agricultural sector have thus also created a need for reforms of the irrigation system. Furthermore, the liberalizations also imply a reduction in the indirect taxation of the agricultural sector, which had indirectly contributed to covering the state's expenses for the operation and maintenance of the irrigation system (Hvidt 1998 and Hvidt 2000) .

3.2 THE IRRIGATION IMPROVEMENT PROJECT IN THE OLD LANDS

The Irrigation Improvement Project (IIP) was formulated as a response to the shortcomings of the traditional irrigation system as well as the predicted demands of the twenty-first century. The prototype IIP was undertaken by Ministry of Public Works and Water Resources and the United States' Agency for International Development (USAID). The project period ran from 1989 to 1996, at which point the improvements developed under the IIP was adopted as the model for the National Irrigation Improvement Program (NIIP) sponsored by the World Bank and Japanese sources (Hvidt 1998).

The purpose of the technological package implemented under the IIP was to ensure efficient water use and optimal crop production by giving farmers the flexibility to irrigate at the time, rate, and duration required by the crops. The IIP package included both technical and social changes to the irrigation system. The principal component was the replacement of individual farmer pumping at multiple points along the mesqa with collective pumping at a single point. To this end, the IIP introduced continuous flow in branch and distributary canals, high level mesqas with single point lifting and water user associations (WUAs), downstream control/demand irrigation, and an Irrigation Advisory Service (IAS) (Hvidt 1998).

The aim of replacing the rotational operation of the branch and distributary canals with continuous flow was to enable farmers to irrigate according to the water needs of their crops. However, continuous flow only implies continuous availability of water, not increased amounts of water. Each command area would thus still receive the same amount of water each month, as it did under the old rotational system. If water was previously supplied under a "five days on – ten days off" delivery schedule, the daily deliveries under the continuous flow scheme would only amount to 1/3 of the deliveries of a previous "on-day". Only 1/3 of the farmers would hence be able to irrigate during a given day, but there would be three times as many days during which irrigation would now be possible (Hvidt 1998).

The old mesqas below field level were replaced by elevated concrete-lined mesqas. Instead of the previous system of individual farmers pumping water at multiple points along the old mesqas, single point pumping from the branch canal into the elevated mesqa was introduced, and the water would then flow by gravity within the mesqa to the field outlets. The hydraulic capacity of the mesqa was designed for continuous flow and operation for 16 hours per day.[8] Only two or three farmers would typically be able to take water at the same time. (Hvidt 1998 and Hellegers and Perry 2004)

The scheduling of irrigations among the different farmers was undertaken by the Water User Associations (WUAs). A WUA is an organizational unit, which is owned, controlled and operated by the members. The WUA owns, operates, and maintain the pumps used for single point lifting. It is responsible for collection of the pumping fees that farmers have to pay for the provision of water and for the operation and maintenance of the elevated mesqa. The WUA also handles conflicts among the users, and it acts as a liaison between the farmers and the Irrigation Advisory Service (IAS). Furthermore, as land holdings in the Old Lands are small and fragmented, WUAs may eventually also make the land holdings along the mesqa function more like one large farm unit. Finally, WUAs along a branch canal may eventually form a federated WUA, which can e.g. monitor the continuous flow or perhaps even conduct wholesale of water (Hvidt 1998).

[8] The traditional irrigation system was designed to operate 24 hours a day, when it was on, but since farmers did not irrigate at night this lead to considerable amounts of irrigation water going straight to the drains during the night (Abu-Zeid and Rady 1992).

In order for the new system of continuous flow in branch canals and increased irrigation flexibility for the farmer to work, the overall water allocation system also had to be modified. Whereas the traditional irrigation system was a supply system in which central authorities decided the flow rate, duration, and frequency of the flows, the new system is a demand system in which flow rate, duration and frequency is essentially determined by the farmers. This implied replacing a so-called up-stream control system with a down-stream control system. However, the downstream control system is not going to provide farmers with unrestricted amounts of water. It merely aims to provide farmers with water on demand within the boundaries of a maximum flow rate based on the irrigation needs of the area (Hvidt 1998).[9]

However, as pointed out by Hellegers and Perry, the new IIP system is not problem-free. The introduction of pumps at the head of mesqas without ensuring a sufficient capacity of the distributary canals may simply move the supply constraint upstream to the distributary canals. This implies that the distribution problem within the mesqa in the traditional irrigation system will be replaced by distribution problems between mesqas in the new irrigation system. Furthermore, there is some evidence to suggest that farmers have found the new pumps at the head of the mesqas unreliable. Many have therefore resorted to installing their own pumps drawing water directly from the distributary canals and thus circumventing the new mesqas. The construction standards for the new elevated mesqas have also been poor, and failures in the above-ground system are unfortunately much more serious than failures in the traditional below-ground system. Finally there is the issue of volumetric measurement of water allocations, which was not feasible under the traditional system due to the individual multi-point pumping system. The new system is in principle capable of measuring the amount of water farmers pump into the elevated mesqa (due to the collective single-point pumping mechanism), but this is often not working and volumetric water allocation is consequently not yet possible (Hellegers and Perry 2004).

If the initial problems of the IIP system are alleviated, the system may well result in more reliable water deliveries and hence afford the farmers a higher degree of water control. This will in turn enable farmers to reduce over-irrigation and perhaps also enable them to choose more water-sensitive crops, which might be more profitable. The IIP may also provide the

[9] From the description in Hvidt 1998, it is not entirely clear how over-use of water by the farmers can be prevented within the new system.

ability to meter the amount of water delivered to individual farmers (although it is not clear how farmers can be effectively prevented from taking water directly from the distributary canals and thereby bypassing the metering system). These improvements to the irrigation system can be used to increase the economic efficiency of water use, if the government uses them to convey the value of water to the individual farmers either through water pricing or water quotas. However, for areas where return flows are almost 100% recoverable, the IIP will not result in noticeable real water savings despite any increases in farmer water use efficiency, which the IIP may induce. According to Imam, the drainage and percolation flows, which are results of the low conveyance and distribution efficiencies in the traditional irrigation system, are likely to have been re-used unofficially by downstream users. Consequently, water savings produced by improvements in the conveyance and distribution efficiency cannot be considered fully uncommitted resources. However, by reducing the amount of water use cycles, the IIP may nonetheless help preserve the quality of the water (Imam 2004).

3.3 THE IRRIGATION SYSTEM IN THE NEW LANDS

The irrigation system in the New Lands differs from the traditional irrigation system in the Old Lands described in previous sections. In the Old Lands, farmers use the surface irrigation technique, but this technique is banned by law in the New Lands. The reason for this is that the New Lands are located at the ends of the irrigation system mostly outside the Nile's drainage basin. This means that excess water applied in these areas is lost, as it will not be returned to the Nile system. Furthermore, while the Old Lands have clayey soils, New Lands have mostly sandy soils, which are more water permeable and hence, ceteris paribus, would result in higher water losses. (FAO 2005, Brouwer et al 1989 annex I, Hellegers and Perry 2004, and FAO 1997)

Instead of surface irrigation techniques, farmers in the New Lands must use sprinkler or drip irrigation techniques. Sprinkler irrigation resembles rainfall as water is pumped through a pipe system and subsequently sprayed onto the crops through rotating sprinkler heads. Drip irrigation, on the other hand, implies that water is conveyed to the field through a pressurized pipe system from which it drips slowly onto the soil through emitters located close to the plants (Brouwer et al 1988). If the sprinkler and drip irrigation technologies are used efficiently, they require less water than surface irrigation (FAO 2005). This in turn implies that the field irrigation efficiency is higher for sprinkler and drip irrigation than for surface irrigation. According to FAO, average field application efficiency for sprinkler and drip irrigation is thus 75% and 90% respectively, compared to 60% for surface irrigation techniques (Brouwer et al 1989 annex I). Unlike surface irrigation, sprinkler and drip irrigation typically require a continuous supply of water (Abu-Zeid and Rady 1992). While it is not possible to meter individual farmer's appropriation of water in the traditional irrigation system in the Old Lands, the modern irrigation system in the New Lands implies that metering water at the point of delivery is in principle possible (Abu-Zeid and Rady 1992).

4. Managing the supply of irrigation water

The large-scale reclamation of desert land is going to increase the demand for irrigation water in Egypt substantially. However, if Egypt were able to allocate more water to agriculture, the increasing demands for irrigation water needed not result in water scarcity. Additional water allocations for agriculture could in principle be achieved in two different ways – by reallocating water from other sectors in the Egyptian economy to the agricultural sector or by increasing the total amount of water available to Egypt. The latter can be achieved either by increasing the amount of Nile water reaching Egypt or by developing non-conventional water sources within Egypt.

4.1 Agriculture vs. other water-using sectors in Egypt

Reallocating water from the municipal and industrial sectors to the agricultural sector is not a realistic solution for increasing the supply of irrigation water. Currently the amount of water used in these sectors is rather limited compared to the amount of water used in agriculture (cf. section 2), and given the increasing population and the rising living standards, municipal water demands are likely to increase and so are industrial water demands. Furthermore, although there appear to be no clear criteria for water allocation in Egypt, municipal and industrial water requirements are given first priority (Imam 2004). Rather than being a source of additional water for agriculture, the municipal and industrial sectors are thus likely to reduce the amount of water available for irrigation.

4.2 Options for increasing the amount of Nile water reaching Egypt.

The Nile supplies 97% of Egypt's annually renewable water resources (Ministry of Water Resources and Irrigation 2005). If Egypt were somehow able to increase the amount of water reaching the High Aswan Dam, the increasing demands for water in Egypt could be met without increasing water scarcity. There are two options for increasing the amount of water reaching the High Aswan Dam – a reduction in the amount of Nile water allotted to upstream users or augmentation of Nile flows through technical solutions.

Increasing Egypt's water supply by simply increasing Egypt's share of Nile waters is not a viable option. The rights to the Nile waters have been governed by two treaties – one from 1929 between Egypt and Britain and one from 1959 between Egypt and Sudan. The 1929 treaty stipulates that no country can engage in projects that reduce the amount of water reaching Egypt, while the 1959 treaty governs the division of Nile waters between Egypt and Sudan, affording Egypt 55.5 billion cubic meters (BCM) of water from the Nile annually. The upstream countries' needs for Nile water are thus disregarded in the two treaties, and Egypt has assumed the right to veto upstream projects that would negatively affect its water supply (Nkrumah 2004).

The upstream countries – with the exception of Ethiopia – were all colonies of European powers at the time the 1929 treaty was established, and they now strongly object to the treaty and renounce it as being invalid. Egypt, on the other hand, has repeatedly stated that a unilateral change in this treaty would amount to a breach of international law. Upper riparian countries fear – not unfoundedly - that Egypt would in fact use military power to protect and secure its supply of Nile water. Although several of these countries have plans for exploiting Nile water, they do consequently recognize that changes to the treaties would require collective agreement, which would have to include Egypt. Where discussions on how to share Nile waters used to be considered awkward by most governments in the region, these issues are now being debated within the so-called Nile Basin Initiative, which consists of Burundi, the Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. However, Egypt maintains that the upper riparian countries are not as dependent on Nile water as they receive ample rainfall and do not depend on irrigation for crop production (Nkrumah 2004).

Given the current allocation of Nile waters, which favors Egypt at the expense of the upstream countries, Egypt consequently cannot increase its share simply by renegotiating the water allocation treaties. Instead, such negotiations may in fact lead to a reduction in Egypt's share of Nile waters. However, technical solutions may present opportunities for augmenting Nile flows. Given the uncertainty about future agreements on sharing Nile waters, it is not clear whether these technical solutions would indeed augment Egypt's supply of water, but a larger amount of usable Nile flows would make it easier for the riparian countries to reach an agreement.

An important component in the technical solutions to augmenting Nile flows is the reduction of upstream evaporation losses. One option for reducing evaporation losses is the construction of the so-called Blue Nile Reservoirs in Ethiopia. These reservoirs would make it possible to shift over-year storage from Lake Nasser upstream to the upper Blue Nile region, where evaporation rates are around 50% of the rates in Egypt and Sudan. Furthermore, creation of the Blue Nile Reservoirs might even be more valuable for hydropower generation than for water regulation and storage, as the annual potential for hydropower generation here is approximately three times higher than at the High Aswan Dam. As Ethiopia would so far not be able to use all this electricity itself, the country could sell electricity to Egypt and Sudan, perhaps at favorable prices. Such an arrangement would also provide the Ethiopians with incentives to regularly release water in order to maximize hydropower generation. A total of 85% of Egypt's water supply originates in Ethiopia, and the issue of how to secure a regular supply of water, in case Ethiopia were to construct the Blue Nile Reservoirs, is clearly extremely important to Egypt. (Whittington et al 1995)

Another project, which also seeks to reduce the amount of Nile evaporation losses as well as losses from seepage and over-bank flows to swamp land, is the so-called Jonglei project. This project consists of a series of canals designed to drain water from the vast Sudd Swamps in southern Sudan. However, the project was stalled due to the instability in the region, and environmental concerns have also been raised in the discussions about resuming the project. (Whittington et al 1995 and Bader 2004)

4.3 Options for increasing Egypt's water supply through non-Nile sources.

As the preceding paragraphs have illustrated, technical solutions can augment the amount of usable Nile flows, but many of these potential projects suffer from the drawback of being located outside Egypt's borders and hence beyond the full control of the Egyptian government. However, there are also options for increasing Egypt's water supply, which are located within Egypt's borders. Efforts towards utilization of other water sources than Nile surface water include groundwater extraction, reusing drainage and treated waste water, rainfall harvesting, and desalination of sea water.[10]

Egypt has four major groundwater systems: The Nile aquifer, the Nubian sandstone aquifer, the Moghra aquifer, and the Coastal aquifer. The Nile aquifer is a renewable aquifer underlying the Nile Delta and the Nile Valley, and it is directly connected to the Nile River system. It is a shallow aquifer with highly productive wells, meaning that large amounts of water can be abstracted at relatively low pumping costs. Farmers consequently also engage in conjunctive use of surface and groundwater, especially during peak demands on irrigation water. A total of 6.1 BCM are extracted from the aquifer annually. However, the Nile aquifer cannot be counted as an additional water source for Egypt, as it is recharged by percolation from irrigation activities and the Nile. Any project, which reduces the amount of percolation from irrigation activities and water conveyance losses in the areas recharging the aquifer, will consequently not result in real water savings. Being a shallow aquifer the Nile aquifer is also very sensitive to pollution from surface sources. (Ministry of Water Resources and Irrigation 2005, Imam 2004, and Bader 2004)

The Nubian Sandstone aquifer is a large fossil water aquifer shared by Egypt, Sudan, Chad, and Libya. It extends below the vast area of the New Valley governorate in the Western Desert. The whole aquifer holds approximately 150,000 BCM of fossil water, but as the aquifer is very deep – reaching depths of 2000 meters – exploitation of this water resource entails substantial pumping costs. However, the Nubian aquifer also runs beneath the Eastern Desert, and studies have shown that the deep aquifer is connected to shallow aquifers in the middle and south of the desert, which implies potential for groundwater development. (Ministry of Water Resources and Irrigation 2005 and Bader 2004)

The Moghra aquifer is recharged by rainfall and lateral inflow from the Nile aquifer. Land reclamation projects in the Western Desert and industrial and municipal water demand in the Western fringes of the Nile Delta have resulted in high increases in water, which have endangered the quality and sustainability of the aquifer. The Coastal aquifers are located close to the western northern coast of Egypt. These aquifers are recharged by rainfall on the western

[10] In principle Egypt would also have the opportunity to increase the usable fraction of its water supply by reducing the non-beneficial evaporation from e.g. open water canals. However, given the vastness of the Egyptian irrigation system, such an initiative would probably be prohibitively expensive compared to the benefits it could yield.

coast, but saline water beneath the layers of fresh water limits the amounts of water, which can be abstracted from the aquifers (Ministry of Water Resources and Irrigation 2005).

According to Imam, reuse of drainage water from irrigation is an essential element in the Ministry of Water Resources and Irrigation's plan to increase water supply in Egypt. However, the discharge of municipal and industrial wastewater into the drains is posing problems for the traditional scheme of large-scale reuse of drainage water at large-capacity pumping stations. A new scheme of reusing drainage water at a smaller scale is still at the pilot scale (Imam 2004). According to the Ministry of Water Resources and Irrigation, reuse of agricultural drainage water in the Nile Valley and Delta is currently projected to be around 7.5 BCM per year, while the capacity to reuse municipal wastewater is around 0.7 BCM per year.[11] However, it is stressed that reuse of water is merely a recycled bi-product of water-utilization, and hence should be considered demand management intervention rather than being accounted for in the national water resource balance (Ministry of Water Resources and Irrigation 2005).

As for the remaining water resources, sea water desalination is being practiced but only at a limited scale as it is very expensive (Attia 2004). Rainfall harvesting is also being practiced at a limited scale. Although total rainfall-runoff in Sinai, the Northwest Coast, and the catchments of the Eastern Desert draining toward the Red Sea may amount to 1.85 BCM annually, constraints related to topography, (hydro-) geology and soil conditions implies that only parts of this water can in fact be harvested (Imam 2004).

5. EGYPT'S NATIONAL WATER BALANCE.

The previous sections have outlined how water demands are increasing in Egypt due to a growing population and the efforts to reclaim vast amounts of desert land, while the country's limited water supplies are likely to remain more or less fixed in the medium run. The question consequently arises, to what extent the water constraint is currently binding in Egypt?

While it is difficult to assess to what extent the national water constraint is binding, it would appear that this was not the case in Egypt in the late 1990s. Table 1 shows the average annual

[11] It is not clear whether the estimate of 7.5 BCM of drainage water being reused annually also includes unofficial reused of drainage water practiced by the farmers themselves. According to Mohamed (2001), farmers' unofficial reuse of drainage water is also substantial, although the total amount is not known.

figures for Egypt's national water balance in 1997. According to the table, the total water inflow amounted to 58.50 BCM, while total consumptive water use amounted to 45.18 BCM.[12] The total outflow from the system was thus 13.32 BCM of which 12.67 BCM was outflow to the sea. This amount of outflow to the sea may suggest some degree of water surplus. However, it is also clear from the table that substantial amounts of water are already being reused, as water diversions for agriculture, industry and municipalities totaled 72.8 BCM, which exceeds Egypt's total water inflow. Water was consequently being used more than once in Egypt in 1997. To say that the national water constraint was not binding thus merely implies that the options for reusing return flows had not yet been fully exploited in 1997.

Table 1: Egypt's national water balance – average annual figures for 1997

"Input" of water in Egyptian national water balance 1997	
Releases from the High Aswan Dam	55.5
Effective rainfall	1.00
Sea water intrusion	2.00
Total water inputs	58.5
"Output" of water in Egyptian national water balance 1997	
Agriculture (evapotranspiration)	40.82
Industry	0.45
Municipality	0.91
Navigation (fresh water to sea)	0.26
Drainage to sea	12.41
Fayoum drainage	0.65
Evapotranspiration in water ways	3.00
Total water outputs	58.5
Water flows related to agriculture in national water balance	
Water diverted for agriculture	60.73
Evapotranspiration from agriculture	40.82
Return flows from agriculture	19.91
Water flows related to industry and municipality	
Water diverted for industry	7.53
Water diverted for municipalities	4.54
Water consumed by industry	0.45
Water consumed by municipalities	0.91

Source: Adapted from diagram in Mohamed 2001 p 7

[12] Total consumptive water use is calculated as the sum of agricultural evapotranspiration, industry and municipality consumptive use, and evapotranspiration from water ways. On the inflow side, it should be noted that sea water intrusion is included as an "input" into the national water system. Although sea water intrusion is normally included in the Egyptian national water balance, it is not clear how this type of water can be counted in the national fresh water balance, unless it is mixed with sufficient amounts of fresh water to substantially reduce salinity levels.

While an outflow of 13.32 BCM from the system in 1997 may seem like a substantial water surplus, this need not be the case once water quality is taken into consideration. As water is being used and reused on its way from the High Aswan Dam to the Mediterranean Sea, salt and pollution is accumulated in the water flows. Excess water is needed to dilute the salt and pollution concentration in order for the water to remain usable and for the environment not to suffer. It is consequently not enough to merely look at water quantities when assessing water scarcity – the quality of the water must also be considered and its implications must assessed in relation to the different types of water use. However, Mohamed cites a study from 1995, which suggests that polluted spots were still localized in the Nile system, and states that water quality was still adequate for most uses upstream from the Delta. Throughout the Delta, on the other hand, severe water pollution is found downstream from large communities and industrial cities (Mohamed 2001).

Despite the apparent water surplus in the late 1990s, shortages have already been observed in many regions. Mohamed (2001) contends that farmers' unofficial reuse of drainage water is substantial, which suggests that some farmers would like to use more water than they are allotted by the official irrigation system. It should, however, be noted that some of the observed shortage can be a result a misallocation of water between different sections of the irrigation system or between the different seasons. King (2002) thus reports a tendency for under-delivery of water during the peak of summer in four pilot irrigation districts, while there was generally over-delivery of water during the winter season and the transitions from one season to another.

Although the national water balance most likely was not binding in the late 1990s, the ambitious plans for expanding cultivable lands implies that the water constraint is likely to become binding in the near future. Hagan (2002) thus estimates that Egypt in 2017 will face a water deficit of between 4 and 9 BCM depending on the extent to which the future land reclamation plans are realized. While the exact size of the future water deficit will obviously depend on the fate of upstream Nile projects and the extent to which Egypt can develop its non-renewable groundwater sources, it thus seems reasonable to conclude that Egypt will face water scarcity if the land reclamation plans are fully implemented.[13]

[13] Although Egypt is only allotted 55.5 BCM under the 1959 agreement with Sudan, the country has in fact had access to more water, as Sudan has not exploited its water allocation fully. Furthermore, high rainfall at the end of the 1990s also resulted in higher than normal water inflows to Lake Nasser (Hellegers and Perry 2004 and

6. CONCLUSION

As the analysis in the previous sections has demonstrated, Egypt is likely to face water scarcity in the near future due to a growing population and ambitious plans to reclaim desert land for agriculture. As agriculture is by far the largest water consuming sector in the Egyptian economy, and as industrial and municipal water demands are likely to be given priority over agricultural water demands, it will most likely be necessary to regulate the demand for irrigation water. Regulation of water demand may in turn result in adjustments of cropping pattern towards less water-intensive crops, deficit irrigation or in extreme cases idling of land. Unless the Egyptian government is to regulate irrigation water demand by reverting to command and control measures, economic policy instruments must be used to induce farmers to adjust their cropping patterns and activities. As outlined in chapter 1, this could be achieved through volumetric or non-volumetric taxes or quota instruments.

The present analysis has shown that the allocation of irrigation water among farmers has not been efficiently regulated so far. One of the problems in regulating farmers' appropriation of irrigation water has been the inability to meter the amount of water appropriated by the individual farmers in the traditional irrigation system in the Old Lands. However, the new irrigation infrastructure adopted under the Irrigation Improvement Project may eventually provide the opportunity for metering individual farmer's water appropriations. This is a necessary prerequisite if volumetric water pricing were to be introduced in Egypt. However, while it is in principle acceptable to charge for the service of providing water in Egypt, charging for the water itself is generally not acceptable (Hellegers and Perry 2004).[14] The use of non-volumetric pricing instruments or quotas may thus be a more politically acceptable way to regulate the demand for irrigation water in Egypt.

Reuse of return flows from irrigated agriculture is an important part of the strategy towards meeting the increased water demands. Water is already being used more than once in Egypt, as the amount of water applied to the fields significantly exceed the available amount of water entering the system (Mohamed 2001), but there is probably still scope for further increases in

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Hagan 2002). However, neither of these events can obviously be counted as a permanent source of water for Egypt.

[14] The issue of recovering costs from irrigation water provision is very important in the Egyptian context, but it is beyond the scope of the present analysis. For information on cost recovery practices, see e.g. study by Perry on "Alternative Approaches to Cost Sharing for Water Services to Agriculture in Egypt" or study by Attia on "Integrated Approach to Water Resources Management in Egypt: Financial Sustainability".

the reuse return flows from agriculture. The question consequently arises, what policy instruments the government could use in order to optimize the generation and allocation of return flows? This question will be explored in the next chapter, which presents a theoretical analysis of the efficiency properties of different water policy instruments in a situation characterized by both water diversion and recoverable return flow externalities.

CHAPTER 3

ALLOCATING WATER EFFICIENTLY IN THE PRESENCE OF TWO EXTERNALITIES - A THEORETICAL EVALUATION OF WATER POLICY INSTRUMENTS.[♣]

1. INTRODUCTION: EXTERNALITIES IN WATER ALLOCATION.

One of the central features in the economics of irrigation is the potential for significant externalities between different irrigators. The externalities typically arise due to the difficulties of assigning and enforcing property rights to irrigation water.

As outlined in the literature survey in chapter 1, the perhaps most important type of externality is related to the allocation of water diversions between different irrigators. However, irrigators do not only take water out of the irrigation system through their water applications, they typically also give water back to the irrigation system through return flows from their irrigation activities. If these return flows are subsequently recovered by the river basin system they also constitute an externality.[1]

Both the externality related to appropriation of irrigation water and the externality arising from recovery of return flows clearly have implications for the degree to which scarce irrigation water resources are allocated efficiently between competing uses. However, while the policy implications of the former type are well-understood, the policy implications of the latter type of externality have not yet been fully recognized and explored. The purpose of the present analysis is therefore to analyze the efficiency properties of different policy instruments in a situation where both types of externalities are present simultaneously.

The theoretical model presented in the following sections has been constructed to capture key properties of the Egyptian irrigation system as presented in chapter 2. The model describes a crop production system, which is fully dependent on irrigation for covering the water needs of

♣ Advice from Philip Abbott on the modeling framework presented in this chapter and comments on earlier drafts is gratefully acknowledged.

[1] As in previous chapters, the terms water "diverted" and water "applied" (or water "diversions" and water "applications") are used interchangeably. The term "return flow" is used as referring to the entire amount of water applied, which is not evapotranspired, regardless of whether these water flows are recoverable or not.

the crops. This is commensurate with the fact that rainfall in Egypt is too limited and scattered to be a source of water for agricultural production in almost all of Egypt (Bader 2004).

As outlined in chapter 2, the type of externality related to allocation of water diversions is present in Egypt, as there is no mechanism in place to efficiently regulate the individual farmer's appropriation of water. Although the centralized water allocation system does imply a kind of quota scheme for allocating water between different sections of the irrigation system, the traditional irrigation infrastructure in the Old Lands has not allowed for a quota scheme to be implemented at the individual farmer level. The recoverable return flows externality is also present in Egypt, as the Egyptian irrigation system in the Old Lands is characterized by a low degree of field irrigation efficiency and a high degree of return flow recoverability. The low degree of field irrigation efficiency implies that farmers apply substantially more water to their fields than is consumed by their crops. The high degree of return flow recoverability implies that a high fraction of the apparent water losses are subsequently recovered by the river basin system. The combination of these two features, and the fact that the generation and allocation of return flows are not regulated efficiently, implies the presence of the return flow externality.

As outlined in chapter 1, the inefficiencies arising from externalities can be ameliorated through different types of policy interventions including taxes and quotas. The present analysis will primarily focus on tax policy instruments although the quota equivalents of these tax policy instruments will also be presented. The aim of the analysis is to ascertain to what extent the different policy instruments are able to ensure an efficient allocation of irrigation water. This is done by formulating the water allocation problem from the point of view of the social planner and an individual farmer and then comparing the first order conditions of these two problems. The following sections will first present the social planner's problem. Subsequently, the individual farmer's problem is presented under four different types of policy scenarios: Policy instruments targeting input of water applied and generated recoverable return flows, policy instruments only targeting input of water applied, policy instruments targeting input of land, and policy instruments targeting crop output.

2. SOCIETY'S POINT OF VIEW: THE SOCIAL PLANNER'S PROBLEM

The theoretical model, which has been constructed specially for this analysis of the efficiency of different water policy instruments, is formulated as a linear programming problem in line with the agricultural sector model tradition. The model is static and deterministic and thus disregards any dynamic aspects and issues arising due to uncertainty. As the model is tailored specifically to the aforementioned water policy issues, it is highly stylized in its specification of elements not directly related to water application, consumption, and recycling.

2.1. THE SOCIAL PLANNER'S PROBLEM: MODEL SPECIFICATION

The general objective of the social planner is to maximize social welfare subject to the resource constraints facing the economy. In the present analysis it is assumed that efficiency issues can be separated from equity considerations. Achieving the social planner's objective of maximizing social welfare consequently entails maximization of social efficiency under due consideration of farmers' irrigation efficiency and return flow recoverability.[2] Assuming further that the market price of output and purchased inputs correspond to the socially optimal prices of these commodities and that the only non-traded commodities are land and irrigation water, the social planner's problem for a given region can be specified as follows:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i = 1,...,I,\ j = 1,...,J, \text{ and } k = 1,...,K$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} = \overline{X}_j \qquad \text{for all } j = 1,...,J$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} \leq \overline{W}$$

Where:[3]

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[2] Following Mas-Colell et al, a production vector is defined as being efficient "if there is no other feasible production vector that generates as much output…using no additional inputs, and that actually produces more of some output or uses less of some input" (Mas-Colell et al 1995 p 150). The notion of efficiency can be subdivided into technical efficiency and allocative efficiency. Barker et al define a producer as being technically efficient "when producing the maximum amount of output with a given set of input", while a producer is defined as being allocative efficient "if he/she produces at the point dictated by the prices of outputs and inputs that will maximize returns" (Barker et al 2003 p 22). The prefix "social" refers to the fact that efficiency should be evaluated at aggregate national level rather than at the individual farmer level, which implies that the prices used for determining allocative efficiency should reflect true social costs and benefits.

[3] Comment on notation:

- Upper case Latin letters generally denote variables, such as prices or quantities, save for the letters I, J, and K, which are used for indexes.
- Lower case Latin letters denote Leontief production coefficients, save for the letters i, j, and k, which are used for indexes.
- Lower case Greek letters denote special water coefficients, which are expressed as fractions.

- i : Index of crops. $i = 1,...,I$.
- j : Index of farmers, which captures the farmer-specific characteristics of soil type and irrigation technology (e.g. surface irrigation, sprinkler irrigation, or drip irrigation). $j = 1,...,J$.
- k : Index of water-yield production techniques, which captures the different possible combinations of crop water consumption and realized crop yields. $k = 1,...,K$.

- P_i : Price of crop i, measured in LE/ton.[4]
- C_Z : Cost of purchased inputs Z, measured in LE/ton.
- X_{ijk} : Size of area cultivated with crop i by farmer j using production technique k. X_{ijk} is measured in the Egyptian area unit feddan.
- $\overline{X}_j$: Total amount of land available to farmer j, measured in feddan.
- $\overline{W}$: Total amount of water, which is available for crop water consumption or irretrievable loss, measured in cubic meters.

- y_{ijk} : Yield of crop i per area unit for farmer j when using production technique k. y_{ijk} is measured in ton/feddan.
- z_{ijk} : Amount of input Z per area unit used for production of crop i by farmer j using production technique k. z_{ijk} is measured in ton/feddan.
- e_{ijk} : Amount of water evapotranspired (or "consumed") per area unit by crop i produced by farmer j using production technique k. e_{ijk} is measured in cubic meters/feddan.
- d_{ijk} : Amount of water applied per area unit for production of crop i by farmer j using production technique k. d_{ijk} 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: $d_{ijk} = \frac{1}{\alpha_{ijk}} e_{ijk}$

[4] LE is an abbreviation for Egyptian pounds.

- α_{ijk} : Field irrigation efficiency for crop i produced by farmer j when using production technique k. α_{ijk} is measured as the share of water applied, which is consumed by the crops. $0 \leq \alpha_{ijk} \leq 1$.
- β_j : Fraction of return flows produced by farmer j, which are recovered by the river basin system. $0 \leq \beta_j \leq 1$.

According to the model specification, the social planner's objective is to maximize producer surplus, subject to individual farmer land constraints and a national water constraint. The fixed amount of land and water available for agricultural production implies that the value of these production factors are determined by their opportunity costs. In the remaining part of this section various features of the land and water constraint will be explored in more detail.

In order to keep the model simple, reallocation of land between farmers is not allowed, and the land constraint in the social planner's problem is consequently specified at the individual farmer level.[5] The land constraints specify that the sum of an individual farmer's land areas allocated to the production of different crops has to equal the fixed amount of land available to the farmer. The fact that the land constraint is assumed to hold for each farmer implies that each farmer is assumed to be able to produce at least one type of crop at non-negative profits. Given the fact that yields and purchased input requirements are potentially farmer-specific in this model, this is not a trivial assumption. In theory situations may consequently arise where the land constraint would not bind for a given farmer. However, in the current model set-up, land does not produce externalities as farmers include the shadow price of land in their maximization problem (cf. the specification of the farmer's problem in section 3). The possibility of non-binding land constraints will consequently not be explored in the present analysis.

[5] The fact that land is not allowed to be reallocated across farmers may appear to be an obstacle to the maximization of social efficiency. However, the present model features constant returns to scale leaving no room for efficiency gains due to increasing returns. Furthermore, the farmer-specific characteristics like soil type and choice of irrigation technology, which are emphasized in the analysis, are primarily related to location of the farmer's land rather than the farmer's innate personal abilities. This implies that redistribution of land between farmers with different farmer-specific characteristics should not change the outcome of the present analysis. In a more realistic setting with non-convexities in the production set and / or differing managerial skills across farmers, redistribution of land across farmers would of course be expected to affect social efficiency.

In order to adequately capture the return flow aspect, the national water constraint is specified in terms of water consumed and water irretrievably lost, rather than water applied. The constraint specifies that the sum across all farmers of water consumed or irretrievably lost should be less than or equal to the fixed amount of water, which is available for permanent "removal" from the river basin system. The basic point is that when return flows are at least partially recoverable, what matters from the social planner's point of view is not how much water the farmer applies to his field, but rather how much of this water is permanently taken out of the water system, as the rest of the water applied will become available for additional application cycles, when these return flow are recovered.

The amount of water consumed by a crop is equated with the crop's evapotranspiration. As previously outlined, 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" (Allen et al 1998 p 1).[6] According to FAO, crop evapotranspiration is affected by factors such as weather parameters, crop characteristics, and management and environmental aspects (Allen et al 1998). As the present model is formulated for a given agro-climatic region, the effect of weather parameters on crop evapotranspiration is assumed to be identical for all farmers located in this region. Weather parameters consequently do not appear explicitly in the model. Crop characteristics, on the other hand, are included in the model as crop evapotranspiration is specified as depending on the choice of crop (index i). However, as this is a static one period model, the differences in crop response to water stress in different parts of the growth period are disregarded.

FAO defines crop evapotranspiration under standard conditions as "the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions" (Allen et al 1998 chapter p 5). However, crops can also be grown under less than optimal conditions, which may subsequently affect crop evapotranspiration rates. In particular crops may be grown using less than the optimal amounts of water. This in turn implies a reduction in the actual water consumption and the realized yield of the crop, and it may also affect the amount of other inputs used in production of the crop. The crop evapotranspiration

[6] 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 (Allen et al 1998).

coefficient and the yield coefficient are consequently assumed to depend on the choice of water-yield technique, and so are the other input coefficients.

In the present analysis, crop evapotranspiration rates are also assumed to be potentially farmer-specific. According to FAO, "the effect of soil water content on [evapotranspiration] is conditioned primarily by the magnitude of the water deficit and the type of soil" (Allen et al 1998 p 5). As outlined above, the water deficit dimension is captured by the different water-yield technologies, which are specified as being non-farmer-specific. However, soil type is assumed to be a farmer-specific characteristic, and crop evapotranspiration consequently becomes a farmer-specific variable.[7] Apart from water shortage, crop evapotranspiration rates may also be adversely affected by e.g. pests and diseases, soil salinity, low soil fertility and waterlogging (Allen et al 1998), but these features are not considered in the present model.

Field irrigation efficiency is defined as the fraction of water applied, which is evapotranspired by the crops, and it is captured by the parameter α_{ijk}. According to Caswell and Zilberman, "the fraction of water applied which is actually utilized by the plant is a function of the water-holding capacity of the soil and the method of water application" (Caswell and Zilberman 1986 p 799). The field irrigation efficiency parameter is consequently assumed be determined by soil type and irrigation technology (e.g. surface irrigation, sprinkler irrigation, or drip irrigation), which are specified as farmer-specific characteristics.

Given that the model does not allow for reallocation of land between farmers, soil type is not a decision variable for the farmer and can therefore be treated as a constant farmer-specific parameter.[8] Irrigation technology, on the other hand, is in principle a decision variable for the farmer. However, technical aspects of the irrigation system in the Old Lands in Egypt may leave the farmer little choice in his use of irrigation technology. Furthermore, as the focus of the present analysis is the allocation of irrigation water in a static setting, irrigation technology is treated as a constant farmer-specific parameter in this model. This aspect of the model will be further examined in the discussion section. Apart from the farmer specific

[7] Previous versions of this model have operated with the assumption of evapotranspiration not being farmer-specific. This was based on the notion that the water-yield technique dimension would capture all effects of water stress on crop evapotranspiration rates. However, if the water-yield technique dimension is non-farmer-specific it cannot capture the implications of soil type in the case of water stress. The present analysis consequently allows for evapotranspiration rates to depend on farmer-specific characteristics.

[8] Soil type can and – in many places of the world – often does vary within a farmer's landholding, but this issue is ignored here.

characteristics, the field irrigation efficiency parameter is assumed to potentially depend on the choice of crops, as “excess” water is part of the production of certain crops like rice, and it may also depend on the water-yield production technique with which the crop is produced.

In order for the return flows generated by low field irrigation efficiency to constitute an externality, they must be at least partially recoverable. The degree to which return flows generated by farmer j are recoverable is captured by the parameter β_j. As this is a static model the temporal aspects of return flow recoverability are not considered. The implications of this simplification will be examined further in the discussion section.

Return flows are recoverable when drainage water from the fields is returned to the water source or when irrigation water, which has percolated into the ground, recharges aquifers from which the water can subsequently be retrieved. The return flow recoverability parameter will thus depend on the general drainage and percolation characteristics of the region in which the farmer is located. The degree of return flow recoverability is assumed to be farmer-specific in order to capture the impact of farmer location on the recoverability of return flows. First of all, the drainage and percolation characteristics may differ within the agro-climatic region being studied. Second of all, the issue of whether return flows can be recovered and reused for irrigation depends on the location where they resurface. While recoverable return flows generated by up-stream farmers would increase water availability for downstream farmers, recoverable return flows from downstream farmers may not benefit upstream farmers, as pumping the water back upstream may be too costly to be profitable. The farmer’s location may consequently matter for the extent to which the return flows he generates are recoverable from an economic point of view, and the farmer-specific return flow recoverability parameter captures important aspects of this phenomenon.[9] The spatial dimension of return flows is examined further in the discussion section.[10]

The externality of recoverable return flows arises when the return flows generated by one farmer are recovered and reused by another farmer. However, farmers may in principle also

[9] A farmer’s location would also matter for the degree of return flow recoverability, if some of the return flows from the farmer’s fields were irretrievably lost on their way to the river or aquifer. However, to keep the model simple conveyance losses are disregarded.

[10] A previous version of the model operated with the assumption of the return flow recoverability parameter being non-specific. However, this model could not capture the upstream-downstream dimension, which is clearly important in the Egyptian case.

reutilize their own return flows in the sense that drainage water may be pumped directly from the drains back on to the fields.[11] Such immediate reuse of irrigation water would lower the fraction of water initially applied to the field, which subsequently becomes available for other farmers in the form of recoverable return flows. The possibility of farmers reusing their own drainage water seems to suggest that the return flow recoverability parameter should be a choice variable for the farmer rather than a constant parameter, but in fact this possibility is implicitly taken into consideration in the specification of the model. The point is that the social planner's problem and the subsequent farmer's problems are all formulated in terms of land allocation. By choosing how much land to allocate to a given crop, which is to be produced using a given water-yield technique, the farmer in question has implicitly also chosen the amount of other inputs to be used as well as the amount of output to be produced. This implies that the farmer's use of water is fully specified in terms of his allocation of land and thus the return flow recoverability parameter need not be considered a decision variable for the farmer.[12]

Before turning to the actual model analysis a few caveats need to be raised. First of all, the specification of water applied, water consumed, and return flows in the model focuses on the quantities of water applied, evapotranspired, 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 in the policy analysis, and leaching requirements are not considered either.[13] Possibilities for introducing water quality considerations into the model will be examined in the discussion section. Secondly, the model does not take account of the costs related to the provision of irrigation water and retrieval of return flows. These issues will also be addressed in the discussion section.

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[11] Use of drainage water for irrigation is not allowed in Egypt without permission from the Ministry of Irrigation, which uses certain criteria for water salinity to determine whether or not drainage water is suitable for reuse (Bader 2004). In spite of this legislation, Egyptian farmers' unofficial reuse of drainage water is substantial (Mohamed 2001 and Bader 2004).

[12] In order for the farmers return flow coefficient to be unaffected by reuse of his own irrigation water, the social planner has to be able to monitor the total amount of water the farmer applies to his field, whether this water is taken from the irrigation canals or the drains. In reality farmers would probably often be able to hide water application from the drains from the social planner and in some cases this would also be possible for water application from the irrigation canals. In the present analysis this kind of cheating is disregarded. It is recognized, though, that it would have consequences for the relative efficiency of water taxes vs. other taxes, which are levied on variables, which the farmer is not able to conceal from the social planner.

[13] In this respect, the present model is similar to the so-called "idealized" integrated water resource system (IWS) in Keller et al 1996, which was discussed in chapter 1. Like in the idealized IWS model, water in the present model is pure, there is no rainfall, and there is no non-beneficial evapotranspiration. However, unlike in the idealized IWS model, return flows in the present model need not be fully recoverable. Keller et al included the possibility of non-recoverable return flows in their other model – the so-called "real" IWS model, which also featured salts, leaching requirements, and non-beneficial evapotranspiration.

2.2. SOCIAL PLANNER'S PROBLEM: FIRST ORDER CONDITIONS.

The approach used to determine the socially optimal policy design for allocating irrigation water in the presence of return flow externalities centers on the first order conditions for the social planner's problem and the individual farmers' problems. The first order conditions are derived using the Lagrange optimization method. The Lagrange function for the social planner's problem may be written as:

$$L = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - \sum_{j=1}^{J}\lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$
$$-\lambda_2[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j]$$

As some of the constraints of the optimization problem are inequalities rather than equalities the first order conditions for this optimization problem are given by the following Kuhn-Tucker conditions:[14]

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk})) \leq 0$$

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))) = 0$$

for all $i = 1,...,I$, $j = 1,...,J$, and $k = 1,...,K$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] = 0 \qquad \text{for all } j = 1,...,J$$

$$\lambda_2 \geq 0$$

$$\frac{\partial L}{\partial \lambda_2} = -[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] \geq 0$$

$$\lambda_2\frac{\partial L}{\partial \lambda_2} = -\lambda_2[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] = 0$$

[14] The other conditions, which need to be fulfilled in order for the first order conditions to be sufficient conditions for optimization, is that the objective function and the constraint functions be C^1 functions, that the Lagrange function be a concave function of X_{ijk}, and that a solution $(X^*_{ijk}, \lambda^*_{1j}, \lambda^*_2)$ for all $i = 1,...,I$, $j = 1,...,J$, $k = 1,...,K$ exist (cf. Berck and Sydsæter 1992, p 75). As both the objective function and the constraints are linear in X_{ijk}, the first condition is met. The second condition is also met as the Lagrange function is also linear in X_{ijk}.

The first of these first order conditions is the non-negativity constraint on the activity level, which simply states that a farmer cannot allocate a negative amount of land to the production of a crop. The second condition states that the profits per area unit (defined as revenue minus costs of purchased inputs and opportunity costs of non-traded endowments) for all activities must be either zero or negative in the optimum. The third condition is a complementary slackness condition, stating that in the optimum it is not possible to have a non-zero activity level without profits per area unit being zero for this activity. Taken together these three conditions assert that a positive activity level implies that profits per area unit for the activity in question must be zero, while a zero activity level implies that profits per area unit for the activity in question are negative. [15]

The fourth condition is simply the individual farmers' land constraint, stating that for each farmer the sum of land areas used for production activities must equal his initial land holdings.

The three last conditions relate to the water constraint. The first of these conditions states that the social planner's shadow price of water must be non-negative. As the social planner's water constraint is formulated in terms of water consumed or irretrievably lost, the social planner's shadow price of water relates to water consumed or lost. The second of these three conditions is simply the national water constraint, which states that the sum of water consumed or irretrievably lost must not be greater than the fixed amount of water, which can be permanently removed from the water system. The final of the three conditions is a complementary slackness condition stating that it is not possible to have a non-zero shadow price of water unless the national water constraint binds. Taken together the three conditions assert that the social planner's shadow price of water consumed or lost will be positive, if the national water constraint binds, and will equal zero, if the constraint does not bind.

These first order conditions sum up the conditions, which have to be met, in order for the irrigation water to be allocated in a socially efficient manner. Provided the social planner cannot actually dictate the actions of the farmers, his only options for implementing the socially efficient allocation of water is to design the water allocation policy instruments in

[15] It is also possible to have degenerate solutions, where both elements of the complementary slackness condition equal zero in the optimum. This occurs when two or more crop activities are equally profitable. However, according to Hazell and Norton, degeneracy is rarely a serious problem in practice (Hazell and Norton 1986). This special case will thus not be considered explicitly in the following analysis.

such a way as to align the individual farmer's water allocation incentives with his own water allocation incentives. The following section will present the individual farmer's production and water allocation incentives under different tax and quota policy schemes designed to regulate the allocation of irrigation water. As the policy analysis is based directly on the first order conditions, the actual solution to the social planner's problem has been deferred to appendix A. The solution to the farmer's problem is presented in appendix B.

3. FARMER'S POINT OF VIEW: THE FARMER'S PROBLEM UNDER DIFFERENT POLICIES

Unlike the social planner, the individual farmer is not concerned about the national water constraint. The only thing that matters to him is his own access to irrigation water and how it affects the profitability of his production. The following sections will present the individual farmer's problem under the following four types of policy scenarios: Policy instruments targeting input of water applied and generated recoverable return flows, policy instruments only targeting input of water applied, policy instruments targeting input of land, and policy instruments targeting crop output.

3.1. FARMER'S PROBLEM: POLICY INSTRUMENTS TARGETTING WATER APPLIED AND RECOVERABLE RETURN FLOWS.

Since the farmer's unregulated use of irrigation water gives rise to two types of externalities, it should be possible to achieve a socially optimal allocation of irrigation water by using two policy instruments, which each targets one of the externalities.

As the first type of externality from irrigation water allocation is associated with the application of irrigation water, a tax is placed on the amount of irrigation water applied by each farmer. The second type of externality is associated with recoverable return flows. As only quantity – not quality – of water is considered in this model, recoverable return flows constitute a positive externality. A credit is consequently introduced for the amount of recoverable return flows generated by the farmer. With these two policy instruments in place farmer j's problem can be expressed in the following way:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K}d_{ijk}X_{ijk} + T_R\sum_{i=1}^{I}\sum_{k=1}^{K}\beta_j(d_{ijk} - e_{ijk})X_{ijk}$$

Subject to:

$X_{ijk} \geq 0$ for all $i = 1,...,I$ and $k = 1,...,K$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} = \overline{X}_j$$

Where:

- T_D : Tax on water applied, measured in LE/cubic meter.
- T_R : Credit for recoverable return flows, measured in LE/cubic meter.

According to this model specification, the individual farmer's objective is to maximize producer surplus including water taxes and credits, subject to his individual land constraint. The Lagrange function for farmer j's problem can be written as:

$$L = \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R)X_{ijk} - \lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} - \overline{X}_j]$$

The first order conditions for this maximization problem are given by the following Kuhn-Tucker conditions:

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j} \leq 0$$

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j}) = 0$$

for all $i = 1,..., I$ and $k = 1,..., K$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} - \overline{X}_j] = 0$$

Comparing these first order conditions for farmer j's problem to the first order conditions of the social planner's problem derived in section 2.2, there are obviously strong similarities. The non-negativity constraints on activity levels are trivially identical. As the model does not allow for reallocation of land between farmers, the individual farmer's land constraints are also identical. The main difference between the two sets of first order conditions is the fact that while water is treated as an endowment in the social planner's problem, it is in fact treated as a purchased input in the farmer's problem, although the price of water is a tax rate rather than a market price. The second of the first order conditions outlined above consequently states that it is the farmer's profit per area unit for a given crop and water-yield technique after deduction of the tax on water applied and addition of the credit on recoverable return flows, which must be either zero or negative in the optimum. The third condition is again the corresponding complementary slackness condition stating that in the optimum it is not possible to have a non-zero activity level without profits per area unit being zero for this activity.

The social planner's problem basically consists of optimization problems for each of the J farmer's, which are tied together through the national water constraint. However, as water is treated as a purchased input from the farmer's point of view, the national water constraint does not appear in farmer j's problem. Instead equilibrium between national water supply and demand is assumed to be achieved through adjustment of the tax rate on water applied and the credit rate for recoverable return flows.

In order for a socially optimal allocation of water to be implemented through taxation of water applied and crediting of recoverable return flows, the individual farmer has to be given the same water allocation incentives as the social planner has. As the farmer's water allocation decisions are inferred from his allocation of land to the production of the different crops using the various water-yield techniques, this implies giving him the incentives to choose the same land allocation with respect to crops and water-yield techniques as the social planner would choose. The socially optimal levels for the tax and credit rates are consequently those, which ensure that the farmer's profits per area unit correspond to the social planner's profits per area unit. In order for the corresponding first order conditions from the farmer and the social planner's problems to be identical, the following condition must hold:

$$y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R = \lambda_2(d_{ijk} - \beta_j(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow T_D + \beta_j(1-\alpha_{ijk})T_R = \lambda_2(1-\beta_j(1-\alpha_{ijk}))$$

$$\Leftrightarrow T_D = T_R = \lambda_2$$

This result says that the tax rate on water applied should be equal to the credit rate on recoverable return flows, which in turn should be set equal to the social planner's shadow price of water consumed or irretrievably lost. This is not a surprising result given the model specification. Since the model does not incorporate temporal or quality aspects of the return flows, there are no inherent differences between initial water diversions and recycled recoverable return flows, and they should consequently be valued at the same rate. As both the tax rate on water applied and the credit rate for recoverable return flows are determined unambiguously, in the sense that neither of these rates depends on either farmer-specific characteristics or choice of crop or water-yield technique, it also follows that the introduction of such a policy scheme would achieve a socially optimal allocation of water.[16]

In order to better understand the implications of this result, the condition $T_R = T_D$ is substituted into the farmer's objective function:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K} d_{ijk}X_{ijk} + T_R\sum_{i=1}^{I}\sum_{k=1}^{K}\beta_j(d_{ijk} - e_{ijk})X_{ijk}$$

$$\Leftrightarrow \max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K} d_{ijk}X_{ijk} + T_D\sum_{i=1}^{I}\sum_{k=1}^{K}(d_{ijk} - e_{ijk})X_{ijk}$$

$$\Leftrightarrow \max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K}(d_{ijk} - \beta_j(d_{ijk} - e_{ijk}))X_{ijk}$$

$$\Leftrightarrow \max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K}(e_{ijk} + (1-\beta)(d_{ijk} - e_{ijk}))X_{ijk}$$

As these calculations show, taxing water applied and crediting recoverable return flows by T_D amounts to taxing water consumed or irretrievably lost by T_D. As these are exactly the aspects of irrigation water use, which are assumed to matter from society's point of view, it is not surprising that T_D should be set equal to society's shadow price of water consumed or irretrievably lost.

However, while the combination of taxing water applied and crediting recoverable return flows will ensure a socially optimal allocation of irrigation water in a theoretical model, it is not likely that this approach can be implemented in reality. The reason is that this policy scheme presupposes that the social planner is able to meter or deduce not only the farmer's water application but also his return flows. While it is technically feasible to meter the amount of water the farmer applies to his field given the right type of irrigation infrastructure, it will generally not be possible to meter his return flows, as only a part of these will end up in the drainage system, while the rest may percolate into the ground.

[16] In former versions of the model, where the return flow recoverability parameter was assumed to be non-farmer-specific, crediting recoverable return flows by T_R was equivalent to crediting all return flows by βT_R. However, in the present model, where return flow recoverability is assumed to be a farmer-specific variable, this is no longer the case, as the latter type of policy scheme would imply that the credit rates had to be farmer-specific.

Even if the social planner is able to meter the farmer's water application, he is not likely to be able to estimate the size of the farmer's return flows either, as this would require not only knowledge of the farmer's choice of crops, but also his choice of water-yield techniques for producing these crops as well as the farmer-specific field irrigation efficiency coefficient. While it may be relatively easy for the social planner to determine what type of crop the farmer is growing on his land, it would be substantially more difficult to determine what water-yield technique the crop is produced with and what the farmer's exact irrigation efficiency is for this particular crop. As mentioned earlier, irrigation efficiency is determined by the water-holding capacity of the soil and the method of water application. Determining the general type of irrigation technology being used may be reasonably simple, but determining the soil type may be rather expensive, depending on the degree to which soil types differ within a given region.[17] The social planner would also have to determine the farmer-specific return flow recoverability fraction. Again the cost of doing so would depend on the extent to which return flow recoverability varies substantially across farmers in a region.

Given these considerations it seems reasonable to conclude that while it may be technically possible for the social planner to obtain the required knowledge on farmer's choice of water-yield technique, as well as his irrigation efficiency and the recoverability of his return flows, it would most likely be too expensive to attain this information, at least for a social planner in a developing country. In the following sections it will consequently be assumed that neither the choice of water-yield technique nor the farmer-specific irrigation efficiency or return flow recoverability is fully observable to the social planner. The social planner is, however, assumed to know the joint distribution of these parameters for the region in question, and this enables him to calculate the social shadow price of water consumed or irretrievably lost, which enters into the tax rate equations.

3.2. Farmer's problem: Policy instruments targetting only water applied

While the first-best policy scheme of taxing water applied and crediting recoverable return flows is not implementable and thus remains of theoretical bench-mark case, it is in principle

[17] Irrigation efficiency is also affected by the degree of land leveling undertaken by the farmer, which may also be difficult for the social planner to observe. The issue of land leveling is considered further in the discussion section.

possible to implement a single tax on water applied. The question is then to what extent taxing only water applied will result in a socially optimal allocation of irrigation water.

If a single tax is introduced on water applied, farmer j's problem becomes:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K}d_{ijk}X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i=1,...,I \text{ and } k=1,...,K$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} = \overline{X}_j$$

Once again the farmer's objective is to maximize producer surplus subject to his individual land constraint, but this time his producer surplus only includes the tax on water applied. The Lagrange function for farmer j's problem can subsequently be written as:

$$L = \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D)X_{ijk} - \lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$

The first order conditions are given by the Kuhn-Tucker conditions:

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D - \lambda_{1j} \leq 0$$

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D - \lambda_{1j}) = 0$$

$$\text{for all } i=1,...,I \text{ and } k=1,...,K$$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] = 0$$

The interpretation of these first order conditions are basically identical to the interpretation of the first order conditions for farmer j's problem in section 3.1, except that in the present case the farmer does not receive a credit for his recoverable return flows.

Comparing this set of farmer's first order conditions with the first order conditions for the social planner's problem, it follows that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D - \lambda_{1j} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow d_{ijk}T_D = \lambda_2(d_{ijk} - \beta_j(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow T_D = \lambda_2(1-\beta_j(1-\alpha_{ijk}))$$

This result shows that in order to ensure an optimal allocation of irrigation water, the tax on water applied should be set equal to the social shadow price of water consumed times *the fraction* of water applied, which is not recycled (i.e. the fraction of water applied, which is either consumed or irretrievably lost). This in turn implies that the tax rate on water applied should be lower than the social shadow price of water consumed in order to compensate for the fact that a fraction of water applied is recycled. However, as the result also shows, the fraction of water applied, which is not recycled, depends on the field irrigation efficiency, which is assumed to depend on farmer-specific features as well as choice of crop and water-yield production technology. Provided that irrigation efficiency does indeed differ across either farmers or crops or water-yield production technologies, it will consequently not be possible to achieve a socially efficient allocation of irrigation water using a single tax on water applied. Furthermore, the fraction of water applied, which is not recycled, also depends on the farmer-specific degree of return flow recoverability. To the extent that this differs across farmers, it will also not be possible to achieve a first-best allocation of irrigation water using a single tax on water applied.

It is worth noting the role of return flow recoverability in this result. If $\beta_j = 0$ for all farmers, meaning that no return flows are recovered, then a socially optimal allocation of water can be achieved by setting $T_D = \lambda_2$. This is not surprising, because if no return flows are recovered then the externality related to the recoverability of return flows disappears. The only remaining externality then relates to the allocation of water diversions, and it can be alleviated through the introduction of a tax on water applied. It should also be noted that the importance of field irrigation efficiency from a society's point of view is inversely related to the fraction of return flows, which are recovered. In the case of $\beta_j = 0$, the degree of field irrigation efficiency is thus highly important from the social planner's point of view. However, if socially optimal pricing of water diversions is introduced, then farmers bear the full costs of irrigation inefficiency, and they will therefore have the proper incentives to reduce these losses through their choices of crops, and water-yield techniques.[18]

In the case of $\beta_j = 1$ for all farmers, meaning that all return flows are recovered, the model result shows that a socially optimal allocation of water requires the uniform tax rate T_D to equal $\lambda_2 \alpha_{ijk}$, which is not possible if irrigation efficiency differs across farmers, crops, or water-yield production technology. All in all it may be concluded that a single tax on water applied is only able to produce a socially efficient allocation of irrigation water, if return flows are non-recoverable and hence the externality of recoverable return flows non-existent.

Another point to consider is how a single tax on water applied will affect the choices of crops and water-yield techniques in the general setting, where return flows are at least partially recoverable. Looking at the expression for the farmer's profits per area unit, the farmer obviously bases his profit maximization on water applied, whereas the social planner bases his maximization of profits per area unit on water consumed or irretrievably lost. To the extent that water applied were to be uniformly proportional to water consumed or lost across all crops and water-yield techniques, the farmer would choose the same crops and water-yield techniques as the social planner. However, at least in the case of choosing between rice and other crops, this would typically not be the case, as traditional rice production requires application of excess amounts of water. When return flows are at least partially recoverable, a single tax on water applied may thus induce farmers to choose a different mix of crops and perhaps also water-yield techniques than would have been chosen by the social planner, and this is clearly not optimal from society's point of view.

Tax policy instruments are not the only policy instruments, which can be used to alleviate externality problems. In stead of taxing the amount of water applied by the farmer, the social planner could thus target the farmer's use of water by introducing quotas on farmers' application of water. When a quota is introduced on the amount of water applied by each farmer, farmer j's problem becomes:

$$\max_{X_{ijk}} \sum_{i=1}^{I} \sum_{k=1}^{K} (y_{ijk} P_i - z_{ijk} C_Z) X_{ijk}$$

[18] If switching irrigation technology was allowed, then the farmer would also have the right incentives for choosing the socially optimal irrigation technology in this case.

Subject to:

$X_{ijk} \geq 0$ for all $i = 1,..., I$ and $k = 1,..., K$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} = \overline{X}_j$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} d_{ijk} X_{ijk} \leq \overline{D}_j$$

Where:

- $\overline{D}_j$: Maximum amount of water that farmer j can apply to his fields, measured in cubic meters.

According to this specification, the farmer's objective is to maximize producer surplus, subject to his land constraint and his new quota on water application. Computing the first order conditions for this maximization problem and comparing them to the first order conditions of the social planner's problem shows, that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$\lambda_{2j} = \lambda_2(1 - \beta(1 - \alpha_{ijk}))$$

Where:

- λ_{2j}: Farmer j's shadow price of water applied.[19]

This result says that in order for individual quotas on water applied to achieve a socially optimal allocation of water, not only across farmers but also across crops and water-yield techniques, the size of the quota must be set so that the farmer's shadow price of water applied is equal to the social planner's shadow price of water consumed or irretrievably lost times *the fraction* of water applied, which is either consumed or lost. However, as in the case of a single tax on water applied, it will generally not be possible to achieve a socially optimal allocation of water through introduction of farmer-specific quotas on water applied. The reason is again that if the farmer's irrigation efficiency depends on his choice of crops or water-yield techniques he may not chose the socially optimal mix of crops and water-yield techniques, since his incentive would be to optimize his profits given his quota of water applied without regard for his generation of return flows.

[19] Note that while λ_{2j} refers to farmer j's shadow price of water applied, λ_2 refers to the social planner's shadow price of water consumed or irretrievably lost.

Comparing the quota result with the result for a tax on water applied, we see that the tax and quota policy schemes lead to identical solutions with respect to what the farmer's valuation of water applied should be from a socially optimal point of view. However, there are also important differences between the ways the two policy schemes work. The tax policy scheme ensures that each farmer has the same valuation of water applied, since the value of water to the farmer is given by the tax rate, which is identical across farmers. In the quota policy scheme, on the other hand, each farmer's valuation of water depends on the size of his individual water quota.

The quota policy scheme thus implies that the social planner must determine the size of the quota for each individual farmer, and only if the sizes of all farmers' quotas are determined optimally will all farmers place the same value on their water, which is necessary for a socially optimal allocation of water to be achieved. In order to determine the optimal size of each farmer's water quota, the social planner would need a lot of information about each farmer, including information on farmer-specific irrigation efficiency and return flow recoverability, which is assumed not to be fully observable to the social planner. As already mentioned, this information is likely to be to quite costly to collect in a real-world developing country setting, and individual quotas on water applied would still not yield a first-best allocation of water as long as return flows are partially recoverable and irrigation efficiency differs across farmers, crops, or water-yield techniques. It is not initially clear whether allowing farmers to trade their water quotas would alleviate the problem of determining the optimal quota size for each farmer. However, while this is an interesting and relevant policy consideration, it is beyond the scope of the present study. Furthermore, allowing farmers to trade their water quotas would still not result in a first-best allocation of irrigation water due to the lack of incentives for the farmer to consider the impact his recoverable return flows have on others.

3.3. FARMER'S PROBLEM: POLICY INSTRUMENTS TARGETTING LAND USE

The tax policy scheme analyzed in the previous section only targeted water applied. However, when return flows are recoverable, it is water consumed or irretrievably lost, which matters from society's point of view, and a single tax on water applied can consequently not bring about a socially efficient allocation of irrigation water. Furthermore, although it is in principal feasible to meter the amount of water applied by the farmers, the actual irrigation infrastructure in many developing countries is not equipped for volumetric metering at the individual farmer level. The introduction of a tax on water applied would consequently require substantial investments in the irrigation infrastructure in these countries. In Egypt metering at the individual farmer level is not possible in the traditional irrigation system in Old Lands. The new irrigation system, which is being introduced under the Irrigation Improvement Project, does in principle allow for volumetric measurement, but the system has not been working properly (Hellegers and Perry 2004). The use of modern irrigation systems in the New Lands implies that metering of water at the point of delivery is possible (Abu-Zeid and Rady 1992).

In light of the model results and these practical considerations of metering farmers' water application, the question arises whether another policy instrument exists, which would better target the relevant aspects of water use while not relying on volumetric metering. As water consumption is closely tied to the choice of crop and the size of the area used for cultivation of this crop, a possible candidate for such a policy instrument would be crop-specific taxes on cultivated land, which reflect the relative water consumption of the crops. With crop-specific land taxes farmer j's problem becomes:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - \sum_{i=1}^{I}(T_{Li}\sum_{k=1}^{K}X_{ijk})$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i=1,...,I \text{ and } k=1,...,K$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} = \overline{X}_j$$

Where:

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

According to this specification, the farmer's objective is to maximize profits net of crop-specific land taxes, subject to his individual land constraint. The Lagrange function for farmer j's problem can subsequently be written as:

$$L = \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z - T_{Li})X_{ijk} - \lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$

The first order conditions are given by the Kuhn-Tucker conditions:

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - T_{Li} - \lambda_{1j}) = 0$$

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - T_{Li} - \lambda_{1j} \leq 0$$

for all $i = 1,...,I$ and $k = 1,...,K$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} - \overline{X}_j] = 0$$

Again the interpretation of these first order conditions are very similar to the interpretation of the first order conditions for farmer j's problem in section 3.1, except that in the present case crop-specific land taxes have replaced the taxes and credits on water applied and recoverable return flows.

Comparing this set of farmer's first order conditions with the first order conditions for the social planner's problem, it follows that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$y_{ijk}P_i - z_{ijk}C_Z - T_{Li} - \lambda_{1j} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow T_{Li} = \lambda_2(d_{ijk} - \beta_j(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow T_{Li} = \lambda_2(1-\beta_j(1-\alpha_{ijk})d_{ijk}$$

This result says that in order to ensure a socially optimal allocation of irrigation water, the crop-specific land taxes must equal the social shadow price of water consumed times *the amount* of water consumed or irretrievably lost *per area unit* for the crop in question.[20] The crop-specific land taxes can thus be interpreted as the farmer being made to pay for the amount of water he permanently removes from the water system, when he cultivates an area unit with a given crop using a given water-yield technique. However, if field irrigation efficiency differs across farmers or water yield techniques, or if return flow recoverability

[20] Note that $(1-\beta_j(1-\alpha_{ijk})$ is the fraction of water applied, which is not recycled. As previously mentioned, this corresponds to the fraction of water applied, which is either consumed or irretrievably lost. When this fraction is multiplied by the coefficient of water applied per area unit for a given crop, the result becomes the amount (rather than the fraction) of water consumed or irretrievably lost per area unit for the crop in question.

differs across farmers, then a set of crop-specific land taxes will not be able to achieve a first-best allocation of irrigation water and land.

While the result for crop-specific land taxes may initially appear similar to the result in case of a single tax on water applied, further examination of the role of return flow recoverability shows that there is an important difference. The reason is that in the case of $\beta_j = 1$ for all farmers, the socially optimal tax rate for a given crop-specific land tax becomes:

$$T_{Li} = \lambda_2 \alpha_{ijk} d_{ik} = \lambda_2 e_{ijk}$$

If all return flows are recovered by the river basin system, the crop-specific land taxes should be set equal to the social shadow price of water consumed or lost times the amount of water consumed by the crop per area unit. When return flows are fully recoverable, the socially optimal rate for the crop-specific land taxes is consequently independent of farmer irrigation efficiency, as all the water applied, which is not consumed by the crops, will be recovered for another diversion cycle. However, unless the social planner is able to observe or deduce the individual farmer's choice of water-yield technique, it will not be possible to achieve a socially efficient allocation of irrigation water using only crop-specific land taxes, as such taxes cannot address the choice of water-yield technique for a given crop. In this model the social planner is assumed not to be able to verify the farmer's choice of water-yield technique, and he is consequently not able to make the land tax depend on it. Once the land tax has been set for all the crops, the farmer will consequently choose a mix of crops and water-yield techniques, which maximize his profits. Furthermore, crop evapotranspiration rates are also potentially farmer-specific, and crop-specific land taxes would not be able to capture the farmer-specific dimension.

In the case where $\beta_j = 0$ for all farmers, meaning that no water losses are recovered and the only externality arises from the allocation of water diversions, the socially optimal rates for crop-specific land taxes become:

$$T_{Li} = \lambda_2 d_{ijk} = \lambda_2 \frac{e_{ijk}}{\alpha_{ijk}}$$

In this case, the problem of non-observability of not only water-yield technique choice but also farmer-specific irrigation efficiency is present, and crop-specific land taxes will consequently not be able to produce a socially efficient allocation of irrigation water. The problem is that crop-specific land taxes generally target crop water consumption (save for the water-yield technique dimension and the farmer-specific dimension). However, what matters from a social point of view is not only water consumption but also the water losses from non-retrievable return flows, and crop-specific land taxes can only capture the average water losses and not the water-yield technique or farmer-specific dimensions.

Policy instruments targeting farmer's use of land can also take the form of quantitative restrictions on the amount of land, which can be used for the production of a given crop. With crop-specific quotas on land use the farmer problem becomes:

$$\max_{X_{ijk}} \sum_{i=1}^{I} \sum_{k=1}^{K} (y_{ijk} P_i - z_{ijk} C_Z) X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i = 1,...,I \text{ and } k = 1,...,K$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} X_{ijk} = \overline{X}_j$$

$$\sum_{k=1}^{K} X_{ijk} \leq \overline{X}_{ij} \qquad \text{for all } i = 1,...,I$$

Where:

- $\overline{X}_{ij}$: Maximum amount of land that farmer j can use for production of crop i, measured in feddan.

According to this specification, the farmer's objective is to maximize producer surplus, subject to his land constraint and his new crop-specific quotas on land allocation.[21] Computing again the first order conditions for this maximization problem and comparing them to the first order conditions of the social planner's problem shows that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$\lambda_{2ij} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk})) d_{ijk}$$

Where:

- λ_{2ij}: Farmer j's additional shadow price on land due to the crop-specific land quotas.[22]

[21] The assumption that the farmer's aggregate land constraint continues to bind obviously requires that the sum of his crop-land-quotas be at least the size of his land holding.

[22] As farmer j's aggregate land constraint is assumed to bind, farmer j still has a generic shadow price of land (cf. λ_1 in the previous maximization problem). λ_{2ij} is thus the additional shadow value of land used for production of crop i, when the quota on land use for production of crop i is binding.

This result says that in order for the social planner to achieve a socially optimal allocation of irrigation water and land, the size of the crop-specific land quotas for a given farmer should be set so that the additional shadow value on land used for production of crop i due to the land quota for crop i is equal to the social planners shadow price of water consumed times *the amount* of water consumed or irretrievably lost *per area unit* for the crop in question.

Comparing the quota result with the result for crop-specific land taxes, we see again that the tax and a quota policy scheme lead to identical solutions with respect to what the farmer's valuation of land used for producing a given crop should be from a socially optimal point of view. As in the case of crop-specific land taxes, the additional shadow value of land due to the introduction of crop-specific land quotas can be interpreted as making the farmer value the amount of water required for growing each of the crops. However, as in the case of quotas on water applied, the social planner will have to determine the optimal crop-land quotas for each farmer, which would require information the social planner is assumed not to have. Only if the sizes of all farmers' quotas were determined optimally would all farmers place the same value on their irrigation water, which is necessary for a socially optimal allocation of water to be achieved. Compared to the case of quotas on water applied, the problem of implementing optimal quotas for land use would be compounded by the fact that the social planner would have to determine and enforce the optimal size of up to i-1 crop-land quotas per farmer. Again it is not clear whether the problem of allocating crop-land quotas efficiently across farmers could be alleviated by allowing farmers to trade their crop-land quotas. However, the issue of enforcing the restrictions on each farmer's use of his land would remain and the resulting allocation of land and water would still not be first-best.

3.4. FARMER'S PROBLEM POLICY INSTRUMENTS TARGETTING CROP OUTPUT

The policy instruments analyzed so far have been directed at the farmer's use of inputs in the form of water and land. However, the social planner can also affect the farmer's use of water through policy instruments targeting the farmer's generation of output. One example of such a policy scheme would be crop-specific output taxes. With crop-specific taxes levied on the amount of output produced, farmer j's problem becomes:[23]

[23] An alternative to levying output taxes on the amount of output produced would be to introduce ad valorem taxes on output. However, from a water management point of view, the salient aspect is the amount of output

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - \sum_{i=1}^{I}T_{Oi}\sum_{k=1}^{K}y_{ijk}X_{ijk}$$

Subject to:

$X_{ijk} \geq 0$ for all $i = 1,...,I$ and $k = 1,...,K$

$$\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} = \overline{X}_j$$

Where:

- T_{Oi}: Crop specific output tax, measured in LE/tonne.

According to this specification, the farmer's objective is to maximize profits net of the crop-specific output taxes, subject to his individual land constraint. It should be noted that the present formulation of the farmer's problem implies that the output tax be levied on total amount of output produced rather than just the amount of output marketed. In many developing countries, home consumption accounts for a large fraction of total agricultural output. In such cases it may well be more difficult to implement taxes on the amount of output produced than to implement taxes on the amount of land or even water used in production. However, further investigation of these issues is beyond the scope of the present chapter.

The Lagrange function for farmer j's problem can subsequently be written as:

$$L = \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}(P_i - T_{Oi}) - z_{ijk}C_Z)X_{ijk} - \lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$

The first order conditions for farmer j's problem are given by the Kuhn-Tucker conditions:

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}(P_i - T_{Oi}) - z_{ijk}C_Z - \lambda_{1j}) = 0$$

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}(P_i - T_{Oi}) - z_{ijk}C_Z - \lambda_{1j} \leq 0$$

for all $i = 1,...,I$ and $k = 1,...,K$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] = 0$$

produced rather than the value of this output, which ceteris paribus makes a specific tax the most appropriate output tax instrument.

The interpretations of these first order conditions are very similar to the interpretations of the farmer's first order conditions in section 3.1, except that in the present case crop-specific output taxes have replaced the taxes and credits on water applied and recoverable return flows.

Comparing this set of farmer's first order conditions with the first order conditions for the social planner's problem we see that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$y_{ijk}(P_i - T_{Oi}) - z_{ijk}C_Z - \lambda_{1j} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ik} + (1-\beta)(d_{ijk} - e_{ik}))$$

$$\Leftrightarrow y_{ijk}T_{Oi} = \lambda_2(d_{ijk} - \beta_j(d_{ijk} - e_{ijk}))$$

$$\Leftrightarrow T_{Oi} = \lambda_2(1-\beta_j(1-\alpha_{ijk}))\frac{d_{ijk}}{y_{ijk}}$$

This result says that in order to achieve a socially optimal allocation of irrigation water, the crop-specific output taxes must be set equal to the social planners shadow price of water consumed times *the amount* of water consumed or irretrievably lost *per output unit* for the crop in question.[24]

Comparing the result for crop-specific output taxes with the result for crop-specific land taxes, we see that they are very similar – the optimal rates for the crop-specific output taxes are equal to the rates for the crop-specific land taxes divided by crop yield. However, there are also several important differences between the two instruments. One of these differences relate to the incentives for farmer's choice between different water-yield techniques for a given crop. While a crop-specific land tax entails a fixed cost for allocating a unit of land to cultivation of a given crop, the cost of allocating a unit of land to cultivation of this crop under the crop-specific output tax scheme depends on the yield the farmer realizes, which in turn depends on his choice of water-yield technique. A crop-specific output tax scheme may thus result in different choice of water-yield techniques than a crop-specific land tax scheme. Disregarding the possibility of over-irrigation, yields and crop water consumption

[24] As noted in section 3.3, $\lambda_2(1-\beta_j(1-\alpha_{ijk})d_{ijk}$ corresponds to the amount of water consumed or irretrievably lost per area unit for crop i using water-yield technique k. When this expression is divided by the yield – i.e. amount of output per area unit - for the crop and water-yield technique in question, the result becomes the amount of water consumed or irretrievably lost per output unit for the given crop and water-yield technique.

requirements will be positively correlated and crop-specific output taxes may therefore in some cases provide the farmer with more socially appropriate water conserving incentives than crop-specific land taxes. However, in spite of this, it is still not given that crop-specific output-tax will lead the farmer to choose the socially optimal water-yield irrigation technique. Furthermore, the yield dimension in crop-specific output taxes also implies that if yields differ across farmer due to differences in soil quality, farmers with high yields will end up paying higher crop-specific land taxes than farmers with low yields, which will not be beneficial from a social efficiency point of view. Crop-specific output taxes are thus not capable of handling non-water related yield differences across farmers, and they also can not handle the farmer-specific dimension in irrigation efficiency, which matters as long as return flows are not 100% recoverable.

Considering the case in which return flows are fully recoverable - and hence $\beta_j = 1$ for all farmers - the socially optimal rates for crop-specific output taxes become:

$$T_{Oi} = \lambda_2 \frac{e_{ijk}}{y_{ijk}}$$

As in the case of crop-specific land taxes, we see that the expression for the optimal crop-specific output tax rates simplifies substantially when return flows are fully recoverable. Furthermore, if the ratio between the crop water consumption requirement and crop yield for each crop were constant across the different water-yield techniques, the socially optimal crop-specific output tax rates would no longer depend on the farmer’s choice of water-yield technique.[25] However, as yields are potentially farmer-specific due e.g. to soil characteristics, the crop-specific output taxes will generally not produce a first-best allocation of irrigation water and land, even in the case where return flows are 100% recoverable and yields and water requirements are directly proportional.

In the case of return flows not being recoverable at all - and hence $\beta_j = 0$ for all farmers - the socially optimal rates for crop-specific output taxes become:

[25] While yield and crop water requirements are highly correlated (Seckler 1996), it is unlikely that the ratio of crop water consumption requirements to crop yields would in reality be completely fixed across different water-yield techniques. The reason for this is that while the present model describes crop production as a single period phenomenon, in reality crop production can be divided into different growth periods. Crop sensitivity to water stress varies across the different growth periods with crops tending to be more sensitive to water stress during “emergence, flowering, and early yield formation than during vegetative (after establishment) and ripening periods” (FAO 2002, section IV). Yield response to water stress would thus depend upon what growth period the water stress occurred in.

$$T_{Oi} = \lambda_2 \frac{d_{ijk}}{y_{ijk}} = \lambda_2 \frac{e_{ijk}}{\alpha_{ijk} y_{ijk}}$$

In this case, the farmer-specific dimension of not only yields but also irrigation efficiency as well as the water-yield technique dimension prevents crop-specific output taxes from producing a first-best allocation of irrigation water and land.

As in the previous policy schemes, policies targeting farmers' production of output could also take the form of quantitative restrictions. When farmer j faces crop-specific output quotas, his optimization problem becomes:

$$\max_{X_{ijk}} \sum_{i=1}^{I} \sum_{k=1}^{K} (y_{ijk} P_i - z_{ijk} C_Z) X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i = 1,...,I \text{ and } k = 1,...,K$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} X_{ijk} = \overline{X}_j$$

$$\sum_{k=1}^{K} y_{ijk} X_{ijk} \leq \overline{Q}_{ij} \qquad \text{for all } i = 1,...,I$$

Where:

- $\overline{Q}_{ij}$: Maximum amount of output that farmer j can produce of crop i, measured in ton.

In this specification the farmer's objective is maximize producer surplus, subject to his land constraint and his new crop-specific output quotas. Computing the first order conditions of this maximization problem and comparing them to the first order conditions of the social planner's problem shows that in order for profits per area unit for a given crop and water-yield technique to be identical in these two optimization problems, the following condition must hold:

$$\lambda_{2ij} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk})) \frac{d_{ijk}}{y_{ijk}}$$

Where:

- λ_{2ij} : The shadow value for farmer j of the output quota for crop i.

This result says that in order to achieve a socially optimal allocation of irrigation water, the size of the crop-specific output quota for a given farmer should be set so that the shadow value of the output quota for crop i is equal to the social planners shadow price of water consumed or lost times *the amount* of water consumed or lost *per output unit* for the crop in question. The quota implementation problems discussed in the previous section persists, as the social planner would have to determine and enforce the optimal size of up i crop output quotas per farmer, based on information he is not assumed to have. Enforcing such an output quota scheme would be easier in the case where farmers have to sell all their output to a centralized marketing agency, but the problem of home consumption persists. Furthermore, the social planner would still not be able ensure that farmers choose the socially optimal water-yield techniques for their crops.

4. DISCUSSION OF MODEL ASSUMPTIONS AND THEIR IMPLICATIONS.

The model, which has been used for analyzing the efficiency properties of the different water policy instruments, rests on several assumptions, which deserve further scrutiny in order to determine their appropriateness and their impact on model results. The present section is consequently dedicated to discussing these assumptions and their implications.

4.1 SUBSTITUTABILITY, UNCERTAINTY, AND DYNAMICS.

Overall the model is characterized by being a static, deterministic model with Leontief production technology. Starting with the implications of the Leontief production technology, this in combination with the few binding constraint on the farmer's and the social planner's problems will result in over-specialized solutions. As shown in appendix A and B, where the social planner's and the farmer's problems are solved explicitly, a given farmer will generally only engage in one non-zero production activity when water allocation is regulated by taxes and this does not seem realistic. This feature of over-specialized solutions is a direct result of the simplified linear production technology and the inability to adequately specify all the constraints, which the farmer actually faces in his production decisions. However, as the objective here is merely to analyze how the externalities arising from allocation of irrigation water diversions and recoverability of return flows may be alleviated through different policy instruments, the use of Leontief production technology is only a problem if it significantly affects the policy conclusions of the analysis.

One way, in which the choice of Leontief technology might affect the conclusions of the analysis, is if the inherent lack of substitutability between different production factors would mask any distortionary impact of the policy instruments, be this impact beneficial or detrimental. However, part of this problem of lacking substitutability has been addressed in the model through the introduction of different water-yield techniques for producing the same crop. As the choice of water-yield technique is assumed to potentially affect the use of other inputs, this specification captures the substitution between water, land, and other inputs.[26] However, it does not capture the substitution between different types of other inputs in the case where the water-land ratio is held constant. While this latter case may clearly be relevant for agricultural production in general, it is not expected to play an important role in the present policy analysis, as none of the analyzed policy instruments target the use of other inputs directly.

The fact that the model is deterministic precludes the incorporation of uncertainty in the analysis. Uncertainty is an important element in irrigation economics in part because uncertainty regarding the timing and amount of future irrigation water deliveries may lead to water hoarding behavior on the part of the individual farmers.[27] In order to adequately capture these features the model would have to be extended to include analysis of uncertainty and farmer attitudes towards risks.

The static property of the model precludes explicit analysis of multi-period aspects like investment decisions. Although analysis of investment decisions on irrigation technology would be relevant for the policy analysis, such matters are consequently not included in the present model, and the farmer is therefore assumed not to have a choice regarding his irrigation technology. However, as mentioned in section 2.1, the typical Egyptian farmer may also not have much choice regarding what irrigation technology to use. Farmers in the Old Lands in Egypt generally use surface irrigation techniques, which do not require continuous supply of irrigation water. Sprinkler and drip irrigation, on the other hand, often require a continuous supply of water (Abu-Zeid and Rady 1992), but this is not available in the Old Lands under the traditional irrigation system, and it may not even become available in these lands following the implementation of the National Irrigation Improvement Project. Bader also lists several restrictions on farmer's adoption of sprinkler and drip irrigation including high capital costs for these techniques (while capital costs of surface irrigation is zero), fragmented land holdings, farmer's low knowledge and skill levels, as well as the notion that

[26] One important example of substitution of water with other inputs is the substitution of water for labor in rice production, as "pounding water in greater depth" is a means to reduce weed growth and hence save on labor costs (Tiwari and Dinar n.d. p 10).

[27] In Egypt there are examples of farmers applying substantially more water to their fields than needed in part due to lack of water control (Hvidt 1998).

most crops like cotton, rice, maize, wheat, and clover should be irrigated using surface irrigation (Bader 2004).[28] In the New Lands in Egypt, the use of sprinkler or drip irrigation is mandated by law, and the farmer's choice of irrigation technology is consequently also somewhat restricted in these areas.[29]

While farmers may have limited choice of irrigation technology, they do, however, have a choice regarding the degree of land preparation they undertake, and this will also affect their field irrigation efficiency. The degree of land preparation may possibly be improved by use of existing capital and more labor, but another way of improving land preparation would be to switch from manual to mechanized land preparation (Mohamed 2001). In this latter case, improvement of land preparation might then also entail some form of investment decisions, which the present model is not well-suited for addressing. However, multi-period investment decisions on irrigation technology could be indirectly introduced into the present static model by annualizing the capital cost and including it as an extra cost term in the farmer's objective function. The input coefficient of water applied would then have to be indexed across types of irrigation technology and so would the yield coefficient and the other inputs coefficient to the extent that yield and the use of other inputs would be affected by the choice of irrigation technology and degree of land preparation.

The lack of a time dimension in the model may also be considered problematic in relation to the recovering of return flows. While return flows from drainage canals may return to the system fairly quickly, this obviously need not be the case with return flows from percolation. In order to fully capture this latter type of return flows, the static model would have to be converted into a dynamic model. However, if the solution to the static model is thought of as a kind of steady state solution to a dynamic model, in which technology, endowments, prices, and policies are constant from one period to the next, then the current return flows, which may not yet be accessible, will be equal to last periods return flows, which would by now have become accessible.[30] The analysis in section 3.1 to 3.4 of the various policy instruments

[28] Note also that rotational irrigation is suitable for cultivation of long-rooted crops (i.e. sugar cane, maize, wheat, and berseem), while it is ill-suited for cultivation of short-rooted crops (i.e. vegetables), as these require more frequent irrigation (Hvidt 1998).

[29] Some of the issues relating to farmer's choice of irrigation technology in a situation where return flows are recoverable have been addressed in models by Chakravorty and Umetsu (cf. Chakravorty and Umetsu 2003 and Umetsu and Chakravorty 1998).

[30] The notion of interpreting a static model with recoverable return flows as being the steady state of a dynamic system is also employed by Chakravorty and Umetsu (cf. Chakravorty and Umetsu 2003)

should then be interpreted as referring to a point in time when the irrigation system have again attained a steady state after the policy instruments have been introduced.

4.2 WATER QUALITY

The perhaps most critical aspect, which the analysis has not addressed, is the fact that reuse of return flows is not merely a question of quantities of water. It is also a question of the quality of water – especially the quality of the return flows. The reason is that every time water is diverted and used for irrigation, the quality of the resulting return flows will be lower than the quality of the water, which was applied, as the crops consumptive use of water reduces the amount of water in which the initial natural salts are dissolved (Williardson et al 1997).[31]

Quantity and quality of water are in some ways closely connected. If the quality of the return flows deteriorates sufficiently, they will no longer be usable even if they are recoverable. This in turn suggests how the quality aspect may be introduced in the present model framework, as the coefficient capturing the recoverability of the return flows, β_j, could be adjusted to measure the fraction of return flows, which are not only recoverable but also reusable. Alternatively the quality aspects could be captured by having β_j measure the fraction of return flows expressed as "clean-water-equivalents".

Whether or not such an adjustment would make sense depends to some extent on how the drainage system is constructed. While drainage water of reasonably good quality may be reused directly for irrigation purposes, drainage water of poorer quality will require mixing with higher quality water before it may be reused (Williardson et al 1997). However, if it is not possible to dilute the poor quality return flows sufficiently or if the return flows have become polluted with toxins making them unsuitable for reuse, mixing return flows and fresh water may ultimately ruin the fresh water resources rather than making the return flows reusable. In order to avoid such a situation, the social planner would need to be able to keep drainage water and fresh water resources separate in the cases where there is a risk of the former damaging the latter. This would in turn imply that the social planner could control which fraction of the recoverable return flows it would be safe to recycle. In Egypt drainage

[31] Since the issue of water quality is not addressed in this model, the necessity and benefits of leaching are also not incorporated in the model. It is not clear whether the leaching requirement could be adequately introduced into the model simply by altering the specification of the field irrigation efficiency coefficient γ_{ijk} to also include the need for additional water for leaching purposes.

water from the Nile Valley is collected in drainage canals and returned to the Nile, resulting in an increase in Nile water salinity (Williardson et al 1997). However, water quality is still adequate for most uses in the Nile Valley (Mohamed 2001). In the Nile Delta drainage water is collected in drainage canals and some of the water is diverted to coastal lakes and the sea. However, government pumping stations also lift some of the water from the Delta drainage canals into the irrigation canals for mixing with fresh water before reusing it for irrigation (Williardson et al 1997). In the Nile Delta there is severe water pollution downstream of large communities and industrial cities, but the water in the irrigation canals remains relatively clean (Mohamed 2001).

If the β_j coefficient is to capture the quality of the return flows, it must be rendered a decision variable for the farmer, as the degree of return flow recoverability would no longer just depend on the drainage and percolation characteristics of the area but also on farmer behavior. The farmer may affect the quality of his return flows through his use of fertilizers and pesticides.

Another important aspect of farmer behavior, which would affect the quality of his return flows, is unofficial reuse of drainage water. While the social planner may be able to estimate the quality of the water resources given the natural and *official* reuse of water, farmers' *unofficial* reuse of drainage water for irrigation makes it more difficult for the social planner to manage the water quality.[32] As mentioned in section 2.1, in the present analysis the farmer's use of water is assumed to be fully specified in terms of his land allocation, and the analysis thus does not allow for farmer's to cheat the social planner by unofficially reusing drainage water. However, it should be noted that farmers' unofficial reuse of drainage water is substantial in Egypt (Mohamed 2001). This would obviously pose a challenge to the introduction of taxes on water applied, as the farmer would have an incentive to substitute parts of his costly fresh irrigation water with free, lower quality drainage water. The crop-specific land tax scheme, on the other hand, would not be as vulnerable to unofficial reuse of drainage water, as the tax is based on inferred water consumption rather than metered water application.

[32] Natural reuse of drainage water takes place, when rivers or canals serve as drains for hydrologic basin aquifer systems (Williardson et al 1997).

4.3 WATER CONVEYANCE AND COST OF WATER DELIVERY.

The final issue, which will be considered here, relates to the distribution of water. In the model delivery of water to the farmers' fields is implicitly assumed to be costless. This is clearly not a realistic assumption, and its implications consequently need to be considered. The costs associated with delivery of irrigation water may be divided into those costs, which are borne directly by the farmer, and those costs, which are borne by society. The farmers' costs may be divided into the variable costs associated with the acquisition of water and the more fixed costs related to maintaining irrigation and drainage infrastructure and equipment. In the traditional irrigation system in the Old Lands in Egypt, water is generally delivered below field level, and farmers therefore have to lift their irrigation water up to field level. Having to lift the irrigation water implies that farmers incur pumping costs, which in principle should give them incentives to conserve water. However, over time low cost pumps have become available, which have lowered the cost of pumping and reduced the time it takes to pump a given amount of water (Hvidt 1998 and Hellegers and Perry 2004). The variable costs of pumping water consequently do not appear to have a large impact on the farmer's water application decisions. However, farmer pumping costs could be introduced into the present framework by simply specifying an additional cost on the farmer's water applications.

With respect to the costs related to maintaining irrigation and drainage infrastructure, Egyptian farmers are only responsible for the tertiary irrigation canals and field drains, while the Egyptian state is responsible for the entire irrigation and drainage system above this level. The operations and maintenance costs for these parts of the irrigation and drainage system are not fully covered by farmers' tax payments, and cost recovery in the irrigation system is consequently an important issue in Egypt. Having to deliver larger amounts of irrigation water due to low field irrigation efficiency as well as potentially having to pump return flows from aquifers in order to reuse them may clearly raise the costs of utilizing return flows. As such, this issue is relevant for the analysis of the socially efficient allocation of irrigation water, as it would tend to increase the profitability of heightening field irrigation efficiency and hence lowering the need for recycling water.[33]

Other important aspects of the conveyance system, which are also not included in the model, relate to the physical efficiency of water conveyance and the ability of the social planner to

[33] Chakravorty and Umetsu (2003) also include aspects of water provision costs in their model with recoverable return flows.

ensure water deliveries to various sections of the irrigation system. Substantial amounts of water are lost in the conveyance system due to either percolation or evaporation. Water losses due to percolation may not be a major problem, if these water losses are recoverable. Water losses due to evaporation, on the other hand, constitute an unbeneficial consumption of water to the extent that they are not converted into precipitation in areas relevant to the social planner. However, with respect to the present policy analysis, evaporation losses may not be that important, if they remain virtually unchanged after the introduction of new water allocation policies. Finally it should be mentioned, that while the ability of the social planner to ensure that the socially optimal amount of water is delivered to the relevant sections of the irrigation system is a major challenge in the real world (cf. the issue of devising water allocation plans in Egypt in chapter 2), this issue cannot be included in the present type of policy analysis, as it would require modeling of the actual layout of the irrigation system in question.

5. CONCLUSION.

The purpose of the present analysis has been to analyze the efficiency properties of different policy instruments in a situation characterized by the presence of two types of externalities – the externality related to the allocation of water diversions between different irrigators and the externality related to recoverability of return flows from irrigation. The policy analysis has focused on the use of tax policy instruments to alleviate these externalities although the use of quotas has also been discussed.

As the set-up is characterized by the simultaneous presence of two externalities, it is hardly surprising that a theoretical first-best solution can be achieved by introducing a Pigovian tax on water applied and a Pigovian credit on recoverable return flows. However, as this approach would require that the social planner be able to meter or deduce the individual farmer's return flows, it is not likely that it can be implemented in reality. The analysis consequently proceeded to investigate the efficiency properties of three other policy schemes, which can in principle be implemented in a real-world setting. The three policy instruments were: a single tax on water applied, crop-specific land taxes, and crop-specific output taxes.

As the analysis showed, neither of these three policy schemes would be able to ensure a fully socially efficient allocation in the presence of recoverable return flows. Conceptually speaking, a single tax on water applied targets the amount of water the farmer applies to his field and thus cannot adequately handle recoverability of return flows. The problem of return flow recoverability arises, when the fraction of water applied, which is not recycled, depends on farmer-specific characteristics and / or choice of crop and water-yield technique, as the single tax rate on water applied can only take account of average return flow recoverability. Crop-specific land and output taxes, on the other hand, target the amount of water consumed in crop production. Conceptually these tax instruments consequently have difficulties handling non-recoverability of return flows adequately. The problem arises when the fraction of water applied, which is not recycled, depends on farmer-specific characteristics and / or the choice of water-yield technique. Furthermore, as crop-specific land taxes and output taxes do not directly target the amount of water used in crop production, the tax rates have to depend on the amount of water used per area unit and the amount of water used per output unit respectively. These variables also depend on farmer-specific characteristics and choice of water-yield technique, which crop-specific land and output taxes generally can not address properly.

While the introduction of a single tax on water applied, crop-specific land taxes, or crop-specific output taxes might well entail a more efficient allocation of irrigation water than in the situation without any regulation of the water allocation, the resulting allocation would in all cases still only be second-best. This conclusion naturally leads to the question of which of these three second-best policy instruments that would produce the more optimal allocation of irrigation water and land. One way of ranking different policy instruments theoretically is to consider whether one policy instrument is a special case of the other policy instrument. If this is the case, use of the former instrument can at most yield the same level of social efficiency as use of the latter, and typically use of the special case instrument will result in a less optimal outcome than use of the more general policy instrument. In the present analysis, a single tax on water applied is a special case of taxing water applied and crediting return flows, and the analysis showed that use of the former instrument would generally result in a less optimal allocation of water and land than use of the latter, except in the case where return flows were not recoverable and the two policy instruments became identical. However, when it comes to the three second-best instruments – water applied tax, crop-specific land taxes, and crop-specific output taxes – none of these policy instruments are special cases of each other and it is consequently not possible to rank the relative efficiency these three instruments using this kind of argument.[34]

The analysis showed that the relative efficiency of the three second-best instruments depends on the values of the key water parameters, which in turn depend on the specific location. In order to determine the relative efficiency of these three policy instruments for allocating irrigation water and land in Egypt, the following chapter will present an evaluation of the three policy instruments in an empirical simulation model of Egypt. However, apart from the efficiency aspects of the different policy instruments, their practical feasibility should also be considered. As already mentioned, metering of individual farmer's water diversion is often very difficult or even impossible. Crop-specific land taxes will generally be easier to implement and in some cases crop-specific output taxes may also be easier to implement than volumetric water taxes. Depending on their efficiency properties, these policy schemes may consequently be the best option for improving the allocation of irrigation water.

As discussed in the last section, the theoretical model presented in this chapter rests on a number of simplifying assumptions, which suggests a need for future research. Two important aspects of reusing return flows, which have not been explicitly included in the model, are thus the issues of the decreasing water quality and the increasing pumping and conveyance costs associated with additional water diversion cycles. Future extensions of the model to account for these issues would clearly be desirable, and as the discussion suggested this may well be doable within the current type of modeling framework.

[34] It is obvious that crop-specific land taxes and output taxes are not generally special cases of a tax on water applied, as the former have the crop-specific dimension, which the latter does not. Furthermore, a tax on water applied can not be implemented as a special case of crop-specific land taxes or crop-specific output taxes, as this would require the social planner to have knowledge about field irrigation efficiency coefficients, choice of water-yield techniques and farmer-specific characteristics. Crop-specific output taxes are also not a special case of crop-specific land taxes, as the former captures more of the water-yield technique choice than does the latter.

The final question is whether crop-specific land taxes can be implemented as a special case of crop-specific output taxes? To see that this is not the case, compare the farmer's objective function in the case of crop-specific land taxes with the farmer's objective function in the case of crop-specific output taxes. In order for the latter to be turned into the former, the crop-specific output tax rate must be set equal to the crop-specific land tax rate divided by the realized crop yield. However, the crop yield coefficient depends on farmer-specific characteristics and the choice of water-yield technique, and these aspects can not be captured merely by crop-specific tax rates. A crop-specific land tax consequently can not be implemented as a special case of a crop-specific output tax.

APPENDIX A - SOLVING THE SOCIAL PLANNER'S PROBLEM.

The social planner's problem and the associated first order Kuhn-Tucker conditions are presented in section 2. However, as the policy analysis is based directly on the first order conditions, the process of actually solving the model of the social planner's problem has been deferred to this appendix. Summarizing from section 2.1, the social planner's problem is specified as:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i = 1,...,I,\ j = 1,...,J, \text{ and } k = 1,...,K,$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K} X_{ijk} = \overline{X}_j \qquad \text{for all } j = 1,...,J$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} \leq \overline{W}_j$$

As outlined in section 2.2 the Lagrange function for this optimization problem is given by:

$$L = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - \sum_{j=1}^{J}\lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$
$$-\lambda_2[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j]$$

The corresponding first order conditions for the social planner's problem are:

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk})) \leq 0$$

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))) = 0$$

$$\text{for all } i = 1,...,I,\ j = 1,...,J, \text{ and } k = 1,...,K,$$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] = 0 \qquad \text{for all } j = 1,...,J$$

$$\lambda_2 \geq 0$$

$$\frac{\partial L}{\partial \lambda_2} = -[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] \geq 0$$

$$\lambda_2 \frac{\partial L}{\partial \lambda_2} = -\lambda_2 [\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] = 0$$

As it is not a priori given that the national water constraint will bind, the model has two kinds of solutions: One solution in which the national water constraint does not bind and one in which it does.

A.1. THE CASE OF A NON-BINDING NATIONAL WATER CONSTRAINT.

If the national water constraint does not bind, the social shadow price of water consumed or lost will be zero. The case of a non-binding national water constraint is consequently characterized by:

$$\lambda_2 = 0$$

$$\frac{\partial L}{\partial \lambda_2} = -[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] \geq 0$$

$$\Leftrightarrow \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{jik}))X_{ijk} \leq \overline{W}_j$$

With a non-binding water constraint, the maximization problem only contains J land constraints. As the model is completely linear this implies that the solution can contain at most J non-zero activities (i.e. $X_{ijk} > 0$ for J activities and $X_{ijk} = 0$ for the remaining (J*I*K)-J activities).

The assumption of a binding land constraint for every farmer ensures that every farmer has at least one positive activity level. As there are at most J non-zero activities this implies that each farmer is undertaking exactly one activity. Letting i* and k* denote the non-zero activity for farmer j we get:

$$X_{i*jk*} = \overline{X}_j \quad \text{and} \quad X_{ijk} = 0 \quad \text{for all } i \neq i* \text{ and } k \neq k*$$

Finally, for a given farmer the choice of crop and production technique i* and k* is determined through the farmer-specific shadow price of land λ_{1j}, which in turn is determined so that for exactly one crop and production technique (i* and k*):

$$\frac{\partial L}{\partial X_{i*jk*}} = y_{i*jk*}P_{i*} - z_{i*jk*}C_Z - \lambda_{1j} = 0$$

while for all other i and k:[35]

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} < 0$$

A.2. THE CASE OF A BINDING NATIONAL WATER CONSTRAINT.

$$\lambda_2 > 0 \text{ and } \frac{\partial L}{\partial \lambda_2} = -[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ik} + (1-\beta)(d_{ijk} - e_{ik}))X_{ijk} - \overline{W}_j] = 0$$

With a binding water constraint, the maximization problem contains J land constraints and one water constraint. As the model is completely linear this implies that the solution can contain at most J+1 non-zero activities (i.e. $X_{ijk} > 0$ for J+1 activities and $X_{ijk} = 0$ for the remaining (J*I*K)-(J+1) activities).

The assumption of a binding land constraint for every farmer assures that every farmer is producing at least one crop. As there is at most J+1 non-zero activities this implies that one farmer may be producing two crops, while every other farmer is producing one crop. Let $\tilde{j}$ denote the farmer producing two goods. Then letting i* and k* denote the non-zero activity for each farmer j, while i** and k** denote the second non-zero activity for farmer $\tilde{j}$ we get:

For $j \neq \tilde{j} : X_{i^*jk^*} = \overline{X}_j$ and $X_{ijk} = 0$ for all $i \neq i^*$ and $k \neq k^*$

For $j = \tilde{j}$: $X_{i^*\tilde{j}k^*} + X_{i^{**}\tilde{j}k^{**}} = \overline{X}_{\tilde{j}}$ and $X_{i\tilde{j}k} = 0$ for all $i \neq i^*, i^{**}$ and $k \neq k^*, k^{**}$

The latter equation contains two unknowns and hence leaves the division of land between farmer $\tilde{j}$'s two non-zero activities undetermined. However, by substituting the first set of equations into the water constraint equation, we get a second equation containing these two unknowns:

$$\frac{\partial L}{\partial \lambda_2} = -[\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))X_{ijk} - \overline{W}_j] = 0$$

$$\Leftrightarrow \begin{array}{l} (e_{i^*\tilde{j}k^*} + (1-\beta_{\tilde{j}})(d_{i^*\tilde{j}k^*} - e_{i^*\tilde{j}k^*}))X_{i^*\tilde{j}k^*} + (e_{i^{**}\tilde{j}k^{**}} + (1-\beta_{\tilde{j}})(d_{i^{**}\tilde{j}k^{**}} - e_{i^{**}\tilde{j}k^{**}}))X_{i^{**}\tilde{j}k^{**}} \\ = \overline{W}_j - \sum_{j \neq \tilde{j}}^{J}(e_{i^*jk^*} + (1-\beta_j)(d_{i^*jk^*} - e_{i^*jk^*}))\overline{X}_j \end{array}$$

[35] It is also possible to have degenerate solutions, where both elements of the complementary slackness condition equal zero in the optimum. As mentioned earlier, this implies that two or more crop activities are equally profitable.

Based on these two equations containing farmer $\tilde{j}$'s two non-zero activities we can determine the division of land between the two activities.

Finally, the economy-wide shadow price of water λ_2 and the farmer-specific shadow prices of land λ_{1j} are determined so that for $j \neq \tilde{j}$:

$$\frac{\partial L}{\partial X_{i^*jk^*}} = y_{i^*jk^*}P_{i^*} - z_{i^*jk^*}C_Z - \lambda_{1j} - \lambda_2(e_{i^*jk^*} + (1-\beta_j)(d_{i^*jk^*} - e_{i^*jk^*})) = 0$$

for exactly one crop and production technique (i* and k*) and for all other i and k:

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - \lambda_{1j} - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk})) < 0$$

while for $j = \tilde{j}$:

$$\frac{\partial L}{\partial X_{i^*\tilde{j}k^*}} = y_{i^*\tilde{j}k^*}P_{i^*} - z_{i^*\tilde{j}k^*}C_Z - \lambda_{1\tilde{j}} - \lambda_2(e_{i^*\tilde{j}k^*} + (1-\beta_{\tilde{j}})(d_{i^*\tilde{j}k^*} - e_{i^*\tilde{j}k^*})) = 0$$

$$\frac{\partial L}{\partial X_{i^{**}\tilde{j}k^{**}}} = y_{i^{**}\tilde{j}k^{**}}P_{i^{**}} - z_{i^{**}\tilde{j}k^{**}}C_Z - \lambda_{1\tilde{j}} - \lambda_2(e_{i^{**}\tilde{j}k^{**}} + (1-\beta_{\tilde{j}})(d_{i^{**}\tilde{j}k^{**}} - e_{i^{**}\tilde{j}k^{**}})) = 0$$

for exactly two combinations of crops and production techniques (i* and k* and i** and k**) while for all other i and k:

$$\frac{\partial L}{\partial X_{i\tilde{j}k}} = y_{i\tilde{j}k}P_i - z_{i\tilde{j}k}C_Z - \lambda_{1\tilde{j}} - \lambda_2(e_{i\tilde{j}k} + (1-\beta_{\tilde{j}})(d_{i\tilde{j}k} - e_{i\tilde{j}k})) < 0$$

APPENDIX B – SOLVING THE FARMER'S PROBLEM

The farmer's problem and the associated first order Kuhn-Tucker conditions are presented in section 3. The version of the farmer's problem, which will be solved explicitly in this appendix, is the one in which water applied is taxed and recoverable return flows are credited. However, the cases of a single tax on water diversions or crop-specific taxes on either land or output may be solved using the same approach.

Summarizing from section 3.1, the farmer's problem in the case of taxing water applied and crediting recoverable return flows is specified as:

$$\max_{X_{ijk}} \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z)X_{ijk} - T_D\sum_{i=1}^{I}\sum_{k=1}^{K}d_{ijk}X_{ijk} + T_R\sum_{i=1}^{I}\sum_{k=1}^{K}\beta_j(d_{ijk} - e_{ijk})X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0 \qquad \text{for all } i = 1,...,I \text{ and } k = 1,...,K,$$

$$\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} = \overline{X}_j$$

As outlined in section 3.1 the Lagrange function for this optimization problem is given by:

$$L = \sum_{i=1}^{I}\sum_{k=1}^{K}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R)X_{ijk} - \lambda_{1j}[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$

The corresponding first order conditions for the farmer's problem are:

$$X_{ijk} \geq 0$$

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j} \leq 0$$

$$X_{ijk}\frac{\partial L}{\partial X_{ijk}} = X_{ijk}(y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j}) = 0$$

$$\text{for all } i = 1,...,I \text{ and } k = 1,...,K,$$

$$\frac{\partial L}{\partial \lambda_{1j}} = -[\sum_{i=1}^{I}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] = 0$$

As the model is completely linear and there is only one binding constraint, the solution can contain at most one non-zero activity.[36] As the land constraint is assumed to bind, this implies that farmer j will produce at least one crop. Together these two features ensure that each farmer has at least one positive activity level. Letting i* and k* denote the non-zero activity for farmer j we get:

$$X_{i^*jk^*} = \overline{X}_j \quad \text{and} \quad X_{ijk} = 0 \quad \text{for all } i \neq i^* \text{ and } k \neq k^*$$

For farmer j the choice of crop and production technique i* and k* is determined through the farmer-specific shadow price of land λ_{1j}, which in turn is determined so that for exactly one crop and production technique (i* and k*):

$$\frac{\partial L}{\partial X_{i^*jk^*}} = y_{i^*jk^*}P_{i^*} - z_{i^*jk^*}C_Z - d_{i^*jk^*}T_D + \beta_j(d_{i^*jk^*} - e_{i^*jk^*})T_R - \lambda_{1j} = 0$$

while for all other i and k: [37]

$$\frac{\partial L}{\partial X_{ijk}} = y_{ijk}P_i - z_{ijk}C_Z - d_{ijk}T_D + \beta_j(d_{ijk} - e_{ijk})T_R - \lambda_{1j} < 0$$

Comparing these results to those for the social planner in the case where the water constraint is binding, we see that the latter case entails the possibility of J+1 non-zero production activities, whereas the former case only seems to imply J non-zero production activities (i.e. one non-zero production activity for each of the J farmers). This apparent inconsistency is resolved by noting that the binding national water constraint is imposed on the farmers as the optimal tax rates are determined based on the social planner's shadow price of water consumed or lost. When the tax rates are determined according to this optimality rule, there will be one farmer, who may have two non-zero crop activities, despite the fact that he only faces one binding constraint according to the specification of the farmer's problem.

[36] However, when the social planner's water constraint is binding there is a further restriction on the tax rates, which implies that one farmer may in fact be producing two crops. This issue is discussed further at the end of the section.
[37] Degeneracy, where both elements of the complementary slackness condition equal zero in the optimum, is also a possibility in this case.

CHAPTER 4

THE POLICY IMPLICATIONS OF USING WATER MORE THAN ONCE IN EGYPT.[♣]

1. INTRODUCTION

The theoretical analysis presented in chapter 3 was aimed at uncovering the efficiency properties of different water policy instruments in a situation characterized by the simultaneous presence of two types of externalities – the externality related to the allocation of water diversions between different irrigators and the externality related to the recoverability of return flows from irrigation. The theoretical analysis identified one type of policy scheme, which was capable of achieving a first-best allocation of resources in the presence of the two externalities, as well as three types of second-best policy schemes. However, it was not possible to rank the three types of second-best policy schemes as their relative ranking would depend on water use parameter values. Determining the ranking of the second-best instruments is important, as the first-best instrument is generally not implementable in a real-world setting.

In order to further analyze the relative efficiency properties of the policy instruments as well as illustrate the implications of the different policy instruments on crop production patterns, the model is implemented empirically. This is done using a non-linear programming model, based on Egyptian crop production data for 1997.[1] The simulations will demonstrate the efficiency and production implications of the different policy instruments in a scenario where irrigation water becomes scarce due to increases in the amount of agricultural land in Egypt. The model is implemented in GAMS. The set-up of the non-linear programming model is presented in section 2, while the data for the simulations is presented in section 3. The main results of the simulation are presented in section 4. Section 5 elaborates on the results through sensitivity analysis and discussion of the robustness of the results, while section 6 concludes.

2. EMPIRICAL MODEL SET-UP

The theoretical analysis in chapter 3 was based on a comparison between the social planner's problem, which featured the national water constraint, and the farmer's problem, which

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♣ The analysis in the present chapter is the result of joint work with Philip Abbott.

[1] The choice of a non-linear model instead of a linear model for the empirical implementation will be further elaborated in section 2.

included the various tax policy instruments that the social planner could use to ensure that the national water constraint would not be violated. By comparing the first-order conditions for these two problems, the optimal tax rate for the different tax policy instruments could subsequently be determined as a function of the social planner's shadow price of water. The externality problem related to allocation of water diversions was incorporated into the theoretical model by not pricing irrigation water in the farmer's problem, except through the introduction of taxes. The externality problem related to recoverable return flows entered the model through the social planner's problem, as the national water constraint was specified in terms of water consumed and non-recoverable return flows rather than in terms of water applied to the field.

The empirical implementation follows the structure of the theoretical model closely. First the social planner's problem is solved in order to determine the optimal cropping pattern and the extent to which the water constraint is binding for the given scenario. Second the farmer's problem is solved for the various policy instruments, with the taxes set at the level which results in the same amount of water being consumed or lost as in the social planner's problem. However, where the theoretical model referred to individual farmers, the empirical model is specified in terms of farmer types and number of farmers of a given type. Farmer type is subsequently equated with the regional location of the farmer, so that each region in the data represents one type of farmer. Specifying the empirical model in terms of farmer types rather than individual farmers has been necessary, as it has not been possible to obtain farmer-specific data.

2.1 THE SOCIAL PLANNER'S PROBLEM

The social planner's problem is formulated in terms of maximization of net social welfare, defined as revenue from crop production minus costs of purchased inputs, subject to farmer-specific summer and winter land constraints as well as the national annual water constraint. Mathematically the social planner's problem is stated as:

$$\max \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K}[P_i y_{ijk} - (C0_{ijk} + dC_{ijk}(X_{ijk} - X0_{ijk}))]N_j X_{ijk}$$

subject to:

$$X_{ijk} \geq 0$$

$$\sum_{i\in IS}\sum_{k=1}^{K} X_{ijk} + \sum_{i\in IP}\sum_{k=1}^{K} X_{ijk} \le \overline{X}_j$$

$$\sum_{i\in IW}\sum_{k=1}^{K} X_{ijk} + \sum_{i\in IP}\sum_{k=1}^{K} X_{ijk} \le \overline{X}_j$$

$$\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K}[e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk})]N_j X_{ijk} \le \overline{W}$$

Where:

- i: Index of crops. $i = 1,...,I$. The set of crops is divided into subsets according to the seasonality of the crop: IS is the set of summer crops, IW is the set of winter crops, and IP is the set of perennial crops.
- j: Index of farmer types, which captures the farmer-type-specific characteristics of soil type and irrigation technology (e.g. surface irrigation, sprinkler irrigation, or drip irrigation). $j = 1,..., J$
- k: Index of water-yield production techniques, which captures the different possible combinations of actual crop water consumption and realized crop yields. $k = 1,..., K$

- X_{ijk}: Size of area cultivated with crop i by a farmer of type j using production technique k. X_{ijk} is measured in million feddan.[2]
- $X0_{ijk}$: Size of area initially cultivated with crop i by a farmer of type j using production technique k.
- $\overline{X}_j$: Total amount of land available to a farmer of type j.
- N_j: Number of farmers of type j
- $\overline{W}$: Total amount of water, which is available for crop water consumption or irretrievable loss, measured in million cubic meters.
- P_i: Price of crop i, measured in LE/ton.[3]
- $C0_{ijk}$: Initial cost of purchased inputs per area unit for production of crop i by a farmer of type j using production technique k. $C0_{ijk}$ is measured in LE/feddan.

[2] As outlined earlier, feddan is the Egyptian measure of area size, corresponding to 0.420 hectares.
[3] LE is the abbreviation of Egyptian pounds.

- dC_{ijk} : Change in costs of purchased inputs per area unit for production of crop i by a farmer of type j using production technique k

- y_{ijk} : Yield of crop i per area unit for a farmer of type j using production technology k. y_{ijk} is measured in ton/feddan.
- e_{ijk} : Amount of water evapotranspired per area unit by crop i produced by a farmer of type j using production technique k. e_{ijk} is measured in cubic meters/feddan.
- d_{ijk} : Amount of water applied per area unit for production of crop i by a farmer of type j using production technique k. d_{ijk} 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: $d_{ijk} = \frac{1}{\alpha_{ijk}} e_{ijk}$
- α_{ijk} : Field irrigation efficiency for crop i produced by a farmer of type j using production technique k. α_{ijk} is measured as the share of water applied, which is consumed by the crops. $0 \leq \alpha_{ijk} \leq 1$
- β_j : Fraction of return flows produced by a farmer of type j, which are recovered within the river basin system. $0 \leq \beta_j \leq 1$

Comparing this formulation of the social planner's problem with the formulation of the social planner's problem in chapter 3, there are many similarities but also some differences. The social planner's objective is thus still to maximize producer surplus, subject to individual farmer land constraints and the national water constraint, but the costs are assumed to be non-linear in the empirical model. The reason for making the cost term non-linear for the empirical simulations is to avoid the over-specialized cropping pattern solutions, which a completely linear model produces. Section 2.3 will elaborate further on the specification of the cost terms. For now it suffices to note that the costs of purchased inputs per area unit (i.e. the average costs) are given as:

$$C_{ijk} = C0_{ijk} + dC_{ijk}(X_{ijk} - X0_{ijk})$$

where C_{ijk} is the cost of purchased inputs per area unit for a farmer of type j producing crop i using production technique k.

The non-linear element in the specification of average costs arises because average cost for a given farmer type is assumed to depend on the amount of land devoted to cultivation of the crop in question. As section 2.3 will show, each farmer type's initial average costs are benchmarked to the initial cropping pattern, and any subsequent changes in the farmer type's cropping pattern are assumed to affect average costs. Average costs will thus increase if a farmer allocates a larger amount of land to the production of the given crop compared to his initial cropping pattern, while they will decrease if he allocates a smaller amount of land to the production of the crop in question. The non-linear cost function consequently exhibits diminishing returns and the supply function will therefore be upward sloping. The use of non-linear cost functions to avoid the over-specialized cropping patterns produced by completely linear models is well-known in the literature. In his 1995 article, Howitt thus focuses on how the introduction of a non-linear yield or a non-linear cost specification can be used to counter the over-specialization problem (Howitt 1995). In her study of means to improve water allocation in Egypt, He (2004) uses an agricultural sector model with a quadratic cost function.

The land constraints in the social planner's problem are specified for individual farmers of a given type,[4] which is comparable to the specification of the land constraints in the theoretical model. However, in the empirical model it is necessary to include the seasonal dimension of land. The land constraint is consequently specified in terms of a summer land constraint and a winter land constraint. Each of these constraints states that the amount of land devoted by the individual farmer to cultivation of the season's crops and the perennial crops must not exceed the amount of land available to this farmer.

While the land constraint in the theoretical model was specified as being binding at all times in order to simplify the analytical exposition, the land constraint in the empirical model is allowed to be non-binding. Assuming the land constraint to be binding at all times did not make a difference for the results from the theoretical model. However, such an assumption could affect the results from an empirical simulation model, as there is no guarantee that the land constraint will remain binding if the model is subjected to a large shock to the land or water endowment. The assumption of a binding land constraint is consequently relaxed in the

[4] X_{ijk} is thus the amount of land devoted by a single farmer of type j to the cultivation of crop i using production technique k. $N_j X_{ijk}$, on the other hand, is the total amount of land devoted to production of crop i by farmers of type j using production technique k.

empirical model in order to assure that the model is sufficiently flexible to adequately handle large shocks.

2.2 THE FARMER'S PROBLEM

The transition from solving the social planner's problem to solving the farmer's problem is accomplished by relaxing the national water constraint and instead introducing the policy instruments, which can be set to ensure that the national water constraint is not violated. The farmer's problem is formulated in terms of maximizing profits after taxes, defined as revenue from crop production minus costs of purchased inputs and any tax payments, subject to his summer and winter land constraints and any quotas on e.g. water. Mathematically the farmer's problem is stated as:

$$\max \sum_{j=1}^{J} N_j \sum_{i=1}^{I} \sum_{k=1}^{K} [(P_i - T_{Oi}) y_{ijk} - (C0_{ijk} + dC_{ijk}(X_{ijk} - X0_{ijk})) - T_{Li} - T_D d_{ijk} + T_R \beta_j (d_{ijk} - e_{ijk})] X_{ijk}$$

Subject to:

$$X_{ijk} \geq 0$$

$$\sum_{i \in IS} \sum_{k=1}^{K} X_{ijk} + \sum_{i \in IP} \sum_{k=1}^{K} X_{ijk} \leq \overline{X}_j$$

$$\sum_{i \in IW} \sum_{k=1}^{K} X_{ijk} + \sum_{i \in IP} \sum_{k=1}^{K} X_{ijk} \leq \overline{X}_j$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} d_{ijk} X_{ijk} \leq \overline{D}_j$$

Where:

- T_{Oi} : Crop-specific output tax, measured in LE/ton.
- T_{Li} : Crop-specific land tax, measured in LE/feddan.
- T_D : Tax on water applied, measured in LE/cubic meter.
- T_R : Credit for recoverable return flows, measured in LE/cubic meter.
- $\overline{D}_j$: Quota on the amount of water that a farmer of type j can apply to his fields, measured in million cubic meters.

Comparing this formulation of the farmer's problem with the different formulations of the farmer's problem in chapter 3, they are quite similar. The present specification has simply merged all the different versions of the farmer's problem into one by including both the water tax and credit instruments, the crop-specific land taxes, the crop-specific output taxes, and the quotas on water applied in one single model.[5] This is merely a practical matter, as each policy instrument is still activated in turn by either setting a positive tax or credit rate or by making the quota binding.

The one aspect, in which the present formulation of the farmer's problem appears to differ from the formulation in chapter 3, is the fact the objective in the present formulation is to maximize the sum of all farmers' profits rather than simply maximizing the individual farmer's profit. However, given the specification of the resource constraints, maximizing the sum of all farmers' profits is in fact identical to the approach of maximizing each individual farmer's profit in the theoretical model. The reason for this is that since farmers are still not allowed to trade land (even though their individual land constraints are no longer required to bind), the only interaction between the different farmers' problems is through the national water constraint. However, when solving the farmer's problem empirically, the binding national water constraint is replaced by one of the water policy instruments, which is set to ensure that the national water constraint is not violated. As the policy instruments address the externalities, which the farmers could inflict on each other in a situation with water scarcity, there are no remaining interactions between the farmers' problems. Maximizing the sum of the farmers' profits is therefore identical to maximizing each individual farmer's problem. All in all, the specification of the farmer's problem in the empirical model thus corresponds closely to the farmer's problem in the theoretical model, except for the non-linear cost specification, which will be explored in the following section.

2.3 BENCHMARKING OF COST PARAMETERS

As noted above, the average costs of purchased inputs are defined as:

$$C_{ijk} = C0_{ijk} + dC_{ijk}(X_{ijk} - X0_{ijk})$$

This expression for the average costs consists of two components – the initial average cost and the change in average costs. As the present section will show, the parameter dC_{ijk} corresponds with a value for the supply elasticity for crop i, and the parameter $C0_{ijk}$ can

[5] The empirical analysis only considers the quota on water applied and not the crop-specific land quotas and the crop-specific output quotas, as the theoretical analysis has addressed the degree of equivalence between the quota instruments and the corresponding taxes sufficiently.

subsequently be determined so as to ensure that the first order conditions are met at the initial land allocation.

The expression for the supply elasticity is derived from the first order conditions for the social planner's maximization problem. While the first order conditions are derived for the social planner's problem in general, the cost parameters are benchmarked under the assumption that the national water constraint is not binding for the initial cropping pattern. As outlined in chapter 2, the national water constraint was not binding in Egypt in 1997, which is the base year for the simulations.

The Lagrange function for the social planner's optimization problem is given as:[6]

$$L = \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K}(P_i y_{ijk} - C0_{ijk} - dC_{ijk}(X_{ijk} - X0_{ijk}))N_j X_{ijk} - \sum_{j=1}^{J}\lambda_{1Sj}N_j[\sum_{i\in IS}\sum_{k=1}^{K}X_{ijk} + \sum_{i\in IP}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j]$$
$$-\sum_{j=1}^{J}\lambda_{1Wj}N_j[\sum_{i\in WS}\sum_{k=1}^{K}X_{ijk} + \sum_{i\in IP}\sum_{k=1}^{K}X_{ijk} - \overline{X}_j] - \lambda_2[\sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{k=1}^{K}(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))N_j X_{ijk} - \overline{W}_j]$$

Because of the seasonal land constraints, the first order conditions for the Lagrange function with respect to X_{ijk} have to be derived specifically for summer, winter, and perennial crops. Focusing on the case where $X_{ijk} > 0$,[7] the first order conditions for summer crops ($i \in IS$), winter crops ($i \in IW$), and perennial crops ($i \in IP$) are given as:

$$\frac{\partial L}{\partial X_{ijk}} = (P_i y_{ijk} - C0_{ijk} - 2dC_{ijk}X_{ijk} + dC_{ijk}X0_{ijk})N_j - \lambda_{1Sj}N_j - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))N_j = 0$$
$$\frac{\partial L}{\partial X_{ijk}} = (P_i y_{ijk} - C0_{ijk} - 2dC_{ijk}X_{ijk} + dC_{ijk}X0_{ijk})N_j - \lambda_{1Wj}N_j - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))N_j = 0$$
$$\frac{\partial L}{\partial X_{ijk}} = (P_i y_{ijk} - C0_{ijk} - 2dC_{ijk}X_{ijk} + dC_{ijk}X0_{ijk})N_j - (\lambda_{1Sj} + \lambda_{1Wj})N_j - \lambda_2(e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))N_j = 0$$

Where:

- λ_{1Sj}: Summer land rents (or shadow price) for farmer type j.
- λ_{1Wj}: Winter land rents for farmer type j.
- λ_2 : Rent of water consumed or lost.

[6] When the national water constraint is non-binding, the social planner's problem and the individual farmers' problems actually become identical, as the taxes in the latter can be set to zero and water quotas can be non-binding without the national water constraint being violated.

[7] While $X_{ijk} = 0$ would be a frequent occurrence in the completely linear model, this is much less likely to occur in the present non-linear model.

Solving each of the first order conditions for summer crops, winter crops, and perennial crop with respect to X_{ijk} yields:

$$X_{ijk} = \frac{1}{2dC_{ijk}}[(P_i y_{ijk} - C0_{ijk} + dC_{ijk} X0_{ijk}) - \lambda_{1Sj} - \lambda_2 (e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))]$$

$$X_{ijk} = \frac{1}{2dC_{ijk}}[(P_i y_{ijk} - C0_{ijk} + dC_{ijk} X0_{ijk}) - \lambda_{1Wj} - \lambda_2 (e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))]$$

$$X_{ijk} = \frac{1}{2dC_{ijk}}[(P_i y_{ijk} - C0_{ijk} + dC_{ijk} X0_{ijk}) - (\lambda_{1Sj} + \lambda_{1Wj}) - \lambda_2 (e_{ijk} + (1-\beta_j)(d_{ijk} - e_{ijk}))]$$

Based on these first order conditions, the supply elasticity for each crop is derived. Assuming that the shadow price of water as well as the land rents are constant (being determined by the other crops),[8] partial differentiation of each of the equations with respect to crop price yields:

$$\frac{\partial X_{ijk}}{\partial P_i} = \frac{1}{2dC_{ijk}} y_{ijk}$$

Extending this equation to obtain an expression for the own-price supply elasticity for crop i finally allows for expressing the change in average costs of purchased inputs as a function of the supply elasticity for the crop in question:[9]

$$\varepsilon_{ijk} = \frac{\partial X_{ijk}}{\partial P_i} \frac{P_i}{X_{ijk}} = \frac{1}{2dC_{ijk}} \frac{P_i y_{ijk}}{X_{ijk}}$$

$$\Leftrightarrow dC_{ijk} = \frac{1}{2\varepsilon_{ijk}} \frac{P_i y_{ijk}}{X_{ijk}}$$

Where:

- ε_{ijk}: The own-price supply elasticity for crop i produced by farmer type j using production technique k.

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[8] Basing the derivation of the supply elasticity expression only on the first order condition $\partial L / \partial X_{ijk} = 0$ and the assumption that land rents are constant is a simplification. However, in the present set-up, the change in land rents following a single price shock would be very small if all other prices are held constant.

[9] The own-price supply elasticity is here expressed in terms of land allocation rather than output. However, when yields are constant, these two elasticities are identical:

$$\varepsilon_{ijk} = \frac{\partial Q_{ijl}}{\partial P_i} \frac{P_i}{Q_{ijk}} = \frac{y_{ijk} \partial X_{ijk}}{\partial P_i} \frac{P_i}{X_{ijk} y} = \frac{\partial X_{ijk}}{\partial P_i} \frac{P_i}{X_{ijk}}$$

Based on this equation, the parameter dC can subsequently be benchmarked to the initial land allocation and the supply elasticity pertaining to this initial equilibrium. In the empirical model, the change in average costs of purchased inputs is thus determined as:

$$dC_{ijk} = \frac{1}{2\varepsilon_i} \frac{P_i y_{ijk}}{(X0_{ijk} + 0.0001)}$$

Comparing this equation with the equation above shows, that the supply elasticity in the empirical model is assumed merely to be crop-specific and hence not depend on farmer type or choice of production technique. This simplification is introduced because supply elasticity data typically would not be so disaggregated as to capture the farmer type or production technique dimension. Furthermore, in order to avoid potential division-by-zero problems in the numerical simulations, a small-but-positive term is added to the denominator. The equation for dC_{ijk} shows the change in average costs for a given crop is inversely related to the supply elasticity for this crop. The more elastic crop supply is, the less expensive it will consequently be for the farmer to increase the amount of land allocated to the crop.

Having determined the change in average costs for each crop, the initial average costs for each crop can subsequently be determined by evaluating the first order conditions at the initial land allocation and non-binding national water constraint (i.e. for $X_{ijk} = X0_{ijk}$ and $\lambda_2 = 0$). Solving the first order condition for each season's crops with respect to $C0_{ijk}$ thus yields:

For summer crops: $C0_{ijk} = P_i y_{ijk} - \lambda 0_{1Sj} - dC_{ijk} X0_{ijk}$

For winter crops: $C0_{ijk} = P_i y_{ijk} - \lambda 0_{1Wj} - dC_{ijk} X0_{ijk}$

For perennial crops: $C0_{ijk} = P_i y_{ijk} - (\lambda 0_{1Sj} + \lambda 0_{1Wj}) - dC_{ijk} X0_{ijk}$

Where:

- $\lambda 0_{1Sj}$: Initial summer land rents for farmer type j.
- $\lambda 0_{1Wj}$: Initial winter land rents for farmer type j.

3. DATA FOR EMPIRICAL MODEL

The basic data requirements for the empirical model comprise the following list of land and water parameters, crop prices, yields, and supply elasticities:[10]

- Initial cropping pattern
- Land endowment of each farmer type
- Number of farmers
- Initial land rents
- Crop evapotranspiration coefficients
- Recoverable fraction of return flows
- Field irrigation efficiency
- Water endowment of system
- Crop prices
- Crop yields
- Crop supply elasticities

The main source for the data have been a version of the so-called Agricultural Sector Model of Egypt (ASME), which is documented in Mohamed 2001, coupled with FAOSTAT core production data[11] and other FAO data. The base year for the data is 1997.

As the presentation of the model set-up demonstrated, the model variables and parameters each have up to three dimensions: crop type, farmer type, and type of water-yield production technology. For each dimension, important decisions have to be made regarding the degrees of aggregation and disaggregation. Before turning to the construction of the actual parameters, the aggregation choices will therefore be presented.

3.1 AGGREGATION OF DATA.

The data from the ASME model has a high degree of detail in the crop type dimension, as it includes 33 different crops. As the primary aim of the simulations in this chapter is to investigate the workings of the different policy instruments rather than making detailed predictions about a large number of crops, the model was made more manageable by reducing the number of crops from 33 to 13. The 13 crops are categorized according to whether they are primarily winter, summer, or perennial crops. This resulted in the following sets of crops:

[10] In addition to these data, solution of the farmer's problem also requires input on tax rates or quotas. However, as these parameters relate specifically to the policy experiments, they will BE addressed in section 4.
[11] http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340

- Winter crops: Wheat, legumes, long berseem, short berseem, winter vegetables, and other winter crops.
- Summer crops: Cotton, rice, maize/sorghum, summer vegetables, other summer crops.
- Perennial crops: Fruits, sugar cane.

These particular sets of crops were chosen to correspond with the set of crops in the International Food Policy Research Institute's (IFPRI) 1997 disaggregated SAM for Egypt, which is used for the CGE analysis in chapter 6. Comparing the sets of crops to the description of Egyptian agriculture in chapter 2, we see that they do indeed capture the main summer and winter crops.

The exact mapping used to aggregate the 33 ASME crops into the 13 IFPRI SAM crops is presented in appendix A. However, three of the aggregated crop types merit further comments. The first pertain to the water-intensive rice crops. The ASME data includes two types of rice – "normal" rice as well as a type of rice, which requires less water (i.e. has lower evapotranspiration than normal rice). As the irrigation-saving type of rice was supposedly not grown in the base year 1997, the lower water requirements of this type of rice is not included in the aggregated data on rice evapotranspiration rates. To the extent that the water-conserving type of rice could substitute for normal rice, the simulations in the present chapter would tend to overestimate the water requirement for rice.[12]

The second comment pertains to the sugar crops. Sugar cane is a highly water intensive crop, while sugar beet has a much lower water requirement. However, in the present aggregation sugar beet has been included in the crop category "other winter crops". To the extent that sugar beet can substitute for sugar cane, the present model will underestimate the possibilities for reducing the water input into sugar production.[13]

[12] Substituting water-conserving rice for normal rice may, however, not be straight forward. Data for 2001 thus suggests that the water-conserving rice had still not become part of the cropping pattern in Egypt.

[13] The issue of substitution between sugar cane and sugar beet has been explored in the Löfgren 1996 analysis "The Cost of Managing with Less: Cutting Water Subsidies and Supplies in Egypt's Agriculture". In the short run simulations, the size of the sugar cane area was kept fixed in this analysis. The long run simulations, on the other hand, allowed for changes in the size of the sugar cane area, which subsequently resulted in a major shift in production from sugar cane to sugar beet. However, according to Löfgren, this should not be taken as a prediction that sugar cane cultivation was going to disappear in Egypt within few years. Contrary to the model assumptions, government restrictions on the sugar cane area did in fact remain in place and the relative crop profitability was changing significantly in those years (Löfgren 1996)

The final comment on the aggregated crop types relates to the perennial crop category "fruit". Although Egypt produces a variety of perennial fruits like apples, peaches, and nectarines (cf. FAOSTAT core production data on area harvested in Egypt in 1997), the only perennial fruits included in the ASME data are apparently citrus fruits. The ASME data thus underestimates the amount of perennial fruit production in Egypt. However, due to lack of water data for non-citrus perennial fruit production in Egypt, the other types of fruit are not included in the data for the present analysis. The crop category fruit consequently only refers to citrus fruits in the present chapter.

Another aspect of the crop aggregation, which merits further comments, is the seasonal dimension. As outlined in chapter 2, Egypt is characterized by having three growing seasons – winter, summer, and nili – where the short nili growing season overlaps with the latter part of the longer summer growing season.[14] While all three growing seasons are reflected in the ASME crop data, the summer and nili season have been combined into one season in the present crop aggregation in order to simplify the model and maintain the same seasonal dimension as in the IFPRI SAM. This combination of the summer and nili seasons into one season does tend to blur the demarcation between the summer and winter season, since some of the nili crop production stretches into the earlier winter months in the ASME model. However, the types of crops grown in the nili season are a subset of the types of crops grown in the summer season. Given that the aim of the model is to analyze the workings of the policy instruments, the seasonal simplification seems reasonable.

The farmer type dimension of the model also requires decisions on the appropriate level of aggregation. For the present simulations, farmer types are defined according to regional location, as the ASME data is disaggregated across ten regions of Egypt. In the empirical analysis the so-called farmer-specific characteristics may thus vary across regions, while farmers within a given region are assumed to be identical.

The notion of defining farmer type by regions differs from the approach taken in the theoretical model, where the farmer-specific dimension referred to individual farmers. The

[14] According to FAO, the winter growing season lasts from November to May, while the summer season lasts from April/May to October and the Nili season runs from July/August to October (FAO 2005). According to the ASME data, on the other hand, winter is defined as covering the period from October to March, while summer and nili covers the period from April to September (Mohamed 2001 p A10). However, the ASME model also allows for adjustments in planting dates – from one month earlier to one month later – which may explain the slight differences in seasonal demarcations.

obvious consequence is that farmer-specific elements from the theoretical model are transferred into region-specific elements in the empirical model, while variations between farmers in the same region are ignored. However, switching from the individual farmer level to the regional level also implies that climatic factors enters the model more directly, as it is no longer reasonable to assume that the model is contained within one agro-climatic region. In the empirical model, evapotranspiration rates will consequently differ across regions due to climatic factors, which was not the case in the theoretical model.

The regional dimension in the ASME data features ten Egyptian regions – five Old Land regions and five New Land regions (although only two of the New Lands regions are registered as having land available for cultivation in 1997, while the other three shows land available for future reclamation). In order to highlight the role of the key water parameters field irrigation efficiency and return flow recoverability in the present policy, the ten ASME regions are aggregated into three regions – the Nile Valley and the Nile Delta (both Old Land regions) and one New Land region. Each of these regions has its own distinctive field-irrigation-efficiency / return-flow-recoverability profile. The exact details of the aggregation from ten regions in the ASME data to three regions in the current model are presented in appendix B. The profile of each of the three aggregate regions will be further discussed in the sections on land and water parameters.

The third dimension in the model is the so-called water-yield technique dimension, which captures the effect on yields of a reduction in water inputs for the production of a given crop. The theoretical model showed that this is an important dimension of the model, because the different water policy instruments are not equally well equipped at handling the choice of water-yield technique. However, it has unfortunately not been possible to obtain the necessary data to implement different water-yield techniques in the empirical model. The problem arises because a reduction in the amount of water used for producing a given crop may also affect the use of purchased fertilizer inputs. According to Kirda (2003), deficit irrigation practices may thus require modification of various agronomic practices including application of less fertilizer. While the ASME data set does contain some data on the link between crop yields and water stress, fertilizer application levels are apparently not graduated by water input. It is consequently not possible to determine how much fertilizer inputs should be reduced when water inputs are reduced. Ignoring the water-fertilizer link would result in costs of purchased inputs being unaffected by reductions in water inputs, which may in turn underestimate the profitability of the deficit-irrigation production techniques.[15] The only water-yield technique included in the present set of simulations is consequently that of optimal water application and maximum yield.

3.2 LAND PARAMETERS.

While the previous sub-section detailed the aggregation issues connected with the different dimensions of the model, the following three sub-sections will document the data work undertaken for the individual model parameters, starting in this sub-section with the land parameters.

The initial cropping pattern is one of the key parameters, as it is not only central to benchmarking of the costs of purchased inputs but is also the parameter, which is used for weighted aggregation of many of the other parameters. The starting point for constructing the initial regional-cropping pattern is the actual national cropping pattern in 1997, as outlined in the ASME data (cf. Mohamed 2001 p A63-A64). The national cropping pattern is subsequently distributed across the ten ASME regions according to relative land availability in each region, as well as certain constraints on crop production in certain regions. The regional cropping pattern is first constructed for the ASME regional disaggregation (with ten regions) and the ASME crop disaggregation (with 33 crops), before the aggregation to three regions and 13 crops is performed. The distribution of national crop production across regions according to regional land availability implies that no crop production was assigned to the three New Land regions, which are listed as not having land available for crop production in 1997.

The constraints on crop production in the various regions in Egypt are derived from the ASME mapping of crops to regions as well as from the ASME policy restrictions on key crops (cf. Mohamed 2001 p A8 and A67). The ASME mapping of crops to regions shows which crops are grown in the different regions of Egypt. The regional cropping patterns are incorporated in the initial cropping pattern for the present empirical model, which implies that cotton crops, sorghum crops, short berseem, rice, sugar cane, flax, sugar beet, summer onions, and lentils are not grown in one or more of the ASME regions (cf. appendix C). In addition to

[15] Fertilizer use may, of course, be unaffected by water deficits, if the farmer did not know about the water deficit at the time of fertilizer application. However, in this case deficit-irrigation would occur by accident rather than as a result of optimizing crop management, and it could consequently not be considered a solution from the farmer’s problem.

this, the policy restrictions from the ASME model on which regions can grow rice and sugar cane are also adopted (cf. appendix C). This implies further restrictions on the regional cropping patterns for these crops. Apart from the regional restrictions on crop production, the initial regional cropping pattern is also constructed so as to ensure that the amount of summer land devoted to production of the perennial crops (i.e. sugar cane and fruit) equals the amount of winter land devoted to the production of these crops.

Once the initial 1997 regional cropping pattern has been constructed for the ten ASME regions and 33 ASME crops, it is subsequently aggregated to the 3-regions / 13-crops aggregation used in the present empirical model. The resulting initial cropping pattern is presented in appendix D. The main characteristics of the initial cropping pattern are:

- Sugar cane is not grown in Delta and New Lands
- Rice is not grown in the Nile Valley
- Short berseem is not grown in the New Lands

The other land parameter required for the empirical model is the land endowment of each farmer type. As detailed above, farmer type is defined in terms of regions. The total land endowment of each farmer type would thus in principle correspond to the regional land endowment. However, comparing the national cropping pattern with the regional land endowments shows that the total amount of land farmed in each season is smaller than the sum of the regional land endowments. The cropping intensity in 1997 was thus "only" 177%, implying that some of the available land was not fully utilized in each season. Given the fact that cultivable land is generally in short supply in Egypt, this apparent "under-utilization" of land is most likely the result of various agronomic constraints not captured in the model. In order to avoid portraying the land constraint as non-binding, the land endowment of each farmer type is therefore set equal to the amount of regional land farmed in each season. The amount of regional land farmed in each season has been determined by distributing the national cropping pattern across the regions according to the relative land endowment of the region, resulting in the following distribution of farmed land:[16]

- Nile Valley: 2.06 mill feddan
- Delta: 3.40 mill feddan

[16] The total amount of land farmed in each season in 1997 was thus 6.52 mill feddan. As the total amount of cultivable land was 7.38 mill feddan – 2.33 mill feddan in the Nile Valley, 3.85 mill feddan in the Delta, and 1.20 mill in the New Lands - this results in the cropping intensity of: (6,52 + 6,52) / 7,38 * 100 = 177%.

- New Lands: 1.06 mill feddan

Comparing the sum of these amounts of land farmed in each region with the sum of land farmed in each season according to the initial cropping pattern shows that the former is marginally higher than the latter. “Rounding up” the amount of land farmed in each region has been necessary, partly because the initial cropping pattern showed that slightly more land was cultivated during the winter season than during summer, and partly to ensure that the initial cropping pattern would not inadvertently be rendered infeasible due to rounding off.

The model also requires data on the number of farmers of each farmer type, which in the present model corresponds to the number of farmers in each region. This parameter is merely required to allow for increasing the amount of land in a region without automatically increasing average costs in this region.[17] The initial number of farmers in each region is consequently set equal to one. In the policy simulations the amount of land in the New Land region is subsequently increased by raising the number of farmer’s in this region.

The final land related parameter, required by the model, is the initial land rents. Data on land rents is also taken from the ASME data set, which specifies land rents by crops and regions (cf. Mohamed 2001 p A48-A49). In the present empirical model, land rents are allowed to vary across regions and across seasons, but within a given region and season they are assumed to be identical across crops. The reason for the latter assumption is that while the ASME data does show variation in land rents across crops, the present model does not capture the agronomic constraints, which would explain these variations.[18] The land rent data is aggregated to the required regional and seasonal dimensions, using the initial regional cropping pattern as weights for the aggregation. Land rents from perennial crops are allocated across seasons so as to not affect the ratio between summer and winter land rents.

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[17] The workings of the policy instruments are illustrated through simulations in which the amount of land in the New Land region is expanded in order to make the national water constraint bind. If the expansion of New Lands had been modeled by merely increasing the land endowment of the existing representative farmer in this region, average cost would automatically increase as the farmer would have to increase the amount of land cultivated with the different crops. This problem is avoided by instead increasing the number of farmers in the New Land region.

[18] Crop rotations are an important example of agronomic constraints, which can explain some of the variations in land rents across crops. One of the common crop rotations is the cultivation of short berseem in winter followed by cotton in summer. The land rent data shows that cotton has one of the highest land rents of the crops displayed, while short berseem produces one of the lowest land rents. However, averaging the land rents of cotton and short berseem results in an annual land rent, which is more in line with the land rents observed for other crops.

3.3 WATER PARAMETERS

The basis for calculating the amount of water consumed by the crops and the amount of water applied to the field are the crop evapotranspiration coefficients. These coefficients specify the amount of water required per area unit for crop evapotranspiration in a non-water-stressed environment.[19] The ASME data contains crop evapotranspiration coefficients for each crop in each region and these evapotranspiration coefficients are differentiated by planting date – one month early, normal planting date, or one month late. The crop evapotranspiration coefficients used in this paper reflect the crop evapotranspiration requirement for normal planting date. The evapotranspiration coefficients are aggregated to the 3 regions / 13 crops aggregation, using the initial regional cropping pattern as weights for the aggregation. As the national water constraint is specified in annual terms, it is not necessary to divide perennial crop evapotranspiration across the two seasons.[20]

The crop evapotranspiration coefficients are presented in appendix E. The table shows that summer crops tend to have higher crop water requirements than winter crops. The most water intensive winter crop is long berseem, while rice is the most water intensive summer crop in the Delta and New Lands. Sugar cane, which is assumed only to be grown in the Nile Valley, is also a highly water intensive crop. From a regional perspective, crop water requirements tend to be highest in the New Lands and lowest in the Delta.

Once the evapotranspiration coefficients have been calculated, the amount of water applied per area unit is determined by dividing the crop evapotranspiration coefficients by the field irrigation efficiency. As outlined in the previous chapters, the field irrigation efficiency parameter is determined by the irrigation technology and soil characteristics. In terms of irrigation technology, there is a clear distinction between the Old Land regions, which generally use surface irrigation techniques, and New Land regions, which are mandated to use either sprinkler or drip irrigation. From an irrigation technology point of view, New Land regions should thus have higher field irrigation efficiency than Old Land regions. However, soil types also differ between Old Lands and New Lands. While the Old Lands are

[19] In simulations with multiple water-yield production techniques there would also be a set of crop evapotranspiration coefficients for each water-stressed production technique.

[20] However, in order to ascertain how water intensive perennial crops are compared to the seasonal crops, it can be useful to distribute the annual perennial crop water requirement across seasons. This can be done following the approach of Robinson et al (2002), which entails that perennial crops are assumed to require 65% of their annual water needs during the summer season and 35% during the winter season.

characterized by clay and loam soils, the New Lands are characterized by sandy and calcareous soils, which tend to be more water permeable than clay and loam soil. From a soil type point of view, the New Lands would thus tend to have lower field irrigation efficiency than the Old Lands.

Given the opposing characteristics of irrigation technology and soil type in the Old and New Lands, the question is what the aggregate effect is on the field irrigation efficiency in these regions. The ASME data set contains regional data on the so-called "field irrigation efficiency factor" (cf. the second column of table 1). These data suggest that the highest field irrigation efficiency is found in the Delta, while the field irrigation efficiency is approximately the same for the Nile Valley and the New Land region.[21] Comparing these numbers from the ASME data set with the standard irrigation technology efficiencies, we see that the field irrigation efficiency in the New Lands is low compared to the standard technological efficiencies.[22] This feature can be explained by the highly water permeable soils in the New Lands. However, the ASME data also suggest that the field irrigation efficiency in the Old Lands is substantially higher than the standard efficiency values for flood irrigation. Possible explanations for this finding can be the clay soils in the Old Lands, the flat topography, and the (at times parsimonious) rotational deliveries of irrigation water (cf. personal correspondence with Ahmed Shawky Mohamed). Farmers' unofficial reuse of drainage water would also tend to increase the observed field irrigation efficiencies. Despite these factors the ASME field irrigation efficiency coefficients for the Delta region still appear to be quite high.

[21] The regional field irrigation efficiency coefficients from the ASME data set have been aggregated to the required 3 region aggregation using regional crop water consumption data. However, as three of the five ASME New Lands regions are not listed as having cultivable land in 1997, the characteristics of these regions are not reflected in the aggregated numbers for the New Lands region. As the field irrigation efficiency is lower than average in the three excluded regions, the aggregate numbers thus tends to overestimate the field irrigation efficiency of the New Lands marginally.

[22] Both sprinkler and drip irrigation is used in the New Lands, but drip irrigation is slightly more prevalent than sprinkler irrigation (Bader 2004 and FAO 2005). As the standard irrigation efficiency for drip technology and sprinkler technology is respectively 90% and 75%, the standard irrigation technology efficiency for the New Lands is estimated to be 85%.

TABLE 1: DIFFERENT MEASURES OF FIELD IRRIGATION EFFICIENCY

	Standard irrigation technology efficiency	ASME field efficiency of irrigation	ASME field efficiency of irrigation incl. conveyance and distribution efficiency
Nile Valley	0.6	0.75	0.56
Delta	0.6	0.85	0.68
New Lands	0.85	0.74	0.55

Source: Own calculations based on ASME data (Mohamed p 2001 p A40). The ASME measures of field irrigation efficiency have been aggregated to the required 3 region aggregation using regional crop water consumption data. The displayed numbers reflect the regional field irrigation efficiencies before making adjustments for the field irrigation efficiency of rice (see below).

In order to best capture the reality of irrigation efficiency in Egypt, the policy simulation are carried out using the ASME field efficiencies of irrigation in the second column of table 1. However, in order to be able to determine the amount of water available for agricultural production, it is necessary to take account of the fact that water is also lost in the course of conveying and distributing the irrigation water from the original source to the farmers' fields, and not all of these water losses are recoverable. The ASME data set contains information on the conveyance and distribution efficiency in the different regions of Egypt. Multiplying these conveyance and distribution efficiencies with the ASME field irrigation efficiencies shows the fraction of the total amount of water diverted for agriculture in a given region, which is ends up being consumed by the crops (cf. the third column of table 1). Once total crop water consumption has been determined based on the evapotranspiration coefficients, it is consequently possible to determine the total amount of water diverted for agriculture as well as the total amount of water, which is either consumed by the crop or irretrievably lost during either conveyance or irrigation. This information is used later in this section in order to determine the total amount of water available for irrigation. The irrigation efficiency coefficients used in the simulations in section 4, on the other hand, only include the field irrigation efficiency and not the conveyance and distribution efficiency. This is done in order to avoid making water applied include losses from the conveyance and distribution system. While this would not affect the analysis of crop-specific land and output taxes, it would affect the analysis of water applied taxes. In the Egyptian irrigation system, farmers are not responsible for the upkeep of the general irrigation water conveyance infrastructure.

Within a given region, the field irrigation efficiency coefficients are assumed to be identical across all crops except for rice. The reason for making the field irrigation coefficient crop-specific for rice is that traditional cultivation of rice implies the use of additional amounts of water for soaking the paddy fields. In order to capture the additional water needed for rice production within the present framework, the field irrigation efficiency for rice is set equal to 70% of the field irrigation efficiency coefficient for the other crops in that region. This assumption of lower irrigation efficiency for rice than for other crops especially influences water use in the Delta region, as the vast majority of Egyptian rice production takes place in this region.

The other key water parameter in the model is the recoverability of return flows, which also varies across regions. As outlined in the previous chapters, return flows from agriculture are composed of drainage water and deep percolation water. Water from the drains may be readily recovered, while percolation water flows are recoverable if they accumulate in aquifers from which they can be pumped at reasonable costs.

The recoverability of return flows varies widely across the different regions of Egypt. In the Nile Valley, all drainage water is returned to the Nile and percolation flows recharge aquifers of good quality from which the water can readily be retrieved. Percolation flows from much of the Delta also recharge such aquifers. Delta drainage water is either pumped back into the irrigation canals or pumped to the Northern Lakes or the sea (FAO 2005and Keller et al 1996). In the New Lands drainage water is not returned to the Nile system.[23]

The ASME data set contains information on which proportion of regional drainage "naturally" returns to the Nile, and which proportion leaves the system (either by going to sinks or the sea, cf. Mohamed 2001 p A78). According to these data, almost all drainage in the Nile Valley naturally returns to the Nile, while no drainage from the Delta or the New Lands naturally returns to the Nile. However, according to a later version of the ASME model, which has a higher degree of regional disaggregation, all drainage from the southern parts of the Eastern and Middle Delta returns to the Nile.[24] In this version of the ASME

[23] As outlined in chapter 2, the New Lands are mostly located outside the Nile's drainage basin. Hellegers and Perry consequently conclude that "any excess irrigation supplies in to these areas are lost to the system" (Hellegers and Perry 2004 p 64). However, it is not entirely clear from the literature whether it is possible to collect any drainage water for local reuse in these areas.

[24] Although the 1997 version of the ASME model does not list drainage from the Old Land Delta regions as returning "naturally" to the Nile, it does state that drainage reuse is possible in the Old Land Delta regions as well as in two New Land regions, which are located next to the Old Land Delta regions (cf. Mohamed 2001 p A8). The discrepancy between the two version of the ASME model with respect to Delta return flow recoverability may thus simply be due to a distinction in the 1997 version of the model between drainage water

model, the southern parts of the Delta account for 50% of total Delta land. Based on these ASME data, the regional return flow recoverability coefficients for the present simulations are set as shown in table 2. No distinction is made between the recoverability of drainage water and deep percolation flows, as the recoverability of percolation flows from the different regions of Egypt appears to follow that of drainage flow recoverability (cf. previous paragraph) and the model does not take account of ground water pumping costs.

TABLE 2: REGIONAL RETURN FLOW RECOVERABILITY COEFFICIENTS

	Nile Valley	Delta	New Lands
Return flow recoverability coefficient	0.95	0.50	0.00

Source: Own calculations based on Mohamed 2001 p A78 and later version of ASME model

The final water parameter required for the simulations is the water endowment of the system. However, before setting this parameter it is necessary to consider how aggregate water use in the model's initial cropping pattern compares to actual water use in 1997 captured by the Egyptian national water balance presented in table 3. Aggregate water use in the model's initial solution is computed using the ASME field efficiency of irrigation including conveyance and distribution efficiency in order to account for any non-recoverable water losses from the water conveyance and distribution system.

Starting with crop evapotranspiration, the initial cropping pattern, which was constructed in section 3.2, produces total crop evapotranspiration of 34 BCM. As the present model assumes full coverage of crop evapotranspiration needs (i.e. no water stress or deficit irrigation), it would tend to overestimate the true evapotranspiration produced by the initial cropping pattern. However, as outlined in section 3.1, the initial cropping pattern also underestimates the amount of perennial fruit production. In order to gain a true picture of the total evapotranspiration in Egypt, the evapotranspiration of these crops would have to be added to the evapotranspiration calculated here. In terms of return flows, the initial cropping pattern combined with the ASME field irrigation and conveyance / distribution efficiencies (including the adjustment for rice) produces a total of 27 BCM of return flows, of which 14 BCM are recoverable. According to this data the total amount of water diverted for agriculture is thus 34 + 27 = 61 BCM.

returning "naturally" to the system and drainage water being returned to the system through government or farmer intervention.

In order to compare these water use figures with the numbers from the national water balance discussed in chapter 2, the table detailing the national water balances for 1997 is repeated here. Comparing the water figures produced by the initial cropping pattern to those found in table 3 below, they initially appear to differ on several accounts. According to table 3, total crop evapotranspiration thus amounted to 41 BCM, while return flows from agriculture amounted to 20 BCM. However, some of this discrepancy may be explained by the observation that the national water balance does not explicitly account for New Land return flows going to sinks. If these flows to sinks are in fact counted as a part of evapotranspiration rather than as return flows, the discrepancy between the national water balance and the present model numbers would be reduced. According to table 3, the total amount of water diverted for agriculture in 1997 was 61 BCM, which is in line with the total water diversion produced by the model's initial cropping pattern.

TABLE 3: THE EGYPTIAN NATIONAL WATER BALANCE IN 1997

"Input" of water in Egyptian national water balance 1997	
Releases from the High Aswan Dam	55.5
Effective rainfall	1.00
Sea water intrusion	2.00
Total water inputs	58.5
"Output" of water in Egyptian national water balance 1997	
Agriculture (evapotranspiration)	40.82
Industry	0.45
Municipality	0.91
Navigation (fresh water to sea)	0.26
Drainage to sea	12.41
Fayoum drainage	0.65
Evapotranspiration in water ways	3.00
Total water outputs	58.5
Water flows related to agriculture in national water balance	
Water diverted for agriculture	60.73
Evapotranspiration from agriculture	40.82
Return flows from agriculture	19.91

Source: Adapted from diagram in Mohamed 2001 p 7

As outlined in chapter 3, the true water constraint of the system should be specified in terms of water evapotranspired and non-recoverable return flows, as these are the amounts of water which are "taken out" of the system. According to table 3, the total amount of water evapotranspired or lost (in the form of drainage to sea or sinks) amounted to almost 54 BCM in 1997,[25] while the present data (including conveyance and distribution efficiency) estimates the amount of water evapotranspired or lost from irrigation or conveyance to be 47 BCM. However, this discrepancy might be explained by the assumption in the present data that 50% of drainage flows in the Delta are in fact recoverable (as these recoverable return flows are estimated to be on the order of 6 BCM). The point is that although return flows are recoverable, they need not be recovered if the water constraint is not binding. As concluded in chapter 2, the national water constraint in Egypt was most likely not binding in 1997, which would explain why the full possibility for reusing drainage water in the Delta was not exploited.

The Egyptian national water balance thus suggests that almost 54 BCM was available for agricultural evapotranspiration or water losses in 1997. This will consequently be the overall water constraint for the agricultural sector.[26] However, as mentioned earlier, the non-recoverable losses from the conveyance and distribution system has to be subtracted from the overall water constraint for the agricultural sector in order to determine, how much water is actually available for irrigation at the field level. As the simulations in the present chapter will be based solely on the ASME field irrigation efficiency coefficients, it is the amount of water available for irrigation at the field level, which is the relevant water constraint. Subtracting the non-recoverable losses from the conveyance system from the 54 BCM of water available to agriculture yields a total of 47 BCM of water available for application to the fields. This will consequently be the national water constraint in the simulations.

3.4 Crop prices and yields and supply elasticities

Apart from the land and water parameters, the empirical model requires data for three other parameters, namely crop prices, crop yields, and crop supply elasticities.

[25] According to table 3, evaporation from agriculture amounted to 40.82 BCM, while drainage to sea and drainage from Fayoum (which is part of the Nile Valley region) amounted to 12.41BCM and 0.65 BCM respectively. Adding these numbers shows that the total amount of water evapotranspired or lost (in the form of drainage to sea or sinks) amounted to 53.88 BCM in 1997.

[26] Although the water constraint was not binding in terms of water quantities, it is not clear how large the water surplus actually was, if water quality is also taken into account (cf. chapter 2). However, the present version of the model is not equipped to adequately handle water quality issues. These issues consequently have to be disregarded in the present analysis. In an attempt to not significantly overestimate the water resources available for agriculture by disregarding the quality aspect, the actual and potential use of non-renewable ground water resources for irrigation in some of the New Land regions are not added to the total amount of water available for agriculture.

As the empirical model is concerned with farmer behavior, the prices in the model are producer prices. The ASME model does contain data on crop prices, but the price data pertains to final and processed crop commodities rather than primary crops. While FAOSTAT has data on Egyptian producer prices in 1997, the exact mapping from the FAOSTAT crop categories to the ASME crop categories is not clear for the more aggregate crop categories. This in turn makes it difficult to use FAOSTAT data for these crop categories. However, comparing the ASME data with the FAOSTAT data shows that the ASME prices on final goods generally do correspond to producer prices. For the aggregate crop categories, for which FAOSTAT producer prices cannot be reliably computed, the ASME price data is consequently used.

In the cases where the ASME price data does not appear to reflect producer prices, crop prices have been taken from other sources. In the case of sugar cane and sugar beet, producer prices are taken from the FAOSTAT core production data on producer prices, as the ASME prices refer to processed sugar. FAOSTAT producer prices are also used in stead of ASME prices in the case of tomatoes, as the tomato producer prices reported by FAOSTAT are lower than the final commodity prices for tomatoes reported in the ASME data set. In the case of cotton, the average farm-gate price for 1997 is taken from Nassar and Mansour (2003 p 146). As it has not been possible to find 1997 price data for short berseem and long berseem, producer prices for these two crops for 1996 are taken from a FAO publication on Egyptian agriculture (cf. FAO 2000). Finally in the case of flax, the price is taken from the ASME data set, but it only reflects the price of flax and not the price of flax seed, as it has not been possible to adequately integrate flax seed production in the data.[27] For all the cases where the same final crop commodity is produced in several different seasons, prices for these primary crops are assumed to be the same in all seasons. Crop prices are aggregated to the required 13 crop

[27] The problem arises, as the primary crop flax can be used for production of both flax and flax seed. When flax is produced for fiber production, it is generally harvested earlier than when it is produced for seed production (Wikipedia 2006). The ASME data does contain yield data for flax seed production, but no information on flax seed prices. The FAOSTAT data, on the other hand, does contain information on flax seed prices, but the information on the amount of land used for flax seed production is not compatible with the ASME data information on flax production. It has consequently not been possible to determine, which proportion of the flax area that is used for flax seed production. As flax is not one of the major crops in Egypt, the simplifying assumption has been made, that the entire area cultivated with flax is used for flax fiber production. Both prices and yields used for flax consequently pertain to flax fibers. According to the ASME cropping pattern, flax is only grown in the Delta region and parts of the Nile Valley (cf. appendix C).

aggregation using actual quantities produced in 1997.[28] The resulting set of prices is presented in appendix F.

The empirical model also requires crop yield data – preferably by region. Regionalized yield data is taken from the ASME model and aggregated to the 3 regions / 13 crops aggregation, using the initial cropping pattern. As was the case with the evapotranspiration coefficient, the ASME regional yields depend on planting date. Keeping with the assumption for the evapotranspiration coefficients, the regional yield data is adjusted to reflect normal planting date. For crops, which are not grown in one or more of the three regions according to the initial cropping pattern, yields are set equal to zero. This implies that yields are zero for rice in the Nile Valley, short berseem in the New Lands, and sugar cane in the Delta and New Lands. This approach is similar to that used in the ASME model, where the mapping of crops to regions is done through the yield data.[29] The resulting set of regional yields is presented in appendix G. Comparing crop yields across the different regions shows that yields tend to be highest in the Nile Valley and lowest in the New Lands.

The final parameter required by the empirical model is crop supply elasticities, which are used for calculating the changes in average costs when the cropping pattern changes. Unfortunately it has not been possible to find estimates of Egyptian crop supply elasticities in the literature.[30] It has consequently not been possible to make the supply elasticity crop-specific. For the present simulations a uniform elasticity of 15 is used, which implies that crop supply is highly elastic. The motivation for assuming that crop supply is very elastic is – in the absence of information on crop supply elasticities – to prevent an ad hoc assumption of inelastic crop supply from dominating the model by making changes in the cropping pattern very costly. The implications of setting the crop supply elasticity equal to 15 is further explored in section 5, which features a sensitivity analysis of the crop supply elasticity.

[28] The actual crop quantities produced in 1997 are calculated using data on the cropping pattern and the actual yields in 1997 (cf. Mohamed 2001 A63-A64).

[29] For sugar cane in the Delta and short berseem in the two New Lands regions, which had land available for cultivation in 1997, the ASME data consequently does not report any yields. With regard to rice in the Nile Valley and sugar cane in the New Lands regions, the ASME data does report yield data, but policy restrictions prevents these crops from being grown in these regions. As mentioned in section 3.2 both cropping pattern and crop policy restrictions are enforced for the initial cropping pattern, and through the yield data also for the subsequent simulations.

[30] One data set, which might be used to obtain estimates for Egyptian crop supply elasticities, is the so-called 1997 Egypt Integrated Household Survey. In a report on this survey by Abt Associates, it is stated that attempts to estimate crop supply elasticities have so far not been very successful due to a large extent “to the limited variation inherent in cross-sectional price data, and the fact that producer prices are simply not observed in a number of regions of Egypt…because of a lack of transactions” (Abt Associates 1999 p V).

4. SIMULATION DESIGN AND RESULTS

In order to analyze the workings of the different policy instruments in a situation characterized by the simultaneous presence of the water diversion externality and the recoverable return flow externality, simulations are run for each of the four tax policy instruments and the water quota instrument, and the outcomes of these policy simulations are compared with the outcome of the social planner's maximization problem.

4.1 SIMULATION DESIGN.

For both the water diversion and recoverable return flow externalities to be relevant from a social efficiency point of view, water has to be a scarce resource. While the national water constraint was not binding in the base year 1997, the Egyptian government's plan to increase the amount of agricultural land significantly by reclaiming desert land will require large amounts of water. The starting point for the present simulations is thus an increase in the total amount of land in the New Lands region, which results in the water constraint becoming binding.

According to the land supply data, the amount of land cultivated in the New Lands in 1997 amounted to 1.06 million feddan. As the total amount of cultivated land amounted to 6.52 million feddan, doubling the amount of cultivated land in the New Land region would entail a 16% increase in total amount of cultivated land, while tripling the amount of cultivated land in the New Land region would entail a 33% increase in the total amount of cultivated land. Comparing these numbers with the ambitious government land reclamation plans presented in chapter 2 suggests that a scenario of tripling the amount of cultivated land in the New Land regions would be in line with land reclamation plans.[31] However, simulations show that this would results in the land constraint in the New Lands becoming non-binding, due to water scarcity. As reclamation of desert land is quite costly, it would hardly seem logical to keep on reclaiming land once the land constraint had ceased to be binding. Furthermore, land reclamation has so far progressed at a slower pace than initially planned (Mohamed 2001). In the following simulations, the amount of cultivated land in the New Lands region will thus

[31] According to Ross Hagan (2002), the amount of irrigated land totaled 7.8 million feddan in 2000 and was planned to increase to 11.7 million feddan by 2017. The amount of land reclamation already underway or completed amounted to 2.4 million feddan. While these numbers differ slightly from those presented in chapter 2, they confirm that a scenario of expanding agricultural land by 2.12 million feddan would be in line with the land reclamation plans already underway.

“only” be doubled. This is done by increasing the number of farmers in the New Lands from one to two in order to ensure that the reclaimed New Land areas will have the same cost function as the existing New Land area. Doubling the amount of New Lands results in the national water constraint becoming binding, which in turn allows for analysis of how well the different policy instruments alleviate the water diversion and the recoverable return flow externalities.

As outlined in section 3, the ASME data contains five New Land regions, but only two of these regions are listed as having land available for cultivation in 1997. As the initial cropping pattern has been used directly or indirectly as weights for most of the weighted parameter aggregations, this implies that land, water, and yield parameters of the New Land region only represent the two regions, which had land available for cultivation in 1997. The question consequently arises to what extent the New Land region is representative for the other reclaimable lands in Egypt for such key variables as crop evapotranspiration, irrigation efficiency, and return flow recoverability.

The three ASME regions, which did not have land available for cultivation in 1997, are Sinai, Toshka (also known as the “New Valley” project), and the so-called “sandy soils with canal irrigation”. Comparing the evapotranspiration coefficients for these three regions with the coefficients for the two New Land regions, which did have land available for cultivation in 1997, shows a tendency for higher crop evapotranspiration coefficients in some of the three excluded regions, although this trend is not unambiguous. With respect to field irrigation efficiency, the three excluded regions tend to have lower field irrigation efficiency than the two included regions. On the other hand, the three excluded regions also tend to have higher conveyance and distribution efficiency than the two included regions. In terms of return flow recoverability, there is no difference between the included and the excluded New Land regions. All in all, the present simulation will thus tend to underestimate the crop water requirements of the real-world New Lands, both in terms of crop water consumption and water application, whereas return flow recoverability is captured adequately

Summing up, the general design of the simulations is to start from a situation characterized by the initial cropping pattern and the non-binding water constraint. The amount of land in the New Land region is subsequently doubled by increasing the number of New Land farmers from one to two. This increase in the amount of cultivated land results in the water constraint becoming binding. A number of simulations are subsequently run in order to demonstrate the efficiency and production implications of the different policy regimes. First the social planner's problem is solved subject to the individual farmer land constraints and the national water constraint in order to determine the socially optimal cropping pattern and the social shadow price of water. Second, the national water constraint is relaxed and the farmer's problem is solved for the various policy instruments subject to the individual land constraints. In these policy simulations taxes (or quotas) are set at the level, which results in the same amount of water being consumed or lost as in the social planner's problem. The five set of policy instruments to be analyzed are:

- Tax on water applied combined with credit on recoverable return flows
- Tax only on water applied
- Quotas on water applied
- Crop-specific land taxes
- Crop-specific output taxes

The model is implemented using the GAMS modeling software and the CONOPT solver. The results from the policy simulations will be presented in the following subsections, after the results from the social planner's problem.

4.2 Simulation results: The social planner's problem

The solution to the social planner's problem shows the socially optimal allocation of land and water for the given resource endowment. The solution to the social planner's problem following the enlargement of the New Land region is presented in table 4. The four columns on the left show the levels of the different variables, while the four columns on the right show the percentage change in these variables compared to the social optimum before doubling the amount of New Lands. [32]

The first section of table 4 shows the implications for social welfare of doubling the amount of New Land. Net social welfare, which is defined as the difference between revenue and the cost of purchased inputs, increases by 14.29%, when the amount of New Land is doubled. As

[32] The solution to the social planner's problem for the initial resource endowment is presented in appendix H. The solution to the social planner's problem for the initial resource endowment is not completely identical to the initial cropping pattern. This is due to the fact that the regional land endowment has been specified so as to not be strictly binding for the initial cropping pattern (cf. section 3.2). The solution to the social planner's problem for the initial regional land endowment thus entails a marginal increase in the production of all crops along with marginal declines in regional land rents.

doubling the amount of New Land corresponds to an increase in the total amount of land by 16.26%, welfare thus increases by less than the increase in land resources. This is primarily due to the fact that doubling the amount of land in the New Lands results in the water constraint becoming binding. The fact that the water constraint has become binding is indicated by the strictly positive shadow price for water under the heading resource rents.[33]

Farmer profits are defined as revenue minus the cost of purchased inputs and taxes. In this social optimum scenario, where the social planner is implicitly assumed to be able to enforce the optimal resource allocation without the use of policy instruments, farmer profits are naturally equal to social welfare.

The section on water use shows that the onset of water scarcity produces a reallocation of water from the Old Land regions to the expanded New Lands region, compared to the amount of water available in the Old Lands in the initial optimum (i.e. before the expansion of the New Lands). This in turn lowers the net social welfare generated in the Old Land regions by -0.38% in the Nile Valley and -0.85% in the Delta. The reduction in net social welfare is more pronounced in the Delta than in the Nile Valley, as the reduction in irrigation water for the Delta is larger than reduction in irrigation water for the Nile Valley. The amount of irrigation water consumed or lost is thus reduced by 8.68% for the Delta and only by 4.06% for the Nile Valley. The reduction in the amount of irrigation water allocated to the Delta is closely connected with the reduction in the region's highly water intensive rice production (cf. discussion below). The binding water constraint also affects net social welfare in the New Lands as this only increase by 96.71%, although the amount of land in this region increases by 100%.

[33] Even if the water constraint had not become binding, total welfare would not have increased as much as total land, as yields in the New Lands region are generally lower than yields in the other regions, with the notable exception of the yields for legumes (cf. appendix G).

TABLE 4: SIMULATION RESULTS FOR THE SOCIAL PLANNER'S PROBLEM (CONT'D ON NEXT PAGE)

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from initial optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1434	2428	1388	5250	-0.38%	-0.85%	96.71%	14.29%
Farmer profit (Revenue - Cost - Taxes)	1434	2428	1388	5250	-0.38%	-0.85%	96.71%	14.29%
Revenue	8874	14819	6994	30687	-1.69%	-1.00%	97.14%	11.41%
Cost of purchased inputs	7440	12391	5605	25437	-1.94%	-1.03%	97.25%	10.84%
Total taxes collected	0	0	0	0				
Tax on water applied	0	0	0	0				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	0	0	0	0				
					% Change from initial optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10568	17859	18573	47000	-4.06%	-8.68%	81.48%	15.18%
Quotas on water applied	100000	100000	200000	400000	0.00%	0.00%	100.00%	33.33%
Water applied	13860	20244	18573	52677	-4.06%	-10.06%	81.48%	11.63%
Recovered return flows	3292	2385	0	5677	-4.06%	-19.24%	0.00%	-11.08%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0245				% Change from initial optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	223	223	158		-20.26%	-16.13%	-40.33%	
Summer	203	212	163		-25.47%	-30.94%	-43.78%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from initial optimum Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	1.86%	-2.14%	100.80%	19.13%
Legumes	0.13	0.25	0.27	0.65	15.12%	7.03%	221.50%	51.18%
Long berseem	0.37	0.71	0.46	1.54	-13.95%	-16.72%	49.33%	-3.04%
Short berseem	0.36	0.57	0.00	0.93	34.52%	30.03%	0.00%	31.72%
Winter vegetables	0.12	0.24	0.20	0.57	3.34%	1.78%	135.40%	28.22%
Other winter crops	0.07	0.13	0.09	0.29	8.53%	3.79%	164.80%	29.37%
Cotton	0.22	0.64	0.11	0.97	-8.35%	11.83%	106.57%	12.19%
Rice	0.00	0.91	0.14	1.05	0.00%	-31.48%	-39.29%	-32.64%
Maize / sorghum	1.07	1.09	1.28	3.44	8.28%	30.26%	155.28%	47.85%
Summer vegetables	0.37	0.47	0.39	1.23	4.14%	15.23%	118.28%	30.72%
Other summer crops	0.07	0.11	0.09	0.27	-5.72%	24.59%	126.37%	32.47%
Fruits (citrus)	0.11	0.19	0.11	0.41	2.75%	7.83%	98.14%	20.82%
Sugar cane	0.22	0.00	0.00	0.22	-25.75%	0.00%	0.00%	-25.75%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from initial optimum Valley	Delta	NewLand	Total
Wheat	1.71	2.98	1.36	6.05	1.86%	-2.14%	100.80%	12.04%
Legumes	0.14	0.31	0.34	0.79	15.12%	7.03%	221.50%	51.84%
Long berseem	9.70	17.44	9.34	36.48	-13.95%	-16.72%	49.34%	-5.17%
Short berseem	4.51	5.60	0.00	10.11	34.52%	30.03%	0.00%	32.00%
Winter vegetables	1.52	2.12	1.77	5.41	3.34%	1.78%	135.40%	25.59%
Other winter crops	0.56	0.82	0.23	1.61	8.53%	3.79%	164.80%	15.65%
Cotton	0.24	0.64	0.07	0.95	-8.35%	11.83%	106.57%	9.67%
Rice	0.00	3.07	0.35	3.43	0.00%	-31.48%	-39.29%	-32.38%
Maize / sorghum	2.78	3.28	2.61	8.67	8.28%	30.26%	155.28%	41.97%
Summer vegetables	4.03	5.04	3.76	12.83	4.14%	15.23%	118.28%	28.75%
Other summer crops	0.07	0.09	0.07	0.23	-5.72%	24.59%	126.37%	28.19%
Fruits (citrus)	0.68	1.56	0.57	2.81	2.75%	7.83%	98.14%	17.33%
Sugar cane	9.90	0.00	0.00	9.90	-25.75%	0.00%	0.00%	-25.75%

The effect on water allocation of expanding the New Land region can be appreciated by considering the distribution of water consumed or lost across regions. Before the expansion of the New Lands, the Delta accounted for 48% of water consumed or lost, while the Nile Valley and the New Lands accounted for 27% and 25% respectively (cf. appendix H). After the expansion of the New Lands, the Delta accounts for 38% of water consumed or lost, while the Nile Valley and the New Lands account for 22% and 40% respectively. Some of the increase in New Land water consumption is covered by the water surplus in the system prior to the expansion of the New Lands. While a total of 47BCM of water was available for irrigation, the amount of water consumed or lost before the land expansion thus only amounted to 41 BCM, leaving a surplus 6 BCM of water (cf. appendix H). However, before the expansion more than 10 BCM of water was still consumed or lost in the New Lands. The water surplus in the initial optimum consequently only covers part of the water needed for the expanded New Lands region. The rest of the water thus has to be taken from the Old Lands.

The water use section clearly illustrates the difference in return flow recoverability across regions. In the Nile Valley return flows are virtually fully recoverable. As the field irrigation efficiency is constant across the set of crops grown in the Nile Valley, any reduction in the amount of water applied (-4.06%) translates into comparable reductions in the amount of water consumed or lost (-4.06%) and the amount of recoverable return flows from the Nile Valley (-4.06%).[34] In the New Lands, on the other hand, return flows are not recoverable at all. Any increase in the amount of water applied (81.48%) thus results in a comparable increase in the amount of water consumed or lost (81.48%), while the amount of recoverable return flows naturally stays unchanged (0%). When return flows are non-recoverable the change in the amount of water consumed or lost will always equal the change in the amount of water applied regardless of whether field irrigation efficiency differs across crops.

In the Delta, return flows are partially recoverable and field irrigation efficiency differs across crops, as the majority of the Egyptian rice production takes place in the Delta. Given the lower field irrigation efficiency for rice, rice produces a disproportionate amount of the return flows in the Delta. When rice production in the Delta declines substantially, as is the case in the present simulation (-31.48%), this consequently results in a larger reduction in the amount

[34] Note that water applied equals the sum of water consumed or lost plus recovered return flows.

of return flows and hence also in the amount of recoverable return flows (-19.24%) than in the amount of water applied (-10.06%) or the amount of water consumed or lost (-8.68%).

The final aspect to consider in the water use section is the quotas on water applied. This is one of the policy instruments, which can be used to regulate the farmer's use of irrigation water. As the social planner's problem does not include any policy instruments, the quotas are set so as to be non-binding. This will also be the case for all the versions of the farmer's problem, which uses tax policy instruments.

As water becomes scarce in the social planner's problem, winter and summer land rents drop in all three regions. Not surprisingly, the largest drop in both winter and summer land rents is to be found in the New Lands (-40.33% and 43.78% respectively), which tend to have the poorest crop yields and the highest crop water requirements of the three regions (cf. appendix E and G). For all regions it is the case that summer land rents are reduced more than winter land rents. This is not surprising given that summer crops tend to have higher water requirements than winter crops (cf. appendix E).

The changes to crop land allocation following the expansion of the New Lands clearly demonstrate how water scarcity affects the cropping pattern in the different regions of Egypt. In the absence of water scarcity, the expansion of New Lands would not have resulted in any changes to the cropping pattern in the Nile Valley and the Delta, whereas the land allocation should have gone up by 100% for all crops in the New Lands. However, the presence of a binding water constraint produces large reallocations in the cropping pattern of all regions. Not surprisingly, the general pattern shows a shift away from water intensive crops like rice, sugar cane, and long berseem, toward less water intensive crops like maize / sorghum, short berseem, and legumes.

In the Nile Valley, the most important crop in the initial winter land allocation is wheat, followed by long berseem, and sugar cane (cf. appendix H). Sugar cane and long berseem are water intensive crops. As water becomes scarce, winter land is consequently shifted away from these crops (by 25.75% and 13.94% respectively) into short berseem (which increases by 34.51%). The most important crop in the initial summer land allocation is maize / sorghum, which is a relatively less water intensive crop. The relative Nile Valley summer cropping pattern is consequently not that affected by the water constraint, except for the perennial crop sugar cane, which drops by 25.75%

The most important crop in the initial winter land allocation in the Delta is wheat followed by long berseem. As was the case in the Nile Valley, the onset of water scarcity induces a shift away from long berseem (which drops by 16.72%) towards short berseem (which increases by 30.02%). As for Delta summer land, the most important crop in the initial land allocation is rice, which accounts for almost 40% of Delta summer land. As rice has a high evapotranspiration coefficient and furthermore requires extra water for cultivation, rice production is highly affected by water scarcity and drops by 31.48%.[35] The land is instead used for production of maize / sorghum (which increases by 30.26%) and summer vegetables and cotton (which increases by 15.23% and 11.83% respectively).

In the New Lands, the binding water constraint also produces major changes to the cropping pattern. The most important winter crops in the initial New Lands cropping pattern are wheat and long berseem. As was the case in the Old Lands, the production of the water intensive long berseem crop drops relatively to the other winter crops, as the area with long berseem only increase by 49.32%, while the amount of winter land in the region increases by 100%. However, while the Old Lands saw a sharp increase in production of short berseem, this crop is not grown in the New Lands. Instead the New Lands see an even more pronounced increase in the production of legumes, which is the other non-water-intensive winter crop. Legume production in the New Lands thus increases by 221.24% compared to the 100% increase in the amount of New Land. While this may appear to be a dramatic increase, it should be noted that legumes only accounted for 8% of winter land in the initial New Land cropping pattern. Another one of the small winter crops, which also realizes a substantial increase following the expansion of the New Lands, is the category "other winter crops", which increases by 164.31%. However, while this category normally consists of flax, barley, and sugar beet, the

[35] While rice production in the Delta is treated like the production of any other crop in the model, there is in fact an extra benefit from rice cultivation in the Delta, as the percolating return flows from rice production counter the intrusion of sea water into the aquifer underlying the Delta. There is consequently an added social benefit to rice production in the Delta above and beyond production of the crop itself. In order to effectively prevent the intrusion of sea water into the aquifer, rice production in the Delta must equal at least 50% of rice production in the initial cropping pattern (cf. Mohamed 2001 p A68). However, in the current set of simulations rice production does not drop below 50% of the base case production. As there appear to be no extra social benefits to rice production, once the intrusion of sea water is kept in check, treating rice production like the production of any other crop seems reasonable for the current set of simulations. If rice production were to drop below 50% of the base year area, it would be necessary to introduce a lower bound for the rice area in the model.

cropping pattern in the New Land only includes barley and some sugar beet. There are consequently aggregation problems for this crop category, which implies that its results should not be attributed too much emphasis. Other winter crops only account for 3% of the land in the initial New Land cropping pattern.

The largest changes to the initial cropping pattern occur for summer land in the New Land region, as rice production not only declines relative to production of other crops, but in absolute terms by 39.27%. Rice was the second most important summer crop in the initial cropping pattern for the New Lands, accounting for 22% of the land, but after the expansion of the New Lands and the onset of water scarcity rice only accounts for 7% of summer land in the region. The reason for this major decline in rice production in the New Lands is that the extra water requirement for rice production (which was captured by the lower field irrigation efficiency coefficient) has a much larger impact in the New Lands than in the Delta, as return flows in the New Lands are not recoverable. The decline in New Lands' rice production is countered by an increase in New Lands maize / sorghum production.

The final aspect to consider about table 4 relates to the data on production and changes in production. Comparing the latter with the changes in land allocation shows, that changes in production and changes in land allocation are identical at the regional level. This should obviously also be the case, as the difference between land allocation and production are simply yields. However, as yields are regional and actually do differ substantially across regions (cf. appendix G), total changes to production differ from total changes in land allocation. This is most pronounced for other winter crops, wheat, and maize / sorghum, which are also crops for which yields differ noticeably across regions.[36] The changes in total production shows that the only crop sectors, which actually contract at the national level following the expansion of the New Lands, are rice, sugar cane, and long berseem (by 32.38%. 25.75% and 5.17% respectively). The crop sectors, which expand the most at the national level, are legumes, maize sorghum, and short berseem (by 51.84%, 41.97%, and 32.00% respectively).

Before turning to the policy simulations for the farmer's problem, it is instructive to take a look at the cost parameters and how the changes in average costs relate to the land allocation

[36] In the case of other winter crops, the differences in yields across regions are partly due to the compositional effects of the initial cropping pattern mentioned earlier.

and production data. The cost parameters for the solution to the social planner's problem following the expansion of the New Lands are presented in table 5. The first three columns contain the initial average costs for each crop in each region, while the second set of columns contain the new average costs following the changes to the cropping pattern. The third set of columns show the percentage change in average costs following the changes to the cropping pattern (i.e. the relative difference between C and C0). The percentage changes in average costs are generally rather small due to the assumption of a high crop supply elasticity.

Comparing the percentage change in average costs with the changes in land allocation confirms that the larges increases in average costs occurs for those crops for which production expands the most, while the largest decreases in average costs occurs for those crops for which production contracts the most. In the Nile Valley average costs consequently increases the most for short berseem (1.60%) and decreases the most for sugar cane (-1.01%). In the Delta average costs increases the most for short berseem and maize / sorghum (by 1.51% and 1.32% respectively), while decreasing the most for rice (-1.24%). In the New Lands average costs decreases the most for rice and long berseem (-2.87% and -1.03% respectively), while increasing the most for legumes (2.57%) and other winter crops (4.15%). However, as noted above, the category other winter crops presents some aggregation problems, which may also explain the disproportionally large increase in average costs for this crop category.

Summing up, the solution to the social planner's problem shows that an expansion of the New Lands region by 100%, which corresponds to 16% increase in the total amount of agricultural land in Egypt, results in the national water constraint becoming binding and irrigation water being reallocated from the highly fertile Old Lands to the less fertile New Lands. Not surprisingly, the crop sectors most adversely affected by the onset of water scarcity are the highly water intensive sectors rice and sugar cane, while the sectors, which expand the most, are non-water intensive crops like short berseem, maize /sorghum, and legumes.

TABLE 5: COST PARAMETERS FROM SOLUTION TO SOCIAL PLANNER'S PROBLEM.

	Co			C			% change		
	Valley	Delta	NewLand	Valley	Delta	NewLand	Valley	Delta	NewLand
Wheat	1334	1195	625	1335	1194	625	0.09%	-0.08%	0.05%
Legumes	1011	1272	1230	1018	1276	1261	0.68%	0.30%	2.57%
Long berseem	1897	1753	1386	1887	1742	1372	-0.55%	-0.66%	-1.03%
Short berseem	851	614	700*	864	624	700*	1.60%	1.51%	0.00%*
Winter vegetables	4411	3060	3034	4416	3062	3054	0.12%	0.07%	0.67%
Other winter crops	872	631	107	875	632	111	0.40%	0.20%	4.15%
Cotton	2868	2592	1612	2859	2604	1614	-0.31%	0.47%	0.16%
Rice	2200*	2042	1451	2200*	2017	1409	0.00%*	-1.24%	-2.87%
Maize / sorghum	1130	1325	815	1134	1342	826	0.38%	1.32%	1.35%
Summer vegetables	4400	4306	3823	4407	4331	3836	0.16%	0.57%	0.35%
Other summer crops	1600	1241	1128	1597	1254	1135	-0.21%	1.09%	0.61%
Fruits (citrus)	3796	5142	3149	3801	5158	3149	0.12%	0.31%	-0.02%
Sugar cane	3645	3600*	3600*	3608	3600*	3600*	-1.01%	0.00%*	0.00%*

* In the case of sugar cane production in the Delta and the New Lands as well as rice production in the Nile Valley and short berseem in the New Lands, it has not been possible to calculate initial costs through benchmarking, as these crops were not grown in these particular regions. The initial costs for these crops have instead been fixed at what appeared to be reasonable levels before running the simulations. While this makes no difference in the present model, as yields for these crops are set equal to zero in order to preserve the features of the initial cropping pattern, it would be important if non-zero yields were introduced for these crops, as having initial costs equal to zero would distort the simulation results.

4.3 Simulation results: The farmer's problem with tax on water applied and credit for recoverable return flows.

From the social planner's problem we now turn to the farmer's problem under the different types of policy instruments, starting with the case of a tax on water applied combined with a credit on recoverable return flows. In order to solve the farmer's problem, the national water constraint is first relaxed and the tax and credit levels are subsequently set so as to ensure that the amount of water consumed or lost exactly equals the national water constraint from the social planner's problem.

In the theoretical model in chapter 3 we found that the socially optimal level for the taxes in the case of a tax on water applied and a credit on recoverable return flows was given by the following equation:

$$T_D = T_R = \lambda_2$$

According to this equation, the uniform tax on water applied and the uniform credit on recoverable return flows should both be equated with the social planner's shadow price of water. Taking the social planner's shadow price of water from the solution to the social planner's problem (cf. "water rent" in table 4), the tax rate on water applied and the credit on recovered return flows are set equal to this shadow price All other tax variables in the farmer's problem are set equal to zero and water applied quotas are set so high as to not be binding. The farmer's problem is subsequently solved, yielding the results in table 6. The four columns on the left show the levels of the different variables, while the four columns on the right show the percentage change in these variables compared to the social optimum presented in the previous section. The approach of relaxing the national water constraint and subsequently using the tax and credit instruments to ensure that the national water constraint is not violated can be seen in the results by noting that even though water rents are equal to zero, the total amount of water consumed or lost does not exceed the national water constraint of 47 BCM.

TABLE 6: SIMULATION RESULTS FOR THE FARMER'S PROBLEM WITH TAX ON WATER APPLIED AND CREDIT ON RECOVERABLE RETURN FLOWS

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from social optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1434	2428	1388	5250	0.00%	0.00%	0.00%	0.00%
Farmer profit (Revenue - Cost - Taxes)	1175	1991	933	4099	-18.06%	-18.02%	-32.77%	-21.93%
Revenue	8874	14819	6994	30687	0.00%	0.00%	0.00%	0.00%
Cost of purchased inputs	7440	12391	5605	25437	0.00%	0.00%	0.00%	0.00%
Total taxes collected	259	437	455	1151				
Tax on water applied	340	496	455	1290				
Credit on water recovered	-81	-58	0	-139				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	0	0	0	0				
					% Change from social optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10568	17859	18573	47000	0.00%	0.00%	0.00%	0.00%
Quotas on water applied	100000	100000	200000	400000	0.00%	0.00%	0.00%	0.00%
Water applied	13860	20244	18573	52677	0.00%	0.00%	0.00%	0.00%
Recovered return flows	3292	2385	0	5677	0.00%	0.00%	0.00%	0.00%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from social optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	223	223	158		0.00%	0.00%	0.00%	
Summer	203	212	163		0.00%	0.00%	0.00%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	0.00%	0.00%	0.00%	0.00%
Legumes	0.13	0.25	0.27	0.65	0.00%	0.00%	0.00%	0.00%
Long berseem	0.37	0.71	0.46	1.54	0.00%	0.00%	0.00%	0.00%
Short berseem	0.36	0.57	0.00	0.93	0.00%	0.00%	0.00%	0.00%
Winter vegetables	0.12	0.24	0.20	0.57	0.00%	0.00%	0.00%	0.00%
Other winter crops	0.07	0.13	0.09	0.29	0.00%	0.00%	0.00%	0.00%
Cotton	0.22	0.64	0.11	0.97	0.00%	0.00%	0.00%	0.00%
Rice	0.00	0.91	0.14	1.05	0.00%	0.00%	0.00%	0.00%
Maize / sorghum	1.07	1.09	1.28	3.44	0.00%	0.00%	0.00%	0.00%
Summer vegetables	0.37	0.47	0.39	1.23	0.00%	0.00%	0.00%	0.00%
Other summer crops	0.07	0.11	0.09	0.27	0.00%	0.00%	0.00%	0.00%
Fruits (citrus)	0.11	0.19	0.11	0.41	0.00%	0.00%	0.00%	0.00%
Sugar cane	0.22	0.00	0.00	0.22	0.00%	0.00%	0.00%	0.00%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	1.71	2.98	1.36	6.05	0.00%	0.00%	0.00%	0.00%
Legumes	0.14	0.31	0.34	0.79	0.00%	0.00%	0.00%	0.00%
Long berseem	9.70	17.44	9.34	36.48	0.00%	0.00%	0.00%	0.00%
Short berseem	4.51	5.60	0.00	10.11	0.00%	0.00%	0.00%	0.00%
Winter vegetables	1.52	2.12	1.77	5.41	0.00%	0.00%	0.00%	0.00%
Other winter crops	0.56	0.82	0.23	1.61	0.00%	0.00%	0.00%	0.00%
Cotton	0.24	0.64	0.07	0.95	0.00%	0.00%	0.00%	0.00%
Rice	0.00	3.07	0.35	3.43	0.00%	0.00%	0.00%	0.00%
Maize / sorghum	2.78	3.28	2.61	8.67	0.00%	0.00%	0.00%	0.00%
Summer vegetables	4.03	5.04	3.76	12.83	0.00%	0.00%	0.00%	0.00%
Other summer crops	0.07	0.09	0.07	0.23	0.00%	0.00%	0.00%	0.00%
Fruits (citrus)	0.68	1.56	0.57	2.81	0.00%	0.00%	0.00%	0.00%
Sugar cane	9.90	0.00	0.00	9.90	0.00%	0.00%	0.00%	0.00%

Comparing the land and water allocation in the present version of the farmer's problem with the socially optimal land and water allocation shows that there is no difference between these two scenarios. This observation thus confirms the result from the theoretical model, that placing a tax on water applied and a credit on recoverable return flows, which both equal the social planner's shadow price of water consumed or lost, will produce a first-best resource allocation.

The main difference between this solution to the farmer's problem and the solution to the social planner's problem is obviously the tax and credit payments. While a tax on water applied and a credit on recoverable return flows can implement a first-best resource allocation, this solution to the water and land allocation problem will result in farmer profits being reduced by 21.93%, compared to a situation in which this resource allocation could be achieved without the use of tax instruments. Looking at the impact on farmer's profits in different regions shows, that farmer profits declines more in the New Lands (-32.77%) than in the Nile Valley and the Delta (-18.06% and -18.02% respectively). This distribution of the tax burden reflects the fact that return flows are not recoverable in the New Lands, while they are partially recoverable in the Delta and virtually fully recoverable in the Nile Valley. The reason why profits do not decrease more in the Delta than in the Nile Valley, in spite of return flows only be partially recoverable in the Delta, is partly that field irrigation efficiency is higher in the Delta than in the Nile Valley for all crops except rice (making the fact that return flows are not fully recoverable less important), and partly that the crop mix differs between the two regions.

Summing up, the results from this version of the farmer's problem shows that it is indeed possible to achieve a first best resource allocation through taxes on water applied and credits on recoverable return flows. However, the efficiency comes at a price as total farmer's profits are reduced by almost 22% due to the tax payments.

4.4 SIMULATION RESULTS: THE FARMER'S PROBLEM WITH TAX ON WATER APPLIED.

A tax on water applied combined with a credit on recoverable return flows can in principle achieve a first best allocation of resources. However, this policy scheme is generally not implementable, as it will normally not be possible to implement a credit on recoverable return flows. If the irrigation system allows for metering of individual farmer water diversions, it is, however, possible to implement a single tax on water applied.

According to the theoretical model in chapter 3, the socially optimal tax rate for a single tax on water applied is given by the following equation:

$$T_D = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk}))$$

This equation shows that in cases where return flows are partially recoverable the socially optimal tax on water applied will be lower than the social shadow price on water. As the tax on water applied is simply a scalar, the socially optimal tax on water applied can be found by varying the tax rate scalar until the total amount of water consumed or lost equals the national water constraint of 47 BCM. Performing this procedure shows that the tax rate on water applied needs to be set equal to 0.20845 in order not to violate the national water constraint. This tax rate is lower than the social planner's shadow price on water (cf. water rents in table 4), thus confirming the insight from the theoretical model.

The solution to the farmer's problem with a single tax on water applied is presented in table 7. The welfare results confirm that a single tax on water applied is a second-best instrument in the presence of recoverable return flows, as the net social welfare is lower than in the first best policy scenario in section 4.3. However, the difference in welfare between using the first-best instruments and the second-best instruments is miniscule, as use of the second-best instrument only reduces welfare by 0.02% compared to the first-best solution. The income and welfare results also show that regulating water use through a single tax on water applied will lower farmer profits by 20.89% compared to the social planner's solution.[37] This is less than in the first best case, where farmer profits were lowered by 21.93%. While this may seem surprising, it is not incompatible with the model, as the model is only concerned with the allocation of natural resources and not the distribution of financial resources between farmers and the government. This result is closely connected with the overall degree of return flow recoverability, as a higher degree of return flow recoverability implies a larger reduction in the second best tax on water applied compared to this tax rate in the first best scheme. This occurs because the optimal tax rate for a single tax on water applied includes an implicit credit for the average national degree of return flow recoverability (cf. the optimal tax rate equation above compared to that in section 4.5).

[37] The reduction in farmer profits is in principle not solely attributable to the tax payments, as 0.02 percentage points of the 20.89% reduction is attributable to the inefficiency of the resource allocation. However, given the relative magnitude in these numbers, reduction in farmer profits is obviously dominated by the tax payment effect.

TABLE 7: SIMULATION RESULTS FOR THE FARMER'S PROBLEM WITH TAX ON WATER APPLIED

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from social optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1432	2422	1395	5249	-0.09%	-0.26%	0.46%	-0.02%
Farmer profit (Revenue - Cost - Taxes)	1145	2007	1002	4153	-20.15%	-17.35%	-27.85%	-20.89%
Revenue	8856	14826	7009	30691	-0.20%	0.04%	0.22%	0.01%
Cost of purchased inputs	7424	12404	5614	25442	-0.22%	0.10%	0.16%	0.02%
Total taxes collected	287	415	393	1096				
Tax on water applied	287	415	393	1096				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	0	0	0	0				
					% Change from social optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10517	17628	18855	47000	-0.49%	-1.29%	1.52%	0.00%
Quotas on water applied	100000	100000	200000	400000	0.00%	0.00%	0.00%	0.00%
Water applied	13792	19919	18855	52566	-0.49%	-1.61%	1.52%	-0.21%
Recovered return flows	3276	2291	0	5566	-0.49%	-3.97%	0.00%	-1.95%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from social optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	217	226	174		-2.95%	1.59%	10.08%	
Summer	195	212	181		-3.96%	-0.37%	11.61%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	0.21%	0.06%	-0.06%	0.05%
Legumes	0.14	0.25	0.26	0.64	1.52%	-0.63%	-5.63%	-2.27%
Long berseem	0.36	0.72	0.49	1.57	-1.88%	1.51%	5.06%	1.77%
Short berseem	0.37	0.56	0.00	0.93	2.98%	-2.00%	0.00%	-0.08%
Winter vegetables	0.12	0.24	0.20	0.56	0.38%	-0.19%	-2.24%	-0.80%
Other winter crops	0.07	0.13	0.09	0.29	0.91%	-0.47%	-3.65%	-1.12%
Cotton	0.22	0.65	0.11	0.98	-1.06%	2.89%	-0.47%	1.61%
Rice	0.00	0.83	0.19	1.02	0.00%	-8.10%	34.20%	-2.43%
Maize / sorghum	1.08	1.13	1.24	3.45	0.89%	3.83%	-3.23%	0.29%
Summer vegetables	0.37	0.47	0.39	1.23	0.46%	1.23%	-1.25%	0.21%
Other summer crops	0.07	0.11	0.09	0.27	-0.70%	4.69%	-1.74%	1.14%
Fruits (citrus)	0.11	0.19	0.11	0.42	0.31%	1.36%	0.14%	0.75%
Sugar cane	0.21	0.00	0.00	0.21	-4.02%	0.00%	0.00%	-4.02%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	1.72	2.98	1.36	6.06	0.21%	0.06%	-0.06%	0.07%
Legumes	0.15	0.31	0.32	0.78	1.52%	-0.63%	-5.63%	-2.36%
Long berseem	9.52	17.71	9.81	37.04	-1.88%	1.51%	5.06%	1.52%
Short berseem	4.65	5.48	0.00	10.13	2.98%	-2.00%	0.00%	0.22%
Winter vegetables	1.53	2.11	1.73	5.37	0.38%	-0.19%	-2.24%	-0.70%
Other winter crops	0.57	0.81	0.22	1.60	0.91%	-0.47%	-3.65%	-0.45%
Cotton	0.24	0.65	0.07	0.96	-1.06%	2.89%	-0.47%	1.64%
Rice	0.00	2.83	0.47	3.30	0.00%	-8.10%	34.20%	-3.75%
Maize / sorghum	2.80	3.41	2.53	8.73	0.89%	3.83%	-3.23%	0.76%
Summer vegetables	4.05	5.10	3.72	12.86	0.46%	1.23%	-1.25%	0.26%
Other summer crops	0.07	0.10	0.07	0.24	-0.70%	4.69%	-1.74%	1.12%
Fruits (citrus)	0.69	1.58	0.57	2.84	0.31%	1.36%	0.14%	0.86%
Sugar cane	9.51	0.00	0.00	9.51	-4.02%	0.00%	0.00%	-4.02%

This notion that a single tax on water applied includes an implicit credit for recoverable return flows is also reflected in the regional decomposition of the income and welfare results. Compared to the first best policy scenario, farmer profit in the New Land region thus decreases less under the single tax on water applied, as the implicit credit for recoverable return flows is also bestowed on New Land farmers, even though return flows from New Lands are not recoverable. Under a single tax on water applied, water thus appears to be less expensive in the New Lands, which is also why social welfare in this region actually increases by 0.46%.

Return flows are virtually fully recoverable in the Nile Valley and a single tax on water applied, which only captures the average national degree of return flow recoverability, will consequently not be beneficial to this region. Comparing the income and welfare results for the Nile Valley with the results from the first best policy scenario shows a larger decline in farmer profits (due to the increased tax payments) as well as a decline in net social welfare of -0.09%. Under a single tax scheme this region is consequently taxed harder than in the first-best case due to the region's return flow recoverability being higher than the national average return flow recoverability.

In the Delta tax payments are also lower under a single tax on water applied than in the first best policy scenario. This is explained by the fact that although return flow recoverability in the Delta exceeds the national average return flow recoverability, the irrigation efficiency in the Delta is also higher than the national average irrigation efficiency. For all other crops than rice, Delta farmers consequently generate relatively smaller return flows than farmers in the other regions.

Under the single tax on water applied, tax payments in the Delta are also lower than in the first best policy scenario. Return flows in this region are only partially recoverable and the effect of a reduction in the tax on water applied turns out to dominate the effect of not receiving credits for the recoverable fraction of the return flows. However, net social welfare in the Delta declines in comparison with the first best policy scenario (by -0.26%). The decline in welfare is due to the deviations in the cropping pattern from the social optimum. As rice produces a disproportionate amount of the return flows, the lack of a direct credit on recoverable return flows results in a lower rice production in the Delta than what is socially optimal.

Comparing the distribution of water consumed or lost across regions to that in the social optimum shows that the changes in water distribution mirror the changes in social welfare. Compared to the social optimum, the amount of water consumed or lost thus increases in the New Lands (by 1.52%), while it declines in the Delta (-1.29%) and in the Nile Valley (-0.49%). This pattern of change is also reflected in land rents for the different regions, except in the case of winter land rents in the Delta, which actually increase. The reason why Delta winter land rents do not decline compared to the first-best policy scenario is that the change from the first-best policy instruments to the second-best policy instruments is primarily detrimental to rice production in the Delta, and rice is a summer crop.

Turning to the impact of a single water applied tax on land allocation and production shows that a single tax on water applied affects the cropping pattern in the regions differently. Comparing the cropping pattern in the New Land to the cropping pattern in the first best policy scenario shows that the lower tax rate for a single tax on water applied increases production of water intensive crops compared to the first-best scenario. In the summer, production of rice in the New Lands thus increase by 34.20%, while production of the water intensive winter crop long berseem increases by 5.06%.

Although return flows are partially recoverable in the Delta, the lower tax rate on water applied also makes production of water intensive winter crops more profitable in the Delta. Production of long berseem is consequently 1.51% higher in the case of a single tax on water applied than in the first best policy scenario. For the winter crops, the reduction in the tax on water applied compared to the first best policy scenario thus outweighs the lack of credits on recoverable return flows. This, however, is not the case for Delta summer crop production. As previously mentioned, the low irrigation efficiency for rice implies that this crop produces a disproportionate amount of the return flows. The lower tax on water applied does not outweigh the lack of credits for recoverable return flows for this crop, and rice production therefore decreases by 8.10% compared to the first best scenario. The production of all other Delta summer crops subsequently increase by a few percentage points compared to the cropping pattern in the first best scenario.

Comparing the Nile Valley cropping pattern to the cropping pattern in the first best scenario shows that the lower tax rate on water applied does not outweigh the lack of a credit on recoverable return flow in this region, where return flow are fully recoverable. Using a single tax on water applied consequently induces a shift from the water intensive crops sugar cane and long berseem towards the other less water intensive crops.

Due to the differences in how a single tax on water applied affects the cropping pattern in the different regions, the changes in total national crop production does not produce a clear picture with respect to the water intensity of the different crops. Comparing total production in this scenario with total production in the first best scenario consequently shows an overall decrease in the production some water intensive crops like rice and sugar cane, while the total production of a water intensive crop like long berseem increases.

All in all the analysis shows that compared to the first best policy scenario, a single tax on water applied tends to favor regions with low return flow recoverability at the expense of regions with high return flow recoverability. This unfortunate distribution of the tax burden across regions could be countered by introducing region-specific taxes on water applied, which reflect the return flow recoverability of the region. While regionalizing the tax on water applied would result in a more socially optimal resource allocation, it would not produce a first-best outcome. This is because a tax on water applied is not able to handle differences in irrigation efficiency across crops in a socially optimal manner in situations where return flows are at least partially recoverable.

4.5 Simulation results: The farmer’s problem with quotas on water applied.

The theoretical chapter demonstrated that the solution produced by a tax on water applied could also be implemented by setting quotas on farmer’s amount of water applied. In order to demonstrate this result empirically, quotas are placed on the total amount of water applied by each farmer. The results from this scenario are presented in table 8. The size of the quotas is determined by the amount of water used in each region in the scenario of a single tax on water applied. This can be confirmed by comparing quotas on water applied in table 8 with the amount of water applied in each region in table 7.

TABLE 8: SIMULATION RESULTS FOR THE FARMER'S PROBLEM WITH QUOTAS ON WATER APPLIED

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from social optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1432	2422	1395	5249	-0.09%	-0.26%	0.46%	-0.02%
Farmer profit (Revenue - Cost - Taxes)	1432	2422	1395	5249	-0.09%	-0.26%	0.46%	-0.02%
Revenue	8856	14826	7009	30691	-0.20%	0.04%	0.22%	0.01%
Cost of purchased inputs	7424	12404	5614	25442	-0.22%	0.10%	0.16%	0.02%
Total taxes collected	0	0	0	0				
Tax on water applied	0	0	0	0				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	0	0	0	0				
					% Change from social optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10516	17628	18855	47000	-0.49%	-1.29%	1.52%	0.00%
Quotas on water applied	13792	19919	18855	52566	-86.21%	-80.08%	-90.57%	-86.86%
Water applied	13792	19919	18855	52566	-0.49%	-1.61%	1.52%	-0.21%
Recovered return flows	3276	2291	0	5566	-0.49%	-3.96%	0.00%	-1.95%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from social optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	217	226	174		-2.96%	1.59%	10.07%	
Summer	195	212	181		-3.98%	-0.36%	11.60%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	0.21%	0.06%	-0.06%	0.05%
Legumes	0.14	0.25	0.26	0.64	1.53%	-0.63%	-5.63%	-2.27%
Long berseem	0.36	0.72	0.49	1.57	-1.89%	1.51%	5.05%	1.77%
Short berseem	0.37	0.56	0.00	0.93	2.99%	-2.00%	0.00%	-0.08%
Winter vegetables	0.12	0.24	0.20	0.56	0.38%	-0.19%	-2.24%	-0.80%
Other winter crops	0.07	0.13	0.09	0.29	0.91%	-0.47%	-3.65%	-1.12%
Cotton	0.22	0.65	0.11	0.98	-1.06%	2.89%	-0.47%	1.61%
Rice	0.00	0.83	0.19	1.02	0.00%	-8.09%	34.17%	-2.43%
Maize / sorghum	1.08	1.13	1.24	3.45	0.89%	3.83%	-3.23%	0.29%
Summer vegetables	0.37	0.47	0.39	1.23	0.46%	1.23%	-1.25%	0.21%
Other summer crops	0.07	0.11	0.09	0.27	-0.71%	4.69%	-1.73%	1.14%
Fruits (citrus)	0.11	0.19	0.11	0.42	0.31%	1.36%	0.14%	0.76%
Sugar cane	0.21	0.00	0.00	0.21	-4.04%	0.00%	0.00%	-4.04%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	1.72	2.98	1.36	6.06	0.21%	0.06%	-0.06%	0.07%
Legumes	0.15	0.31	0.32	0.78	1.53%	-0.63%	-5.63%	-2.36%
Long berseem	9.52	17.71	9.81	37.04	-1.89%	1.51%	5.05%	1.51%
Short berseem	4.65	5.48	0.00	10.13	2.99%	-2.00%	0.00%	0.23%
Winter vegetables	1.53	2.11	1.73	5.37	0.38%	-0.19%	-2.24%	-0.70%
Other winter crops	0.57	0.81	0.22	1.60	0.91%	-0.47%	-3.65%	-0.45%
Cotton	0.24	0.65	0.07	0.96	-1.06%	2.89%	-0.47%	1.64%
Rice	0.00	2.83	0.47	3.30	0.00%	-8.09%	34.17%	-3.75%
Maize / sorghum	2.80	3.41	2.53	8.73	0.89%	3.83%	-3.23%	0.76%
Summer vegetables	4.05	5.10	3.72	12.86	0.46%	1.23%	-1.25%	0.26%
Other summer crops	0.07	0.10	0.07	0.24	-0.71%	4.69%	-1.73%	1.12%
Fruits (citrus)	0.69	1.58	0.57	2.84	0.31%	1.36%	0.14%	0.86%
Sugar cane	9.50	0.00	0.00	9.50	-4.04%	0.00%	0.00%	-4.04%

Comparing the resource allocation produced by the quotas on water applied with the results produced by the single tax on water applied shows that allocation of land and water are identical in these two scenarios (apart from a couple of deviations on the last decimal due to rounding off). The only difference between the two scenarios is as expected the impact on farmer profits. As quotas are assumed to be allocated to farmers free of charge, the only deviation in farmer profits from the social optimum is the loss in efficiency from using a second-best instrument. These losses and their explanation are of course identical to those outlined for a single tax on water applied.

The main point to take from this simulation is thus that the solution produced by a single tax on water applied can be implemented through quotas on water applied without the detrimental impact on farmer profits. However, as detailed in chapter 3, it will often be difficult for the social planner to determine the socially optimal quota size for each farmer. The use of quotas on water applied may consequently be less efficient than the present simulation results suggest.

4.6 SIMULATION RESULTS: THE FARMER'S PROBLEM WITH CROP-SPECIFIC LAND TAXES.

Farmers' use of irrigation water can also be regulated through taxes targeting non-water variables. One example of such a tax scheme is crop-specific land taxes.

According to the theoretical model in chapter 3, the socially optimal tax rate for a set of crop-specific land taxes is given by the following equation:

$$T_{Li} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk}) d_{ijk} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk}) \frac{e_{ijk}}{\alpha_{ijk}}$$

As was the case with a single tax on water applied, a national set of crop-specific land taxes take account of the average field irrigation efficiency and return flow recoverability. A national set of crop-specific taxes thus cannot capture any region-specific aspects of these parameters. However, unlike the case of single tax on water applied, a set of crop-specific land taxes can take crop-specific aspects of field irrigation efficiency into account. As already mentioned, this is important in the case of rice production, as the field irrigation efficiency for rice is assumed to equal 70% of the field irrigation efficiency for other crops in the region.

The tax on water applied was a simple scalar parameter and the socially optimal tax rate could consequently be found by varying the tax scalar parameter until total the total amount of water consumed or lost equaled the national water constraint. The crop-specific land tax, on the other hand, can be expressed as a tax scalar parameter times a vector with an entry for each crop that captures the crop water requirement relative to the other crops' water requirements. As crop water requirements differ across regions, the regional crop water requirements are aggregated to national averages using the initial cropping pattern as weights. Taking account of the lower field irrigation efficiency for rice, the crop-specific land taxes are implemented according to the following set of equations:[38]

For crops other than rice: $T_{Li} = t * \dfrac{\sum_{j=1}^{J}\sum_{k=1}^{K}(X0_{ijk}\, e_{ijk})}{\sum_{j=1}^{J}\sum_{k=1}^{K}X0_{ijk}}$

For rice (i.e. $i = rice$): $T_{Li} = t * \dfrac{\sum_{j=1}^{J}\sum_{k=1}^{K}(X0_{ijk}\,(e_{ijk}/0.7))}{\sum_{j=1}^{J}\sum_{k=1}^{K}X0_{ijk}}$

where t is the tax scalar variable, which is varied until the total amount of water consumed or lost equals 47 BCM. This occurs for $t = 0.026375$

The result for the farmer's problem with crop-specific land taxes are presented in table 9. Starting with the income and welfare results, the total welfare result shows that the set of crop-specific land taxes is a second-best instrument, as total welfare is lower than in the first-best policy case. Furthermore, crop-specific land taxes do not perform as well as the other second-best tax instrument of taxing water applied, as social welfare is lower under the land taxes than the water applied tax. However, the inefficiency of the second-best instrument is again miniscule, as the decrease in social welfare compared to the first-best case is only 0.06%. Turning to the impact on total farmer profits, the results show that crop-specific land taxes reduce farmer profits by 19.91%, which is less than in the case of both a water applied

[38] Including the lower irrigation efficiency for rice in the formula for the rice land tax is a violation of the notion that crop-specific land taxes primarily captures crop water consumption. If return flows were fully recoverable it would thus not be optimal to include the lower irrigation efficiency for rice in the tax formula. However, as rice is grown in the Delta, where return flows are only partially recoverable, and in the New Lands, where return flows are not recoverable at all, the land tax policy scheme becomes more efficient by including the lower irrigation efficiency for rice, as the general tax rate would otherwise have to be set much higher in order to counter the water losses from rice production. If the lower irrigation efficiency for rice was not taken into account in the crop-specific land tax formula, net social welfare would decline by 0.16% and farmer profits would be reduced by 30.25%. As the results in the present section will show, this result is significantly inferior to that which can be achieved by incorporating the lower irrigation efficiency for rice.

tax (-20.89%) and the first-best policy of taxing water applied and crediting return flows (-21.93%).

As in the previous policy cases, the impact on welfare and income differs across regions. The New Lands region fares better under the crop-specific land taxes than under the first-best policy scheme, as social welfare in the region is higher than in the former case (0.42%) and the reduction in farmer profits are smaller (-19.76% compared to -32.77%). The Old Land regions, on the other hand, fare worse under the land taxes than under the first-best policy scheme, as net social welfare declines compared to the first-best policy scenario and tax payments increase. This is most pronounced for the Delta region, where welfare declines by 0.34%. The explanation for these regional differences lies in the fact that the crop-specific land taxes are based on average crop water requirements. As crop water requirements tend to be highest in the New Lands and lowest in the Delta (cf. appendix E), the former region is consequently taxed too lightly while the latter is taxed too heavily from a social efficiency point of view. Furthermore, the land tax scalar parameter implicitly captures the average return flow recoverability. As return flow recoverability is below average in the New Lands and above average in the two Old Land regions, this reinforces the notion of the Old Land regions being taxed too heavily and the New Lands too lightly from a social efficiency point of view.

The fact that the crop-specific land tax taxes the Old Lands too heavily and the New Lands too lightly also has consequences for the allocation of water resources across the regions. Compared to the first-best case, water is thus shifted from the two old land regions to the New Lands region. This shift of resources is also reflected in the land rents, which decrease in the Old Land regions compared to the first-best case, while increasing substantially in the New Lands.

TABLE 9: SIMULATION RESULTS FOR THE FARMER'S PROBLEM WITH CROP-SPECIFIC LAND TAXES

Number of Farmers of Type j	Valley	Delta	NewLand		Valley	Delta	NewLand	
	1	1	2					
					% Change from social optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1433	2420	1394	5247	-0.05%	-0.34%	0.42%	-0.06%
Farmer profit (Revenue - Cost - Taxes)	1167	1924	1114	4205	-18.58%	-20.79%	-19.76%	-19.91%
Revenue	8898	14768	6977	30644	0.27%	-0.34%	-0.24%	-0.14%
Cost of purchased inputs	7466	12348	5582	25396	0.34%	-0.35%	-0.41%	-0.16%
Total taxes collected	266	497	280	1042				
Tax on water applied	0	0	0	0				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	266	497	280	1042				
					% Change from social optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10546	17557	18897	47000	-0.21%	-1.69%	1.74%	0.00%
Quotas on water applied	100000	100000	200000	400000	0.00%	0.00%	0.00%	0.00%
Water applied	13831	19845	18897	52572	-0.21%	-1.97%	1.74%	-0.20%
Recovered return flows	3285	2287	0	5572	-0.21%	-4.10%	0.00%	-1.84%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from social optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	223	215	206		-0.03%	-3.73%	30.75%	
Summer	198	199	203		-2.32%	-6.06%	24.57%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	0.67	1.27	1.01	2.96	-1.15%	-2.68%	3.13%	-0.41%
Legumes	0.14	0.26	0.20	0.60	5.22%	5.10%	-25.60%	-7.65%
Long berseem	0.36	0.69	0.51	1.56	-0.46%	-3.27%	10.34%	1.50%
Short berseem	0.37	0.61	0.00	0.98	2.62%	7.41%	0.00%	5.56%
Winter vegetables	0.12	0.24	0.18	0.55	0.59%	1.35%	-9.73%	-2.78%
Other winter crops	0.07	0.13	0.09	0.29	0.60%	-0.97%	0.87%	-0.02%
Cotton	0.23	0.65	0.12	1.00	6.92%	2.59%	2.88%	3.61%
Rice	0.00	0.84	0.15	0.99	0.00%	-7.82%	7.87%	-5.71%
Maize / sorghum	1.06	1.14	1.25	3.45	-1.22%	4.34%	-1.95%	0.27%
Summer vegetables	0.37	0.47	0.40	1.24	0.94%	0.50%	1.00%	0.79%
Other summer crops	0.07	0.11	0.08	0.27	3.40%	3.17%	-3.26%	1.14%
Fruits (citrus)	0.11	0.19	0.12	0.42	-0.81%	0.74%	8.72%	2.44%
Sugar cane	0.21	0.00	0.00	0.21	-3.29%	0.00%	0.00%	-3.29%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	1.69	2.90	1.40	5.99	-1.15%	-2.68%	3.13%	-0.94%
Legumes	0.15	0.33	0.25	0.73	5.22%	5.10%	-25.60%	-7.88%
Long berseem	9.66	16.87	10.30	36.83	-0.46%	-3.27%	10.34%	0.96%
Short berseem	4.63	6.01	0.00	10.64	2.62%	7.41%	0.00%	5.27%
Winter vegetables	1.53	2.15	1.59	5.27	0.59%	1.35%	-9.73%	-2.48%
Other winter crops	0.56	0.81	0.23	1.61	0.60%	-0.97%	0.87%	-0.16%
Cotton	0.25	0.65	0.08	0.98	6.92%	2.59%	2.88%	3.70%
Rice	0.00	2.83	0.38	3.21	0.00%	-7.82%	7.87%	-6.20%
Maize / sorghum	2.74	3.43	2.56	8.73	-1.22%	4.34%	-1.95%	0.67%
Summer vegetables	4.07	5.06	3.80	12.93	0.94%	0.50%	1.00%	0.79%
Other summer crops	0.08	0.09	0.07	0.24	3.40%	3.17%	-3.26%	1.38%
Fruits (citrus)	0.68	1.57	0.62	2.87	-0.81%	0.74%	8.72%	1.99%
Sugar cane	9.58	0.00	0.00	9.58	-3.29%	0.00%	0.00%	-3.29%

The results for land allocation also show how differently the regions are impacted by the crop-specific land taxes. In the New Lands, water in effect becomes less scarce than in the socially optimal solution resulting in shifts away from less water-intensive crops like legumes (-25.60%) and winter vegetables (-9.73%) toward more water intensive crops like long berseem (10.34%) and rice (7.87%). In the Delta water becomes scarcer compared to the social optimum resulting in shifts away from water intensive crops like long berseem (-3.27%) and rice (-7.82%) towards less water intensive crops like short berseem (7.41%) and maize / sorghum (4.34%). The decline in rice production in the Delta is also partly explained by the fact that adjusting the crop-specific land tax for rice by fully 0.7 makes rice production in this region appear more water intensive than it actually is, as the return flows are in fact partially recoverable in the Delta.

In the Nile Valley there is no clear shift based on crop water intensity. This is explained by the fact that crop water requirements in the Nile Valley are closer to the national average than in the other two regions. However, sugar cane production, which only takes place in the Nile Valley, does decline compared to the social optimum (by 3.29%)

The fact that crop-specific land tax rates are based on average national water requirements have special implications for the crops for which there are large deviations in regional crop water requirements. The most important example of this is the case of wheat. While the impact on wheat production in the other scenarios has been rather minor compared to the impacts on production of other crops, the relative impact on wheat production under crop-specific land taxes is more pronounced. Wheat production in the New Lands thus increases by 3.13% while it decreases in the Delta by 2.68% compared to the first best case. This observation is explained by the fact that water requirements for wheat production in the New Lands are almost twice as high as in the Delta (cf. appendix E). Basing crop-specific land taxes on national average water requirements consequently does have a significant impact on the distribution of crop production across regions for those crops where regional crop water requirements vary substantially. The social efficiency of the crop-specific land taxes could thus be improved if these taxes were made region-specific.

4.7 Simulation results: The farmer's problem with crop-specific output taxes.

The final policy instrument to be considered for regulating farmer's use of irrigation water is crop-specific output taxes.

According to the theoretical model in chapter 3, the socially optimal tax rate for a set of crop-specific output taxes is given by the following equation:

$$T_{Oi} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk})) \frac{d_{ijk}}{y_{ijk}} = \lambda_2 (1 - \beta_j (1 - \alpha_{ijk})) \frac{e_{ijk}}{\alpha_{ijk} y_{ijk}}$$

This equation is clearly very similar to the equation for crop-specific land taxes presented in the previous section. The only difference between the two equations is that the optimal crop-specific output tax is also a function of regional yields.

Given the similarity with case of crop-specific land taxes, the crop-specific output taxes are implemented in a similar fashion, which takes account of the lower field irrigation efficiency for rice. The crop-specific land taxes are consequently implemented in the empirical model through the following equations:

For crops other than rice: $$T_{Oi} = t * \frac{\sum_{j=1}^{J} \sum_{k=1}^{K} (Q0_{ijk} e_{ijk} / y_{ijk})}{\sum_{j=1}^{J} \sum_{k=1}^{K} Q0_{ijk}}$$

For rice (i.e. $i = rice$): $$T_{Oi} = t * \frac{\sum_{j=1}^{J} \sum_{k=1}^{K} (Q0_{ijk} (e_{ijk} / 0.7) / y_{ijk})}{\sum_{j=1}^{J} \sum_{k=1}^{K} Q0_{ijk}}$$

The unit of measure for the term e_{ijk} / y_{ijk} is cubic meters per ton. The weights used for aggregating this term across regions are consequently the initial output $Q0$, which is determined by multiplying the initial land allocation $X0_{ijk}$ with regional yields y_{ijk}. Once again, t is the tax scalar variable, which is varied until the total amount of water consumed or lost equals 47 BCM. This occurs for $t = 0.02885$

The results for the farmer's problem with crop-specific output taxes are presented in table 10. Starting with the results on income and welfare, total net social welfare is 0.15% lower than in the first best case. This makes crop-specific output taxes the least efficient of the second-best policy instruments presented in this chapter. Crop-specific output taxes decrease total farmer profits by 21.11% compared to the social optimum, which is more than the other second-best policy instruments but less than the first-best policy instruments.

TABLE 10: SIMULATION RESULTS FOR THE FARMER'S PROBLEM WITH CROP-SPECIFIC OUTPUT TAXES

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from social optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1431	2413	1398	5242	-0.17%	-0.63%	0.69%	-0.15%
Farmer profit (Revenue - Cost - Taxes)	1129	1853	1160	4142	-21.24%	-23.70%	-16.42%	-21.11%
Revenue	8863	14774	6874	30510	-0.13%	-0.31%	-1.72%	-0.58%
Cost of purchased inputs	7431	12361	5476	25268	-0.12%	-0.25%	-2.31%	-0.67%
Total taxes collected	302	560	238	1100				
Tax on water applied	0	0	0	0				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	302	560	238	1100				
Crop-specific land taxes	0	0	0	0				
					% Change from social optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	10495	17341	19163	47000	-0.69%	-2.90%	3.18%	0.00%
Quotas on water applied	100000	100000	200000	400000	0.00%	0.00%	0.00%	0.00%
Water applied	13764	19561	19163	52488	-0.69%	-3.37%	3.18%	-0.36%
Recovered return flows	3269	2220	0	5489	-0.69%	-6.93%	0.00%	-3.31%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from social optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	211	209	220		-5.31%	-6.36%	39.60%	
Summer	192	182	215		-5.46%	-14.14%	32.47%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	0.65	1.24	1.06	2.95	-4.08%	-5.19%	7.71%	-0.67%
Legumes	0.16	0.26	0.17	0.59	17.99%	5.27%	-36.68%	-9.58%
Long berseem	0.35	0.67	0.48	1.50	-3.26%	-5.64%	2.43%	-2.64%
Short berseem	0.38	0.66	0.00	1.04	6.93%	15.25%	0.00%	12.04%
Winter vegetables	0.12	0.25	0.17	0.55	-1.03%	4.12%	-14.59%	-3.69%
Other winter crops	0.06	0.13	0.12	0.32	-9.35%	0.53%	38.46%	9.83%
Cotton	0.23	0.68	0.12	1.03	2.92%	7.01%	9.80%	6.41%
Rice	0.00	0.79	0.20	0.99	0.00%	-13.17%	44.90%	-5.38%
Maize / sorghum	1.07	1.13	1.22	3.42	-0.24%	4.26%	-4.77%	-0.50%
Summer vegetables	0.37	0.48	0.38	1.24	0.68%	3.42%	-2.97%	0.56%
Other summer crops	0.07	0.12	0.08	0.27	-6.81%	14.34%	-10.73%	0.47%
Fruits (citrus)	0.12	0.19	0.12	0.43	6.71%	-1.52%	7.17%	3.00%
Sugar cane	0.21	0.00	0.00	0.21	-4.12%	0.00%	0.00%	-4.12%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	0.00%	0.00%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from social optimum Valley	Delta	NewLand	Total
Wheat	1.64	2.82	1.47	5.93	-4.08%	-5.19%	7.71%	-1.97%
Legumes	0.17	0.33	0.21	0.71	17.99%	5.27%	-36.68%	-10.20%
Long berseem	9.39	16.46	9.57	35.41	-3.26%	-5.64%	2.43%	-2.94%
Short berseem	4.82	6.45	0.00	11.27	6.93%	15.25%	0.00%	11.54%
Winter vegetables	1.51	2.21	1.51	5.22	-1.03%	4.12%	-14.59%	-3.44%
Other winter crops	0.51	0.82	0.32	1.65	-9.35%	0.53%	38.46%	2.54%
Cotton	0.24	0.68	0.08	1.01	2.92%	7.01%	9.80%	6.20%
Rice	0.00	2.67	0.51	3.18	0.00%	-13.17%	44.90%	-7.19%
Maize / sorghum	2.77	3.42	2.49	8.68	-0.24%	4.26%	-4.77%	0.10%
Summer vegetables	4.06	5.21	3.65	12.92	0.68%	3.42%	-2.97%	0.69%
Other summer crops	0.07	0.10	0.06	0.23	-6.81%	14.34%	-10.73%	0.37%
Fruits (citrus)	0.73	1.53	0.62	2.88	6.71%	-1.52%	7.17%	2.25%
Sugar cane	9.50	0.00	0.00	9.50	-4.12%	0.00%	0.00%	-4.12%

The regional results show that the tendency of the New Land region to gain at the expense of the Old Land regions is even more pronounced under crop-specific output taxes than under crop-specific land taxes. This is due to the fact that not only do the New Lands tend to have the highest crop water requirements, they also tend to have the lowest yields (cf. appendix G). As both of these features imply that the New Lands are getting taxed to lightly, while the Old Lands are getting taxed to heavily, the New Lands are favored even more under the crop-specific output taxes. This trend is also evident in the distribution of water across regions and in the regional land rents.

The results on land allocation also show larger changes compared to the social optimum than in the case of crop-specific land taxes. The notion that crop-specific output taxes make water appear too cheap in the New Lands is confirmed by the fact that production of less water-intensive crops like long berseem and winter vegetables decline substantially (by 36.68% and 14.59% respectively), while production of the water intensive crop rice increases by 44.90%. Production of other winter crops also increases substantially in the New Lands (by 38.46%). However, as previously mentioned, there are aggregation problems for this crop category and the results should therefore not be attributed too much emphasis.

The changes to the cropping pattern in the Delta are similar to those found in the case of crop-specific land taxes, although the magnitudes of the changes are larger. Production of the water intensive crops long berseem and rice thus declines by 5.64% and 13.17% respectively, while production of short berseem increases by 15.25% relative to the first best policy scenario. In the Nile Valley, the picture is once again less clear, as the relative changes in the cropping pattern do not appear closely related to crop water requirements. This may be explained by the fact that the Nile Valley tends to have the highest yields for most crops. The changes to the Nile Valley cropping pattern induced by the output taxes thus appear to be driven more by yields than water requirements. However, production of the water intensive crop sugar cane does decline by 4.12%, while production of the non-water intensive crops short berseem and legumes increase by 6.93% and 17.99% compared to the social optimum. This suggests that crop-specific output taxes have also made water appear relatively more expensive in the Nile Valley compared to the first-best scenario. As was the case with crop-specific land taxes, the efficiency of crop-specific output taxes is thus also negatively affected by the need to base these taxes on national averages for yields and crop evapotranspiration. The efficiency of crop-specific output taxes could consequently also be increased by making these taxes region-specific.

5. DISCUSSION AND ROBUSTNESS OF RESULTS.

The main results from section 4 can be summed up as follows: If the amount of New Land is doubled, which corresponds to increasing the total amount of land by 16%, the national water constraint becomes binding in Egypt. The onset of water scarcity implies that the water diversion externality and the recoverable return flow externality will adversely affect social and individual farmer welfare, unless policy initiatives for countering these externalities are introduced. Section 4 investigated the efficiency and production implications of five different policy instruments: A tax on water applied and a credit on recoverable return flows, a tax on water applied, quotas on water applied, crop-specific land taxes, and crop-specific output taxes. Only the combined tax on water applied and credit on recoverable return flows produced a first-best allocation of land and resources. Of the four remaining second-best instruments the tax on water applied (and the quotas on water applied) was the most efficient, while crop-specific output taxes were the least efficient. However, the differences in efficiency between the various instruments were miniscule.

The fact that there is very little difference between the policy instruments in terms of efficiency is not an indication of it being unimportant how water is allocated across crops and regions, but rather an indication that all the analyzed policy instruments are well-designed to counter the two externalities in the model. How well tailored the crop-specific land taxes and output taxes are for addressing the two externalities may be appreciated by comparing the efficiency and income properties of these two tax instruments with the efficiency and income properties of flat taxes on land or output. Using a flat tax on land to regulate farmers’ water use would thus result in net social welfare declining by more than 9% compared to the social optimum, and the tax rate would have to be set so high as to reduce farmers’ profits by almost 79% in order to prevent a violation of the national water constraint. The land constraint would cease to be binding in the New Lands as well as for Delta winter land, and the cropping pattern would change dramatically with substantial reduction in the production of all other crops than rice, fruits, and sugar cane. Using a flat tax on output to regulate farmers’ water use would result in net social welfare declining by more than 16% compared to the social optimum, while farmers’ profits would be reduced by almost 63%. The land constraint would cease to be binding for winter land in the Nile Valley and Delta, and the cropping pattern would undergo extreme changes with 6 of the 13 crops dropping out completely. Comparing these results for flat land or output taxes to the results for crop-specific land and output taxes, which were only marginally less efficient than the first-best policies, thus shows how well-tailored these latter policies are for handling the water diversion and the recoverable return flow externalities.

All the second-best instruments take account of the national average field irrigation efficiency and return flow recoverability. However, only the crop-specific land taxes and the crop-specific output taxes are able to take account of crop-specific variations in these parameters. On the other hand, the crop-specific land taxes and output taxes are based on national average crop water consumption (and in the case of output taxes also national average yields), whereas a tax on water applied implicitly captures the regional differences in crop water consumption. The question is then whether a policy instrument's ability to capture crop-specific field irrigation efficiency outweighs the fact that this policy instrument must rely on national average crop water requirements. For the case of Egypt, the answer to this question is no given the present data set, as the tax on water applied is marginally more efficient than the crop-specific land taxes and the crop-specific output taxes. However, if the different tax policy instruments were regionalized, this conclusion might change, as the crop-specific land tax and output tax rates would no longer have to be averaged across regions.

The tax instruments were not only similar in terms of efficiency, they were also similar in terms of their impact on farmer profits. All the tax instruments thus reduced farmer profits by around 20% compared to the social optimum after total land had been increased by 16%. It is difficult to judge whether this is a reasonable result. However, using an earlier version of the ASME model with 1990 as the base year, Löfgren did a study on water cost recovery and water scarcity in Egypt. One of the water scarcity scenarios featured a 15% percent cut in the water supply. If farmers' water use had to be reduced accordingly through water pricing, this would lead to a 22% reduction in net farm incomes (Löfgren 1996).[39] The magnitude of the

[39] While the only policy instrument included in the water scarcity analysis was water pricing, the cost recovery scenarios also featured a so-called "crop-water-charge". This crop-water-charge appears to be similar to the crop-specific land taxes in the present analysis, except that the crop-water-charge was differentiated by region and does not appear to be adjusted for the extra water needed in rice cultivation. For the cost recovery study, Löfgren found that the crop-water-charge has almost identical effects as a water charge, in spite of the fact that ASME model features multiple water-yield techniques. While the cost recovery study did not feature water scarcity, this may nonetheless be an important insight for the present analysis, as it suggests that the introduction of multiple water-yield techniques probably would not have a substantial effect on the workings of the water applied tax and the crop-specific land taxes. However, as Löfgren's analysis did not include a policy instrument

tax burden in the present simulation is thus in line with this previous study on water scarcity in Egypt.

The question is, however, how robust the results from the present model are with respect to changes in the data and the model specification. The very small impacts on net social welfare - despite the regional differences especially with respect to return flow recoverability - suggest that the model may be overly flexible. The flexibility of the model is determined by several different factors such as the non-linearity of costs and the lack of agronomic constraints. Furthermore, the level of aggregation is also likely to have a noticeable effect on welfare results. These issues will consequently be discussed in the following subsections, starting with a sensitivity analysis of the non-linear cost element.

5.1 SENSITIVITY ANALYSIS ON CROP SUPPLY ELASTICITIES.

The main difference between the present model and the theoretical model presented in chapter 3 is the non-linearity of the cost function. The non-linearity was incorporated into the cost function by allowing average costs for a given crop to vary with the changes in the amount of land allocated to this crop. The degree to which average costs change as the land allocation deviates from the initial cropping pattern is determined in part by the crop supply elasticities. The purpose of the present section is consequently to determine the extent to which the crop supply elasticities affect the simulation results.

The degree to which average costs changes, as the land allocation changes, is inversely related to the crop supply elasticity. Low crop supply elasticities will thus entail larger changes in average costs, and this will in turn tend to dampen the supply response to a given shock. While the purpose of having a non-linear cost function is to prevent the over-specialized cropping patterns produced by completely linear models, the results from the model should

like crop-specific output taxes, it is still not clear whether multiple water-yield techniques would make this policy instrument more efficient compared to the other second-best instruments.

While there are similarities between Löfgren's analysis and the analysis in the present chapter, there are also several key differences. Although later versions of the ASME model include return flow recoverability, there is no mention of return flows in Löfgren's study. The only externality explicitly considered in the water scarcity scenario is thus the water diversion externality. Although the ASME model features multiple regions, Löfgren's study also does not explore the regional dimension of the water issue, which the present analysis has shown to be important. Furthermore, as water scarcity is induced through cuts in the water supply rather than expansion of the New Lands, Löfgren's analysis does not capture the shifts in average crop water consumption, field irrigation efficiency, and return flow recoverability, which the land reclamation project is inducing.

not be driven by the crop supply elasticities, when these are not based on econometric estimates.

As explained in section 3.4, the simulations in the present chapter are based on a uniform crop supply elasticity of 15. In order to determine the degree to which the crop supply elasticity affects the simulation results, additional series of simulations have been run for crop supply elasticities of 5, 10, and 20. The solution to the social planner's problem after doubling the amount of New Land is presented for each of these crop supply elasticities in appendix I.

Starting with the land allocation results, comparison of the five different solutions to the social planner's problem shows that the elasticities of 10, 15, and 20 all produce identical cropping patterns. For the elasticity of 5, on the other hand, relative changes to the cropping pattern tend to be smaller than for the larger elasticity values. At such low elasticity values, the cost specification consequently starts to dominate the cropping pattern results. At the elasticity value of 15, on the other hand, cropping pattern results seem fairly robust to changes in the crop supply elasticity.

However, there are other parts of the model results that are not robust to changes in the crop supply elasticity. These are the rents on land and water. The decline in land rents following the doubling of New Lands is thus greater for lower elasticity values. For an elasticity of 5, the land constraint even ceases to be binding in the summer season in the New Lands. Water rents are also more affected by lower elasticities, as a lower elasticity produces a higher water rent. The reason why land and water rents exhibit larger absolute and relative changes for lower supply elasticities is that a low supply elasticity makes it more costly for the farmer to change his cropping pattern. Resource rents thus have to change more in order to induce the farmer to adjust his cropping pattern following the onset of water scarcity.

This relationship between the crop supply elasticity and the farmer's responsiveness to changes in prices and rents also has important implications for the impact of taxes on farmer's cropping pattern. Comparing the solution to the farmer's problem under the first-best policy of taxing water applied and crediting recoverable return flows for the five different elasticity values demonstrates, that the reduction in farmer's profits in this scenario is larger for the low elasticity values. For a crop supply elasticity of 5, farmer's profits will thus be reduced by almost 39% under the first-best policy scheme, whereas a crop supply elasticity of 15 or 20 will only result in reduction of farmer's profits by 22 % or 17% respectively.[40] Although an elasticity of 15 yields a reasonably stable cropping pattern, the impact on farmer's profit will thus still depend on the crop elasticity chosen. Without additional data on crop supply elasticities in Egypt, it will consequently not be possible to determine the exact impact on farmers' profits of introducing these water regulation policies.

The main focus of the model has been to investigate the social efficiency properties of the different policy instruments. The final point to consider in the sensitivity analysis is consequently whether the choice of elasticity has any implications for the relative efficiency of the policy instruments. While the actual percentage decline in net social welfare for a given second best instrument differs for different elasticity values, the sensitivity analysis also shows that the ranking of the different tax policy instruments in terms of impact on social efficiency is unchanged across the different elasticity values. The conclusions about which of the second-best policy instruments that will be most efficient from a social point of view are thus robust with respect to the choice of crop supply elasticity.

5.2 OTHER FACTORS AFFECTING MODEL FLEXIBILITY

Other aspects of the data and model specification may also have a significant impact on the simulation results. These aspects include additional restrictions on the cropping pattern, the degree of disaggregation of the farmer dimension, and multiple water-yield production techniques.

In the present analysis, restrictions imposed on the cropping pattern have been limited to only ensuring that crops not grown in a particular region in the initial cropping pattern are not subsequently included in the cropping pattern for this region (cf. the discussion in section 3.4 on yields in certain regions being zero for sugar cane, rice, and short berseem). However, in reality agricultural production is obviously subject to a wide variety of agronomic constraints, which reduces the farmer's ability to substitute between crops.

Crop rotations are examples of central agronomic constraints, which are also important in Egypt. According to FAO, the most prevalent crop rotations in Egypt are cotton rotations, which entail cultivation of short berseem in the winter followed by cotton in the summer. The

[40] The results for the farmer's problem under first-best policies are not included, as the only difference between these results and the results for the social planner's optimum are the tax payments.

cotton crop rotations come in two forms – a 3-year rotation in which land is divided into three parcels (one of which is used for cotton and short berseem), and a 2 year rotation in which land is divided into two blocks (one of which is used for cotton and short berseem). The parcels not used for cotton and short berseem are typically cultivated with wheat and long berseem in the winter. In the summer these crops are then usually followed by rice (in the Northern Delta), maize (in the southern Delta and northern Nile Valley), and sorghum (further south in the Nile Valley). Even further south, cotton is replaced by sugar cane as the cash crop (FAO 2000).

Crop rotations consequently place an intricate web of restrictions on farmer's cropping choices in Egypt, and these webs vary by regions. Including such restrictions in a meaningful way in the present model would require more detailed data on the initial cropping pattern, as well as larger degree of regional disaggregation. As mentioned previously, the aim of the present model is to analyze the workings of the water policy instruments. However, if the present framework were to be used for detailed predictions on real-world cropping response to policy changes, inclusion of crop rotation restrictions would be an important addition to the model. Any additional policy restrictions regarding e.g. upper and lower bounds on cultivation of key crops in various regions should also be included.

Crop rotations are not the only other constraints, which may affect real-world farmers' response to changing circumstances in production. As the model has primarily been concerned with the allocation of land and water, all other factors of production have simply been treated as purchased inputs. Labor is generally not in short supply in Egypt, as open unemployment is estimated to be around 10-13% and the labor force is growing at 2.8 % annually (Radwan 2003). However, this need not imply that agricultural labor is always available in the location and at the times when it is needed. Labor market rigidities as well as the well-known moral hazard problems may in some circumstances force farmers to rely more on family labor. There are also likely to be significant regional differences in the rural labor market operations as the Old Lands tend to be characterized by small-scale, household agriculture, while the New Lands also have large-scale agricultural enterprises (Bader 2004 and Meyer 1998). Additional information on the Egyptian rural labor market would be needed to determine, whether labor availability imposes constraints on farm operations during peak labor demand periods.

The introduction of crop rotations as well as other constraints on farm operations would serve to limit the flexibility of the model and hence the farmers ability to respond to changing production circumstances. This might in turn imply larger differences in net social welfare in the different policy scenarios. The rather limited impact on social welfare of using second-best instruments to allocate water may thus in part be explained by the model being overly flexible.

However, in some respects the present version of the model is also overly restrictive. As outlined in section 3.1, it was not possible to obtain the necessary data for a satisfactory implementation of multiple water-yield production techniques. The present model consequently only allows farmer to produce crops using the optimal amount of water. As farmers are generally able to adjust crop water input under water-stressed conditions, the lack of multiple water-yield production techniques reduces the farmer's options for responding to water scarcity. An area for future work would thus be to obtain the necessary information for including multiple water-yield techniques. This might not only be important for the welfare results, but also for the ranking of the policy instruments. As the theoretical analysis in chapter 3 showed, the presence of multiple water-yield techniques may thus affect the relative ranking of the different second-best policy instruments, as some of these are likely to have a more socially optimal impact on the choice of water-yield technique.

5.3 WELFARE RESULTS AND AGGREGATION ISSUES.

The final aspect to be considered in this discussion section is the issue of how welfare results are affected by the data aggregation levels. As previously outlined, there is a shift in aggregation level from the theoretical model to the empirical model, as the former is concerned with individual farmers, while the latter operates with regional farmer types. While it has been necessary to adopt this shift due to lack of individual farmer data, it does have implications for the welfare results in the model. The reason is that operating with regional farmer types conceals the differences between individual farmers. As the welfare properties of the second-best instruments are in some respects inversely related to the degree of heterogeneity in the data,[41] relying on one homogenous farmer type in each region instead of regional groups of individual, heterogeneous farmers would tend to overestimate the

[41] A related, but not completely parallel, example is how crop-specific output taxes were less efficient than crop-specific land taxes, because the former instrument relied on average crop yields and average crop water consumption, whereas the latter only relied on average crop water consumption.

efficiency of the second-best instruments. The very small differences in net social welfare between the first-best and the various second-best policy instruments may thus also be explained by the inability to account for real-world farmer heterogeneity in the present data set.

6. CONCLUSIONS

The purpose of this chapter has been to analyze the efficiency and production implications of using five different sets of policies to regulate farmers' use of water in a situation characterized by the simultaneous presence of the water diversion externality and the recoverable return flows externality. The theoretical analysis in chapter 3 was able to identify first-best and second-best policy instruments. However, it was not possible to theoretically rank the second-best policy instruments as the ranking would depend on parameter values.

The empirical analysis carried out in this chapter has shown that the second best instrument of a water applied tax (or alternatively a set of water applied quotas) is more socially efficient at regulating Egyptian farmers' water use than are crop-specific land taxes and crop-specific output taxes. However, the differences in these policy instruments' efficiency were very small.

The small differences in net social efficiency between the first best instrument of taxing water applied and crediting recoverable return flows and the second-best instrument of simply taxing water applied raises some issues about the importance of handling recoverable return flows correctly. In and of themselves, recoverable return flows are undoubtedly important in the Egyptian national water balance. In the social optimum recoverable return flows thus amount to 12% of water consumed or lost. The question is merely whether using policy instruments, which capture the return flow recoverability correctly, makes a substantial difference in terms of welfare and production. The present analysis suggests that total social welfare is not significant adversely affected by the use of a second-best instrument like a single tax on water applied, as long as the tax rate is right. In terms of production, on the other hand, there are more discernible effects for water-intensive crops, especially at the regional level. The use of a tax on water applied thus reduces rice production in the Delta by 8%, while rice production in the New Lands is increased by 34% compared to first-best policy instrument case. This translates into a 3.75% decrease in total Egyptian rice production. The production of sugar cane is also affected by a switch from first-best to second-best water taxes, as under a single tax on water applied total production of sugar cane drops by 4% compared to the first-best policy case.

The fact that relatively large shifts in the cropping pattern - as in the case of crop-specific output taxes - only produces very small changes in net social welfare suggest that the model is overly flexible in some respects. As outlined in section 5, the lack of detailed agronomic constraints is thus likely to overestimate the farmer's ability to adjust his cropping pattern. Furthermore, the second-best policy instruments will also appear overly efficient due to the lack of data on farmer-heterogeneity within each region. Inclusion of such features in the model may consequently alter the magnitudes of the welfare and production results.

Regulating farmer's use of irrigation water through tax policy instruments will obviously have an impact on farmer profits. The analysis showed that all the tax instruments would reduce farmer profits by around 20%. This is not likely to be well received in the Egyptian countryside, as the notion of charging for irrigation water itself is generally not acceptable (Hellegers and Perry 2004). This makes the option of using quotas in stead of taxes on water applied politically appealing. However, as previously noted, it may be difficult for the government to determine the optimal size of individual farmer water quotas, if farmers are heterogeneous. If quota sizes are not optimal, the efficiency of the quota instrument is likely to deteriorate noticeably. Enforcement of individual quotas on water applied also requires the ability to meter individual farmer water diversions. As outlined in chapter 2, this is not yet possible in many of the Egyptian regions. Crop-specific land taxes and output taxes, on the other hand, do not require the ability to meter individual farmer water diversions. As crop-specific land taxes would typically be easier to implement than crop-specific output taxes (cf. chapter 1), this may consequently be the best instrument for regulating irrigation water use in Egypt.[42]

The issue of how taxes affect farmers' profits point to an important limitation in the model, as the model does not distinguish between the utility of funds in the hands of the government

[42] The notion that high implementation costs results in volumetric water pricing not being the optimal solution to the ensuing water scarcity problem in Egyptian agriculture is also supported by Perry's study on financing of Egyptian irrigation services. Referring to Löfgren's analysis of Egyptian water subsidies and scarcity (cf. section 5), Perry thus concludes that the benefits from being able to meter individual farmers' water diversions in Egypt (in terms of the increase in efficiency from using volumetric water pricing compared to an inefficient rationing mechanism featuring externalities between head-end and tail-end farmers on the irrigation canal) are not likely to make it worth the cost of upgrading the irrigation infrastructure to allow for volumetric metering, in the case of a 15% reduction of water supplies (Perry 1996).

and funds in the hands of the farmers. This is an unrealistic feature of the model, as the only situation in which the distribution of funds will not affect social efficiency is if the government is able to costlessly redistribute funds across agents in society. Unfortunately, this is generally not the case in the real world. However, while the notion of reducing farmer profits by 20% may seem undesirable, it is important to remember that the tax revenue can be spent in ways which are beneficial to the farmers. The impact on farmer utility consequently need not be as negative as the impact on farmer profits.

While the model captures many of the features, which are determining for the efficiency and production impact of the different policy instrument, there are also several features, which would benefit from additional future work. As outlined in section 5, it would thus be desirable to obtain the necessary data for including additional water-yield techniques. As mentioned above, farmer-specific data would also improve the estimate of the policies efficiency potentials, and the model would benefit from the introduction of various agronomic constraints. Another feature, which has been disregarded in the analysis, is the issue of recovering the water delivery costs. These costs are currently being subsidized by the Egyptian government. The revenue from introducing taxes to regulate farmers' water use could be used to cover the water delivery costs. However, this would obviously limit the amount of water tax revenue, which could be spent on other farmer-welfare-improving initiatives.

APPENDIX A: CROP AGGREGATION

Season	IFPRI SAM crops (13)	ASME crops (33)
Winter	Wheat	Wheat
	Legumes	Fava beans, lentils, other legumes
	Long berseem	Long berseem
	Short berseem	Short berseem
	Winter vegetables	Onions (winter), tomatoes (winter), vegetables (winter)
	Other winter crops	Barley, flax, sugar beet
Summer and nili	Cotton	Extra long staple cotton, long staple cotton, medium staple cotton
	Rice	Rice, rice irri-saving variety*
	Maize/sorghum	Maize (summer and nili), sorghum (summer and nili)
	Summer vegetables	Onions (summer), potatoes (summer and nili), tomatoes (summer and nili), vegetables (summer and nili)
	Other summer crops	Ground nuts, soybeans, sesame
Perennial	Fruits	Citrus
	Sugar cane	Sugar cane

* 1997 ASME base data shows no production of the irrigation-saving rice variety (cf. Mohamed 2001 p A63).

APPENDIX B: REGIONAL AGGREGATION

Aggregate regions (3)	ASME regions (10)
Nile Valley	Upper Egypt
	Middle Egypt
Delta	Eastern Delta
	Middle Delta
	Western Delta
New Lands	Sandy soils with ground water irrigation (Matrouh, Wadi El Gedid, North & South Sinai)
	Calcareous soil with canal irrigation (Nuberia area, under Beheira)
	Sandy soils with canal irrigation* (other old new lands in the Old Land regions)
	Sinai* (North Sinai)
	Toshka* (also known as the “New Valley” project)

* 1997 ASME data shows no land available yet for cultivation in the regions sandy-soils-with canal-irrigation, Sinai, and Toshka (cf. Mohamed 2001 p A28)

APPENDIX C: CROPS NOT GROWN IN PARTICULAR REGIONS

Aggregate regions	ASME regions (with crop land in base year)	ASME mapping of crops not grown in given region	ASME policy restrictions on crops	Restrictions on crops adopted in empirical model
Nile Valley	Upper Egypt	Extra long staple cotton Rice Flax Summer onion	Rice	Extra long staple cotton Rice Flax Summer onion
	Middle Egypt	Extra long staple cotton	Rice	Extra long staple cotton Rice
Delta	Eastern Delta	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum	Sugar cane	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum
	Middle Delta	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum	Sugar cane	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum
	Western Delta	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum Lentil	Sugar cane	Sugar cane Medium long staple cotton Summer sorghum Nili sorghum Lentil
New Lands	Calcareous soil with canal irrigation (Nuberia area, under Beheira)	Extra long staple cotton Long staple cotton Medium long staple cotton Short berseem Flax	Sugar cane	Extra long staple cotton Long staple cotton Medium long staple cotton Short berseem Flax Sugar cane
	Sandy soils with ground water irrigation (Matrouh, Wadi El Gedid, North & South Sinai)	Extra long staple cotton Medium long staple cotton Nili sorghum Short berseem Flax Summer onion Sugar beet	Rice Sugar cane	Extra long staple cotton Medium long staple cotton Nili sorghum Short berseem Flax Summer onion Sugar beet Rice Sugar cane

Source: Table compiled from data in Mohamed 2001 (p A5, A8-A9, A67). Regions, which had no land available for cultivation in 1997, as well as crops, which were not grown in 1997 (i.e. the irrigation-saving rice variety), are omitted from the table.

APPENDIX D: INITIAL REGIONAL CROPPING PATTERN (MILL FEDDAN)

Season	Crops	Nile Valley	Delta	New Lands
Winter	Wheat	0.667	1.334	0.486
	Legumes	0.116	0.230	0.084
	Long berseem	0.425	0.851	0.310
	Short berseem	0.266	0.438	0.000
	Winter vegetables	0.119	0.237	0.086
	Other winter crops	0.064	0.125	0.033
Summer and nili	Cotton	0.239	0.567	0.054
	Rice	0.000	1.320	0.230
	Maize/sorghum	0.983	0.831	0.496
	Summer vegetables	0.354	0.405	0.179
	Other summer crops	0.076	0.086	0.038
Perennial	Fruits	0.108	0.178	0.055
	Sugar cane	0.291	0.000	0.000

Source: Own calculations based on Mohamed 2001 p A8, A28, and A67.

APPENDIX E: CROP EVAPOTRANSPIRATION COEFFICIENTS (CUBIC METERS PER FEDDAN)

Season	Crops	Nile Valley	Delta	New Lands
Winter	Wheat	2193	1689	3216
	Legumes	1735	1328	1326
	Long berseem	3118	2483	4098
	Short berseem	1193	922	1575*
	Winter vegetables	1842	1455	2006
	Other winter crops	2004	1520	2969
Summer and nili	Cotton	3513	2677	3694
	Rice	4750*	4456	4456
	Maize/sorghum	2462	2282	3182
	Summer vegetables	2249	1746	3040
	Other summer crops	3083	2577	3433
Perennial	Fruits	4730	4015	7120
	Sugar cane	8063	7000*	7000*

Source: Own calculations based on data from Mohamed 2001 p A39-A40. Evapotranspiration coefficients for New Lands reflect water requirements in the ASME New Land regions, which had land available for cultivation in 1997. Evapotranspiration coefficients for perennial crops show annual water requirement. For crops not grown in a particular region (marked *), approximate evapotranspiration coefficients have been entered. As yields for these crops are kept equal to zero in the present simulations, these evapotranspiration coefficients do not affect results.

APPENDIX F: CROP PRICES (LE PER TON)

Season	Crops	Price
Winter	Wheat	664
	Legumes	1247
	Long berseem	85
	Short berseem	93
	Winter vegetables	392
	Other winter crops	148
Summer	Cotton	3003
	Rice	718
	Maize/sorghum	560
	Summer vegetables	443
	Other summer crops	1885
Perennial	Fruits	731
	Sugar cane	95

Source: Own calculations based on Mohamed p A53, FAOSTAT core production data (http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340), and FAO 2000.

APPENDIX G: REGIONAL YIELD COEFFICIENTS (TON PER FEDDAN)

Season	Crops	Nile Valley	Delta	New Lands
Winter	Wheat	2.515	2.276	1.386
	Legumes	1.071	1.276	1.240
	Long berseem	26.494	24.577	20.096
	Short berseem	12.578	9.793	0.000
	Winter vegetables	12.379	8.776	8.706
	Other winter crops	8.051	6.269	2.599
Summer and nili	Cotton	1.082	0.999	0.656
	Rice	0.000	3.386	2.508
	Maize/sorghum	2.591	3.016	2.041
	Summer vegetables	10.912	10.775	9.604
	Other summer crops	1.028	0.850	0.778
Perennial	Fruits	6.155	8.089	5.242
	Sugar cane	45.715	0.000	0.000

Source: Own calculations based on data from Mohamed 2001 p A50-A51. Yield for crops not grown in particular region, whether due to general cropping pattern or crop policy restrictions, are equal to zero.

APPENDIX H: SOLUTION TO SOCIAL PLANNER'S PROBLEM FOR THE INITIAL RESOURCE ENDOWMENT (CONT'D ON NEXT PAGE).

As explained in section 4.2, the solution to the social planner's problem for the initial resource endowment is not completely identical to the initial cropping pattern, as the land endowment is specified so as to not be strictly binding for the initial cropping pattern. The four columns on the left show the solution to the social planner's problem for the initial resource endowment (i.e. before expansion of the New Lands), while the four columns on the right show the percentage change in the variables compared to the initial cropping pattern and the initial land rents.

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	1					
					% Change from fixed initial solution			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1439	2449	706	4594	0.25%	0.24%	0.56%	0.29%
Farmer profit (Revenue - Cost - Taxes)	1439	2449	706	4594	0.25%	0.24%	0.56%	0.29%
Revenue	9027	14969	3548	27543	0.28%	0.28%	0.55%	0.31%
Cost of purchased inputs	7588	12520	2842	22949	0.28%	0.29%	0.54%	0.32%
Total taxes collected	0	0	0	0				
Tax on water applied	0	0	0	0				
Credit on water recovered	0	0	0	0				
Crop-specific output taxes	0	0	0	0				
Crop-specific land taxes	0	0	0	0				
					% Change from initial optimum			
Water use (mill cubic meters)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Water consumed or lost	11016	19556	10234	40806	0.32%	0.32%	0.66%	0.41%
Quotas on water applied	100000	100000	100000	300000	0.00%	0.00%	0.00%	0.00%
Water applied	14447	22509	10234	47190	0.32%	0.33%	0.66%	0.40%
Recovered return flows	3431	2953	0	6385	0.32%	0.35%	0.00%	0.33%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0000				% Change from fixed initial solution			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	280	266	265		-0.07%	-0.08%	-0.16%	
Summer	272	307	289		-0.22%	-0.20%	-0.27%	

Land allocation (mill feddan)	Valley	Delta	NewLand	Total	% Change from fixed initial solution Valley	Delta	NewLand	Total
Wheat	0.67	1.34	0.49	2.49	0.18%	0.21%	0.71%	0.30%
Legumes	0.12	0.23	0.08	0.43	0.22%	0.20%	0.42%	0.25%
Long berseem	0.43	0.85	0.31	1.59	0.13%	0.15%	0.38%	0.19%
Short berseem	0.27	0.44	0.00	0.71	0.25%	0.34%	0.00%	0.31%
Winter vegetables	0.12	0.24	0.09	0.44	0.06%	0.09%	0.19%	0.10%
Other winter crops	0.06	0.13	0.03	0.22	0.25%	0.34%	1.71%	0.52%
Cotton	0.24	0.57	0.05	0.86	0.28%	0.31%	0.60%	0.32%
Rice	0.00	1.33	0.23	1.56	0.00%	0.38%	0.65%	0.42%
Maize / sorghum	0.99	0.84	0.50	2.33	0.63%	0.55%	1.03%	0.69%
Summer vegetables	0.35	0.41	0.18	0.94	0.19%	0.19%	0.28%	0.21%
Other summer crops	0.08	0.09	0.04	0.20	0.47%	0.58%	0.81%	0.58%
Fruits (citrus)	0.11	0.18	0.06	0.34	0.27%	0.21%	0.48%	0.27%
Sugar cane	0.29	0.00	0.00	0.29	0.28%	0.00%	0.00%	0.28%
Total use of winter land	2.06	3.40	1.06	6.52	0.19%	0.21%	0.57%	0.26%
Total use of summer land	2.06	3.40	1.06	6.52	0.44%	0.38%	0.76%	0.46%

Production (mill ton)	Valley	Delta	NewLand	Total	% Change from fixed initial solution Valley	Delta	NewLand	Total
Wheat	1.68	3.04	0.68	5.40	0.18%	0.21%	0.71%	0.26%
Legumes	0.12	0.29	0.10	0.52	0.22%	0.20%	0.42%	0.25%
Long berseem	11.27	20.95	6.25	38.47	0.13%	0.15%	0.38%	0.18%
Short berseem	3.35	4.30	0.00	7.66	0.25%	0.34%	0.00%	0.30%
Winter vegetables	1.47	2.08	0.75	4.31	0.06%	0.09%	0.19%	0.10%
Other winter crops	0.52	0.79	0.09	1.39	0.25%	0.34%	1.71%	0.39%
Cotton	0.26	0.57	0.04	0.86	0.28%	0.31%	0.60%	0.31%
Rice	0.00	4.49	0.58	5.07	0.00%	0.38%	0.65%	0.41%
Maize / sorghum	2.56	2.52	1.02	6.11	0.63%	0.55%	1.03%	0.66%
Summer vegetables	3.87	4.37	1.72	9.97	0.19%	0.19%	0.28%	0.21%
Other summer crops	0.08	0.07	0.03	0.18	0.47%	0.58%	0.81%	0.57%
Fruits (citrus)	0.67	1.44	0.29	2.40	0.27%	0.21%	0.48%	0.26%
Sugar cane	13.34	0.00	0.00	13.34	0.28%	0.00%	0.00%	0.28%

APPENDIX I (CONT'D ON NEXT PAGES): SOLUTION TO THE SOCIAL PLANNER'S PROBLEM WITH CROP ELASTICITY OF 5

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from initial optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	2028	3403	1792	7223	-0.53%	-1.20%	90.49%	12.44%
Farmer profit (Revenue - Cost - Taxes)	2028	3403	1792	7223	-0.53%	-1.20%	90.49%	12.44%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0598				% Change from initial optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	141	161	3		-49.56%	-39.46%	-98.98%	
Summer	102	74	0		-62.49%	-75.87%	-100.00%	
					% Change from initial optimum			
Land allocation (mill feddan)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.98	1.51%	-1.74%	101.01%	19.30%
Legumes	0.13	0.24	0.25	0.63	12.30%	5.72%	198.92%	45.34%
Long berseem	0.38	0.74	0.49	1.61	-11.35%	-13.62%	58.93%	1.20%
Short berseem	0.34	0.55	0.00	0.89	28.10%	24.44%	0.00%	25.83%
Winter vegetables	0.12	0.24	0.20	0.56	2.72%	1.45%	128.78%	26.61%
Other winter crops	0.07	0.13	0.09	0.28	6.93%	3.08%	153.20%	26.83%
Cotton	0.22	0.62	0.11	0.95	-6.79%	9.63%	94.23%	10.40%
Rice	0.00	0.99	0.17	1.16	0.00%	-25.63%	-25.34%	-25.59%
Maize / sorghum	1.06	1.04	1.13	3.23	6.74%	24.64%	126.26%	38.92%
Summer vegetables	0.37	0.46	0.38	1.20	3.37%	12.40%	109.75%	27.59%
Other summer crops	0.07	0.10	0.08	0.26	-4.65%	20.00%	106.54%	27.17%
Fruits (citrus)	0.11	0.19	0.11	0.41	2.24%	6.37%	92.79%	19.05%
Sugar cane	0.23	0.00	0.00	0.23	-20.96%	0.00%	0.00%	-20.96%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%
Total use of summer land	2.06	3.40	1.97	7.43	0.00%	0.00%	86.30%	14.03%

APPENDIX I (CONT'D): SOLUTION TO THE SOCIAL PLANNER'S PROBLEM WITH CROP ELASTICITY OF 10

Number of Farmers of Type j	Valley	Delta	NewLand		Valley	Delta	NewLand	
	1	1	2					
					% Change from initial optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1581	2667	1494	5742	-0.52%	-1.16%	95.45%	13.67%
Farmer profit (Revenue - Cost - Taxes)	1581	2667	1494	5742	-0.52%	-1.16%	95.45%	13.67%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0367				% Change from initial optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	195	201	104		-30.40%	-24.20%	-60.55%	
Summer	168	164	99		-38.24%	-46.45%	-65.76%	
					% Change from initial optimum			
Land allocation (mill feddan)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	1.86%	-2.14%	100.78%	19.13%
Legumes	0.13	0.25	0.27	0.65	15.11%	7.02%	221.24%	51.17%
Long berseem	0.37	0.71	0.46	1.54	-13.94%	-16.72%	49.32%	-3.04%
Short berseem	0.36	0.57	0.00	0.93	34.51%	30.02%	0.00%	31.72%
Winter vegetables	0.12	0.24	0.20	0.57	3.34%	1.78%	135.25%	28.22%
Other winter crops	0.07	0.13	0.09	0.29	8.52%	3.78%	164.31%	29.36%
Cotton	0.22	0.64	0.11	0.97	-8.34%	11.83%	106.37%	12.19%
Rice	0.00	0.91	0.14	1.05	0.00%	-31.48%	-39.27%	-32.64%
Maize / sorghum	1.07	1.09	1.28	3.44	8.27%	30.26%	155.25%	47.84%
Summer vegetables	0.37	0.47	0.39	1.23	4.14%	15.23%	118.21%	30.72%
Other summer crops	0.07	0.11	0.09	0.27	-5.71%	24.57%	126.05%	32.45%
Fruits (citrus)	0.11	0.19	0.11	0.41	2.75%	7.83%	97.97%	20.81%
Sugar cane	0.22	0.00	0.00	0.22	-25.75%	0.00%	0.00%	-25.75%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%

APPENDIX I (CONT'D): SOLUTION TO THE SOCIAL PLANNER'S PROBLEM WITH CROP ELASTICITY OF 15

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from initial optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1434	2428	1388	5250	-0.38%	-0.85%	96.71%	14.29%
Farmer profit (Revenue - Cost - Taxes)	1434	2428	1388	5250	-0.38%	-0.85%	96.71%	14.29%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0245				% Change from initial optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	223	223	158		-20.26%	-16.13%	-40.33%	
Summer	203	212	163		-25.47%	-30.94%	-43.78%	
					% Change from initial optimum			
Land allocation (mill feddan)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	1.86%	-2.14%	100.78%	19.13%
Legumes	0.13	0.25	0.27	0.65	15.11%	7.02%	221.24%	51.17%
Long berseem	0.37	0.71	0.46	1.54	-13.94%	-16.72%	49.32%	-3.04%
Short berseem	0.36	0.57	0.00	0.93	34.51%	30.02%	0.00%	31.72%
Winter vegetables	0.12	0.24	0.20	0.57	3.34%	1.78%	135.25%	28.22%
Other winter crops	0.07	0.13	0.09	0.29	8.52%	3.78%	164.31%	29.36%
Cotton	0.22	0.64	0.11	0.97	-8.34%	11.83%	106.37%	12.19%
Rice	0.00	0.91	0.14	1.05	0.00%	-31.48%	-39.27%	-32.64%
Maize / sorghum	1.07	1.09	1.28	3.44	8.27%	30.26%	155.25%	47.84%
Summer vegetables	0.37	0.47	0.39	1.23	4.14%	15.23%	118.21%	30.72%
Other summer crops	0.07	0.11	0.09	0.27	-5.71%	24.57%	126.05%	32.45%
Fruits (citrus)	0.11	0.19	0.11	0.41	2.75%	7.83%	97.97%	20.81%
Sugar cane	0.22	0.00	0.00	0.22	-25.75%	0.00%	0.00%	-25.75%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%

APPENDIX I (CONT'D): SOLUTION TO THE SOCIAL PLANNER'S PROBLEM WITH CROP ELASTICITY OF 20

Number of Farmers of Type j	Valley	Delta	NewLand					
	1	1	2					
					% Change from initial optimum			
Income and Welfare (mill LE))	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Net social welfare (Revenue-Cost)	1360	2309	1335	5005	-0.30%	-0.67%	97.43%	14.65%
Farmer profit (Revenue - Cost - Taxes)	1360	2309	1335	5005	-0.30%	-0.67%	97.43%	14.65%
Resource rents								
Water (LE per cubic meter consumed or lost)	0.0184				% Change from initial optimum			
Land (LE per feddan)	Valley	Delta	NewLand		Valley	Delta	NewLand	
Winter	237	234	185		-15.19%	-12.09%	-30.24%	
Summer	221	236	194		-19.09%	-23.19%	-32.81%	
					% Change from initial optimum			
Land allocation (mill feddan)	Valley	Delta	NewLand	Total	Valley	Delta	NewLand	Total
Wheat	0.68	1.31	0.98	2.97	1.86%	-2.14%	100.78%	19.13%
Legumes	0.13	0.25	0.27	0.65	15.11%	7.02%	221.24%	51.17%
Long berseem	0.37	0.71	0.46	1.54	-13.94%	-16.72%	49.32%	-3.04%
Short berseem	0.36	0.57	0.00	0.93	34.51%	30.02%	0.00%	31.72%
Winter vegetables	0.12	0.24	0.20	0.57	3.34%	1.78%	135.25%	28.22%
Other winter crops	0.07	0.13	0.09	0.29	8.52%	3.78%	164.31%	29.36%
Cotton	0.22	0.64	0.11	0.97	-8.34%	11.83%	106.37%	12.19%
Rice	0.00	0.91	0.14	1.05	0.00%	-31.48%	-39.27%	-32.64%
Maize / sorghum	1.07	1.09	1.28	3.44	8.27%	30.26%	155.25%	47.84%
Summer vegetables	0.37	0.47	0.39	1.23	4.14%	15.23%	118.21%	30.72%
Other summer crops	0.07	0.11	0.09	0.27	-5.71%	24.57%	126.05%	32.45%
Fruits (citrus)	0.11	0.19	0.11	0.41	2.75%	7.83%	97.97%	20.81%
Sugar cane	0.22	0.00	0.00	0.22	-25.75%	0.00%	0.00%	-25.75%
Total use of winter land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%
Total use of summer land	2.06	3.40	2.12	7.58	0.00%	0.00%	100.00%	16.26%

CHAPTER 5

THE COMMON AGRICULTURAL POLICY IN AN ENLARGED EUROPE: BRIGHT OR BLEAK PROSPECTS FOR AFRICA?[♣]

1. INTRODUCTION.

The previous chapters have highlighted the importance of Egyptian land reclamation policies for the national water balance and the future composition of the agricultural sector in Egypt. However, the future of Egyptian agriculture is not merely shaped by domestic agricultural policies. Through international trade, Egypt is also affected by changes in agricultural policies in other countries. The European Union is one of Egypt's most important trading partners, as the EU currently account for 42% of total Egyptian exports and 37% of total Egyptian imports (European Commission 2006). In terms of trade in agricultural commodities, the EU is also a very important trading partner for Egypt. Egypt may thus be influenced by current and future changes in the Common Agricultural Policy of the European Union.

The Common Agricultural Policy (CAP) is scheduled to undergo major changes in the coming years. In December 2002 the EU decided to go ahead with the so-called Eastern Enlargement of the European Union by expanding the EU with ten new member countries in 2004, thereby also expanding the domain of the CAP significantly. In June 2003 the EU subsequently reached an agreement on the so-called Mid-term Review (MTR) of the CAP, which entails radical reforms of the CAP and its incentive structure from 2004 onwards. As the EU is one of the major players on the agricultural world markets, the expansion of the CAP and the MTR reform may have a significant impact on world trade in agricultural commodities, thereby also affecting developing countries including Egypt. But how extensive will this impact be, and will the overall effects be positive or negative for the EU's trading

[♣] The present paper is co-authored by Hans Grinsted Jensen. A slightly revised version of the chapter was published as chapter 3 in E. Diaz-Bonilla, S.E. Frandsen, and S. Robinson (eds.): WTO Negotiations and Agricultural Trade Liberalization – The Effect of Developed Countries' Policies on Developing Countries. CAB International 2006. Comments from editors and reviewers on earlier drafts are gratefully acknowledged.

partner? That is the question this chapter seeks to answer focusing specifically on the impact on different regions in Africa, including North Africa.[1]

The purpose of this chapter is consequently to provide a quantitative assessment of how the Eastern Enlargement and the MTR reform will affect agriculture in the African countries in terms of output, trade flows, and overall welfare. This is accomplished by using a modified version of the global general equilibrium model GTAP, where special attention has been given to the modeling of the CAP. However, before turning to this quantitative analysis we will give a brief introduction to the agricultural aspects of the Eastern Enlargement as well as the MTR-reform of the CAP.

2. The Eastern Enlargement of the EU.

After a decade of negotiations and preparations a historic agreement was reached at the European Council meeting in Copenhagen on December 13, 2002: Eight Central and Eastern European Countries (Poland, Hungary, the Czech Republic, the Slovak Republic, Estonia, Latvia, Lithuania, and Slovenia) as well as Cyprus and Malta will accede to the EU in the so-called Eastern Enlargement scheduled for May 1, 2004.

Accession to the EU will have significant consequences for the agricultural sectors in the ten accession countries. The remaining border protection between the existing and the new members will be removed, and the new member countries will adopt the same level of border protection against third countries as that existing in the EU. The latter implies that some accession countries will have to raise existing tariffs on certain commodities significantly, while other accession countries will have to lower their tariffs on various commodities (Jensen and Frandsen 2003a). Thus in some cases the Eastern Enlargement will reduce third countries' access to accession country markets, while in other cases it will – ceteris paribus - enhance access to these markets.[2]

[1] The present analysis was undertaken in 2003, when Egypt had not yet been included in the GTAP database as a separate country. In the present analysis, Egypt is consequently a part of the North African region. Egypt has now been included as a separate country in version 6.2 of the GTAP database, which was released in June 2006.
[2] The EU's Everything But Arms initiative (EBA), which entails a non-reciprocal removal of all EU restrictions on imports (except import of arms) from Least Developed Countries (LDCs) (Yu and Jensen 2003), will also apply in the new member countries after the enlargement. Thus LDCs' access to accession country markets will improve following the Eastern Enlargement.

CAP market measures such as the intervention price system and the export subsidies will be extended to the new member countries from day one. [3] Naturally these measures are also accompanied by an extension of the EU production quota system to the new member countries. Direct payments in the form of area and animal premium will also be extended to the new member countries but these will be phased in over a period of 10 years (cf. European Commission 2002). Furthermore due to a simplified implementation scheme in the initial years as well as the ensuing MTR-reform (cf. section 3.1), the majority of the premiums in the new member countries will be decoupled from production.

The extension of the CAP to the new member countries will obviously be costly. However, in October 2002 the EU leaders agreed on a financial framework, which stabilizes EU spending on CAP expenditures in the period up to 2013 (the so-called Schroeder-Chirac deal). The total expenditures on market measures and direct payments in the enlarged EU comprising 25 countries (henceforth EU25) will consequently be bounded by this financial framework.

3. The MTR-reform of the CAP.

On July 10, 2002 the European Commission presented its proposal for the so-called mid-term review (MTR) of the CAP. This review had been undertaken in accordance with the stipulations of the Agenda 2000 reform of the CAP, and was as such expected, but apparently the radical content of the proposal came as a surprise to many. However, after a year of tough negotiations the European Council finally agreed on how to reform the CAP in June 2003.

The final MTR-reform is comprised of five main elements (cf. Frandsen and Walter-Jørgensen 2006 p 37):

- Continuation of the Agenda 2000 approach to revisions of the market measures for certain commodities.
- Decoupling of direct support by introduction of a single farm income payment based on historical reference of payment.
- Introduction of cross compliance through reduction of direct payments in case of non-compliance with EU standards regarding environment, food safety, animal health and welfare.

[3] Except in the case of export subsidies to sugar, where special rules apply (cf. Jensen and Frandsen 2003a)

- Strengthening of rural development by enhancement of rural development instruments to meet new standards and by redistribution of funds from 1st to 2nd pillar of the CAP (so-called modulation).
- Introduction of a financial discipline mechanism to ensure that the CAP expenditures do not exceed the financial framework.

The details of these five elements are presented in Frandsen and Walter-Jørgensen (2006), and the following presentation will therefore only focus on the key principles in this reform.

The continuation of the Agenda 2000 approach to revisions of the market measures entails a reduction of the intervention prices for a number of commodities, in some cases coupled with increases in the direct support payments for these commodities[4]. In the case of dairy products the intervention price for butter will be reduced by 25 per cent (which is an additional 10% price cut compared to the Agenda 2000 reform), while intervention prices for skimmed milk powder will be lowered by 15 per cent (as agreed in the Agenda 2000 reform). The price reductions are compensated through introduction of a direct payment per ton of milk quota from 2004 and onwards. Milk quotas are to be maintained to 2014/15 (with an increase in the quotas for Greece and Portugal). For cereals on the other hand there will be no change in the intervention price, but the monthly increments are reduced by 50 per cent. The area premium for cereals (as well as oilseeds, protein, and set-aside) remains unchanged (Frandsen and Walter-Jørgensen 2006).

The most radical and innovative feature of the MTR-reform is no doubt the decision to decouple some of the direct support payments from production.[5] This is done by replacing most of the previous area and animal premiums (including the premiums for cereals, oilseeds, and protein crops, as well as the premiums for beef, veal, sheep, goats, and milk) with a single decoupled farm income payment from 2005 (in the case of milk 2006/07) onwards. This

[4] Minimum producer prices (intervention prices) are guaranteed to producers for certain agricultural produce in the EU, through a combination of sales at floor prices to a buffer stock agency and measures taken at the border. Lowering of the intervention price reduces the floor price at which stock agency starts purchasing. Direct support payments are given to farmers as compensation for reductions in intervention prices.

[5] The theoretical concepts of coupled and decoupled support refer to how closely the amount of support is linked to the size of current production. Fully coupled support entails a direct link between the size of current production and the amount of support (the typical example being price support), whereas fully decoupled support means that the amount of support is completely independent of current production (the typical example being direct support payments, which solely depend on historical production in a fixed reference period, and hence do not require any current production) (cf. also Frandsen et al 2003).

single farm income payment, which is based on historical reference of payment, is tied to the land. Howeever, the land can be used for any agricultural activity – save for certain exceptions regarding production of fruit, vegetables, and table potatoes – as long as it is maintained in good agricultural condition.[6]

The decoupling scheme covers the majority of the direct support premiums, and if implemented fully it would have significant consequences for EU agricultural production. However, the member states are granted some discretion regarding the extent of decoupling, as they are allowed to opt for a partial implementation of the decoupling scheme in the following ways (Frandsen and Walter-Jørgensen 2006):

- Retain 25 per cent of the hectare premium or alternatively up to 40 per cent of the supplementary durum wheat aid.
- Retain up to 50 per cent of the sheep and goat premiums.
- Retain up to 100 per cent of the suckler cow premium and up to 40 per cent of the slaughter premium or instead retain either up to 100 per cent of the slaughter premium or alternatively up to 75 per cent of the special male premium component.
- Make additional payments for the purposes of encouraging specific types of farming which are important for the protection or enhancement of the environment and improving the quality and marketing of agricultural products.

The direct payments are also affected by another main element in the MTR-reform. Modulation entails a percentage reduction in the individual farm's direct payments after allowing for a franchise of 5000 €. The saved funds will be used for rural development measures (cf. Frandsen and Walter-Jørgensen 2006). As modulation affects all direct support payments this specifically also entails a reduction in the product specific direct support payments.

[6] The exact restrictions on the production of fruit and vegetables and table potatoes depend on whether the single farm payment is implemented according to the Fischler model or the regional model. Under the former model the farmer cannot receive the single farm payment on land used for growing of these crops. Under the latter model the farmer may receive the single farm payment on land used for the production of these crops, provided that the total amount of land used for production of fruit and vegetables and table potatoes does not exceed the amount of land used for production of these crops in the reference period. Whether this regional model will constrain the production of fruit and vegetables and tables potatoes in reality depends on how the restrictions are administered and how the yields for these crops develop (cf. Jensen and Frandsen 2003c).

4. Modeling the Future Common Agricultural Policy

In order to empirically investigate the impact on developing countries of the Eastern Enlargement and the MTR-reform, we incorporate these policy initiatives into a global CGE model and database - the so-called Global Trade Analysis Project (GTAP).[7] The GTAP model and database are specifically tailored to the analysis of global trade issues, and our analysis is based on an explicit representation of the CAP in this model, where all the EU-25 member countries are individually represented.

The GTAP model is a standard multi-regional, static computable general equilibrium (CGE) model. Like any other applied economic model, this model is of course based on specific assumptions both in terms of theoretical structure as well as the specific parameters and data used. Thus regional production is produced according to a constant return to scale technology in a perfectly competitive environment, and the private demand system is represented by a non-homothetic demand system (a Constant Difference Elasticity function).[8] The foreign trade structure is characterized by the Armington assumption implying imperfect substitutability between domestic and foreign goods (cf. Jensen and Frandsen 2003b). The macroeconomic closure used is a neo-classical closure where investments are endogenous and adjust to accommodate any changes in savings. This approach is adopted at the global level and investments are then allocated across regions to equalize the marginal rate of return in all regions. Although global investments and savings must be equal, this does not apply at the regional level, where the trade balance is endogenously determined as the difference between regional savings and regional investments. This is valid as regional savings enter the regional utility function. The labor market closure used exogenizes the amount of labor, so that the wage rate adjusts to ensure full employment in the model. The numéraire used in the model is a price index as suggested by De Melo and Robinson (1989) and De Melo and Tarr (1992), namely the global primary factor price index.

The following analysis uses version 5 of the GTAP database (with 1997 as the base year) and a CAP specific version of the GTAP model. To keep the model focused and within computational bounds the database is aggregated to 40 countries and 24 commodities of

[7] References for the GTAP model and database are Hertel 1998 and Dimaranan and McDougall 2002. The model is solved using GEMPACK (Harrison and Pearson 1996)

[8] Hence, the present analysis abstracts from features such as imperfect competition and increasing returns to scale, which may, however, be important in certain sectors.

which 12 are primary agricultural goods and 7 are secondary agricultural goods.[9] The GTAP model and database were then used to run three simulation scenarios, and some of the results were then further aggregated across selected commodity and country groupings.

The first of these simulations is a baseline for the period 1997-2013, which provides us with an updated database that subsequently serves as the benchmark against which the impacts of the Eastern Enlargement and the MTR-reform are measured. The baseline features projections of the world economy and incorporates the effects of changes in the CAP as outlined in the Agenda 2000 reform, the Everything But Arms' initiative (EBA),[10] and the EU preferential market access for bovine meat products and other meat products from the Accession Countries (cf. Baker 2002).

The impact of the Eastern Enlargements and the MTR reform are then analyzed in two scenarios, which are build on the updated database for the year 2013. In the first scenario we study the effect of enlarging the EU with the ten new member countries under the current CAP regime of Agenda 2000. This so-called Agenda 2000 scenario thus illustrates the consequences of simply enlarging the EU without further reforms of the CAP (although the budgetary ceiling from the Schroeder-Chirac deal is observed). The second scenario, on the other hand, features the Eastern Enlargement as well as the MTR reform of the CAP. Hence this so-called MTR scenario is the "realistic" scenario, which illustrates the combined effects of the two events.

Both scenarios thus entail the integration of the ten new member countries into the EU and the CAP in the year 2013. Enlargement of the EU implies that all tariffs and export subsidies as well as non-tariff barriers between the EU and the new members countries are abolished. At the same time all sectors in the new member countries are given the same level of protection against third countries as that found in the EU at the time of accession. As previously mentioned, this implies that import tariffs in all the new member countries will change for almost all agricultural commodities – and often significantly so. Export subsidies are also introduced for certain agricultural commodities. Regarding domestic support, the expansion

[9] The commodity group beverages and tobacco is not considered an agricultural commodity in this study (cf. table 1)
[10] The EBA initiative is modelled in the baseline period by reducing all EU tariff rates to zero on imports from Malawi, Mozambique, Tanzania, Zambia, Uganda and the two GTAP aggregate regions Other Southern Africa and the Rest of Sub-Saharan Africa. For an evaluation of the EBA initiative see Yu and Jensen 2006.

of the CAP to the new member countries follows the outlines for domestic support (in terms of direct payments, production quotas and other supply management instruments) laid down by the Copenhagen Agreement. This means that in our analysis the new member countries will receive 100% of the CAP direct payment level, as these payments will be fully phased in the year 2013. The baseline as well as the specific changes in tariffs and export subsidy rates and outlines for domestic support are fully documented in Jensen and Frandsen 2003a and 2003b.

In the Agenda 2000 scenario there are no further changes to the CAP than those implied by enlargement of the EU with the ten new member countries. This means among other things that the domestic support payments, which are introduced in the new member countries, will be coupled to current land use and livestock production in this scenario.

In the MTR-scenario, on the other hand, the CAP in the enlarged EU is reformed in accordance with the stipulations of the MTR-reform. First of all, this entails a number of adjustments to the market measures for certain commodities. Thus the supplementary durum wheat payments are reduced to 285 €/ha in traditional areas and 0 €/ha in well-established areas. Also rice and dairy intervention prices are reduced (modelled as import tariff/export subsidy reductions) and direct payments to rice as well as dairy premiums and additional payments to milk producers are increased. Milk quotas in Portugal and Greece are also expanded.

Second – and more importantly – domestic support payments are also decoupled in the MTR-scenario in accordance with the rules laid out in the MTR-agreement. However, as stated in the previous section, EU-members will have a certain amount of discretion in the implementation of the MTR-reform, which means that we have had to make specific assumptions about how to model the MTR-reform implementation in each member country. In order to make the scenario as realistic as possible, we have based these assumptions on the political debate taking place in each member country about the options for decoupling direct payments. This has resulted in the following assumptions:

COUPLING / DECOUPLING ASSUMPTIONS FOR DOMESTIC SUPPORT IN THE MTR SCENARIO

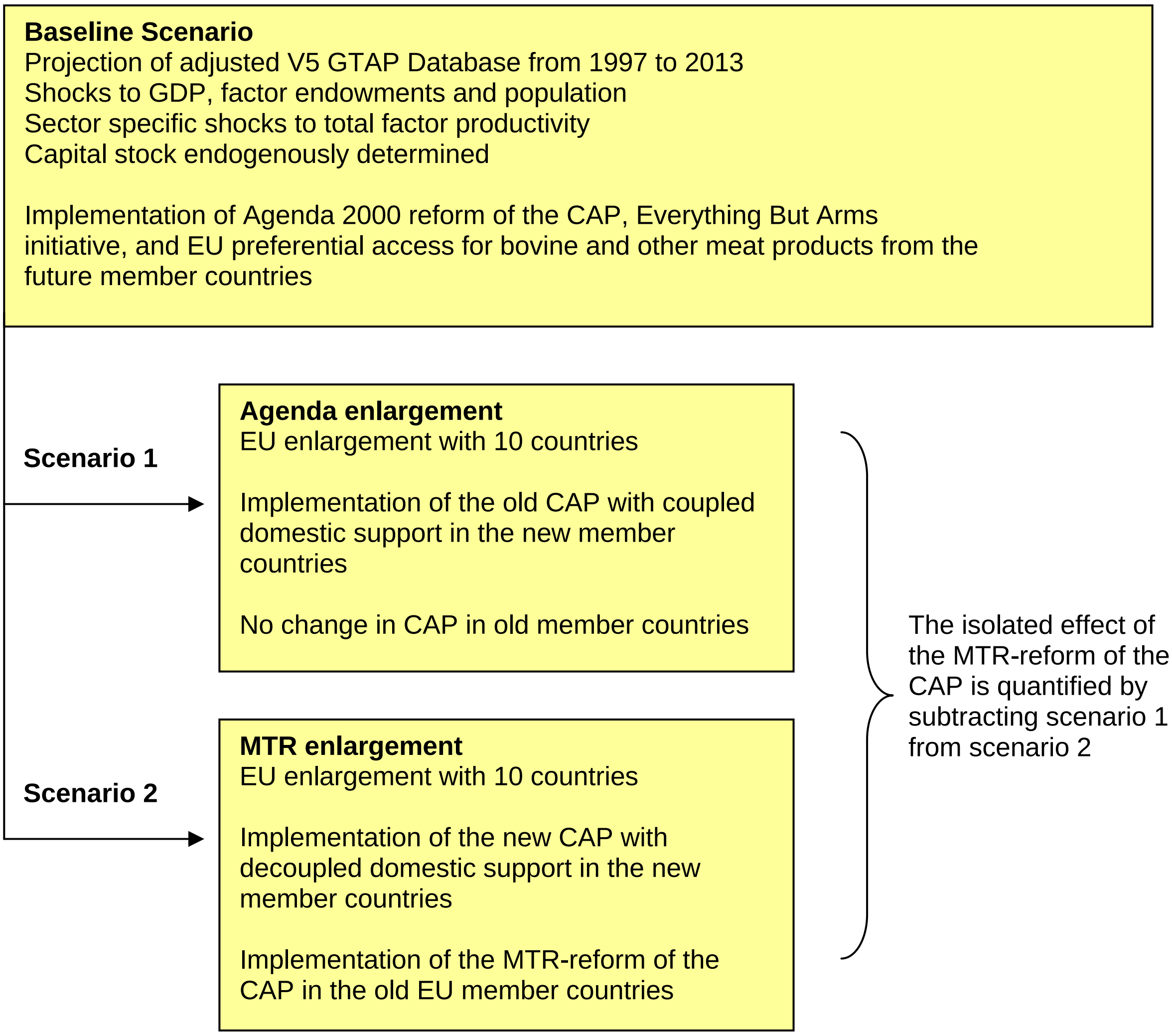
	Cattle	Sheep /Goat	Durum Wheat	Hectare premiums
France	100% veal slaughter premiums 100% suckler cow and 40% slaughter premiums given to bulls, steers cows and heifers from the age of eight months	50% coupling	D	25% coupling
Denmark	75% coupling of special male premium	50% coupling	D	D
Portugal	100% coupling of suckler cow and 40% coupling of slaughter premiums	50% coupling	D	D
Finland	75% coupling of special male premium	50% coupling	D	D
Greece	D	50% coupling	40% coupling	D
Italy	100% coupling of slaughter premiums	D	40% coupling	D
Spain	100% coupling of suckler cow and 40% coupling of slaughter premiums	D	40% coupling	D
Austria	100% coupling of suckler cow and 40% coupling of slaughter premiums	D	D	D
Belgium/Luxembourg	100% coupling of veal slaughter premiums	D	D	D
Germany	100% coupling of veal slaughter premiums	D	D	D
Netherlands	100% coupling of veal slaughter premiums	D	D	D
Sweden	75% coupling of special male premium	D	D	D
Ireland	Full decoupling			
UK	Full decoupling			
All accession countries	Full decoupling			

Note: D is equal to a 100 per cent decoupling of payments.

The decoupled payments of the MTR-reform are modelled by converting direct aid payments in each member country into a uniform hectare payment given to all utilised agricultural area. The results in this chapter consequently illustrate the situation, where direct support is decoupled from production without enforcement of any restrictions on land use. Furthermore, all direct payments have been reduced in accordance with MTR-stipulations on modulation, and the amounts saved have been reallocated to rural development following the MTR-guidelines (cf. Frandsen and Walter-Jørgensen 2006).[11] Figure 1 summarizes the experimental design adopted in the analysis:

[11] In the present analysis, the distribution of direct payments within each class of payment (<= 5000, > 5000 €), aggregated to country level for the old EU-15 members countries, is based on working document n° 12 from the

FIGURE 1: EXPERIMENTAL DESIGN



The Agenda 2000 enlargement scenario thus illustrates the effect of enlarging the EU with the ten new member countries without reforming the CAP, whereas the MTR enlargement scenario shows the effect of enlarging the EU with ten countries while also reforming the CAP in accordance with the MTR agreement. As shown in figure 1, the pure effect of the MTR-reform in an enlarged EU may be derived by comparing the MTR-scenario results with the Agenda scenario results, as any difference between these two sets of results can be attributed to the MTR-reform. It should be noted that the scenario of primary interests is the "realistic" MTR-enlargement scenario, whereas the Agenda 2000 scenario is simply an auxiliary scenario, which helps us in decomposing the results in the MTR-enlargement scenario.

Council Working Party (Council of the European Union 2003). From this data, aggregate national rates of reduction have been calculated and used to modulate direct payments.

5. RESULTS FOR PRODUCTION IN EU25.

As the effects of the Eastern Enlargement and the MTR-reform on third world countries will be a result of the impacts these reforms have on EU agricultural production and trade, the natural starting point for this analysis is to consider the changes in EU25 agricultural production.

TABLE 1. CHANGE IN VOLUME OF PRODUCTION IN EU25, BASELINE 2013 = INDEX 100

	MTR Enl.	Contribution from			MTR Enl.	Contribution from	
		Enl.	MTR			Enl.	MTR
Primary Agricultural Commodities	*Index*	*Change in index*		*Secondary Agricultural Commodities*	*Index*	*Change in index*	
Cereals (incl. paddy rice)	93.7	1.8	-8.1	Bovine meat products	95.7	0.1	-4.4
Vegetables, fruits, nuts	103.4	-1.0	4.4	Other meat products	99.7	-0.6	0.3
Oilseeds	99.6	0.1	-0.5	Vegetable oils and fats	99.4	-0.5	-0.1
Sugar cane and beet	99.9	-0.4	0.3	Dairy produce	97.2	-1.6	-1.2
Plant based fibers	97.9	-3.5	1.4	Sugar	100.0	-0.1	0.1
Other crops	103.3	-2.0	5.2	Other processed foods (incl. rice)	100.1	0.1	-0.1
Bovine animals	92.8	0.0	-7.2				
Other animals	100.7	-0.3	1.0	*Other Commodities*			
Raw milk	92.9	-6.0	-1.1	Beverages and tobacco	99.0	-1.1	0.1
Wool	106.2	-2.5	8.7	Textiles/wearing apparel	103.5	3.5	-0.1
				Natural resources	99.9	-0.1	0.0
				Manufactures	100.2	0.1	0.1
				Services	100.0	-0.1	0.0

Note: The reported EU25 results are constructed by aggregating the results for the 25 individual EU member countries. The results for wheat and other grains (which form the major part of the aggregate "cereals") and the results for bovine animals, other animals, and raw milk are aggregated using FAOSTAT quantities, while the remaining results are aggregated using GTAP value shares.

The first column of results in table 1 shows the aggregate supply response for EU25 in the MTR-enlargement scenario, while the second and third column of results serve to decompose these aggregate supply responses by showing which amount of the change is attributable to the enlargement and which amount is attributable to the MTR-reform. Considering the example of cereals, we see that the combined effect of enlarging the EU and implementing the MTR-reform will result in a 6.3 per cent decline in EU25 production of cereals. Decomposing this result we see that an enlargement of the EU with no reform of the CAP (i.e. the Agenda scenario) would result in a 1.8 per cent increase in EU25 production of cereals, while a subsequent MTR-reform in the enlarged EU25 would bring about a 8.1 per cent reduction in the aggregate cereal production (relative to the baseline production level). In total this means we get a 1.8 + (-8.1) = -6.3 percent change in total cereal production in the "realistic" MTR-enlargement scenario.

Looking at the overall supply response in the MTR-enlargement scenario, we see that the most dramatic changes relate to the three important commodity groups cereals, bovine animals, and raw milk, as volume of production for these three commodities decline by respectively 6.3, 7.2, and 7.1 per cent. Furthermore, the decomposition shows that in the case of cereal and bovine animal production these declines are the result of the MTR-reform. It is not surprising that decoupling of the cereal area premiums and the bovine animal premiums under the MTR-reform leads to a significant decline in the production of these commodities. However, it may seem strange that an extension of the old and coupled Agenda 2000 CAP to the new member countries apparently would not result in large increases in the production of cereals and bovine animals, despite the prevalence of partially coupled support for these commodities under Agenda 2000. However, the aggregate EU25 response conceals the fact that production of these commodities in the new member countries would indeed increase under an Agenda 2000 enlargement, but at the same time cereal and bovine animal production would decrease slightly in the existing EU member countries resulting in minor or non-existing effects on aggregate production.

Turning to the case of raw milk we see that the decline in production in the MTR-enlargement scenario is primarily attributable to the enlargement effect. This is due to the fact that extension of the CAP to the new member countries also entails the introduction of milk quotas in these countries. These quotas are binding in all the new member countries and lead to an overall reduction in their raw milk production of 35 per cent, which results in total EU25 production of raw milk declining by 6 per cent. The reason why the MTR-reductions in intervention prices and decoupling of direct payments to milk only results in an additional 1.1 per cent drop in raw milk production is that the milk quotas continue to be binding in most countries after the implementation of the MTR-reform (cf. Jensen and Frandsen 2003b).

While decoupling under the MTR-reform pulls resources out of the sectors, which used to receive coupled direct payment, it also pushes resources into sectors, which were previously unsupported or which continue to receive coupled support, as these sectors have become relatively more profitable following the decoupling under the MTR-reform. The MTR-enlargement scenario consequently shows an increase in the production of e.g. other crops and vegetables, fruits, and nuts of respectively 3.3 and 3.4 per cent[12]. However, it should be noted that our modeling of the MTR-reform builds on the assumption that there will be no restrictions on the use of agricultural land receiving the single farm payment (which is, however, not the intent of the MTR-reform when it comes to production of vegetables, fruit, and nuts cf. section 3). Should these restrictions on area use be enforced, our analysis overestimates the expansionary effect in the vegetables, fruit, and nuts sector. However, the analysis does show that the MTR-reform will increase the incentives to produce these commodities, and if the area restrictions are not stringently enforced, EU25 production will indeed increase.

Summing up the EU25 supply response results for the MTR-enlargement scenario, we see that for most commodities the effect of MTR-reform dominates the effect of enlarging the EU (with the production of raw milk being a notable exception). The changes in composition of EU25 agricultural production are therefore characterized by the shifts induced by the decoupling scheme, which entail a shift of production away from sectors, which used to receive coupled direct payments (e.g. cereals and bovine animals), into sectors, which were previously unsupported or remain unreformed (e.g. other crops and vegetables, fruits, and nuts). These changes in EU25 agricultural production do not only affect the EU; they also affect the rest of the world including developing countries through international trade.

6. RESULTS FOR EU25 TRADE WITH AFRICA.

Due to historical ties and geographic proximity the EU is typically an important trading partner for African countries. For many of these economies, agricultural exports are a significant source of export revenue. However, at the same time a number of African countries are not self-sufficient in food production, making food imports a vital necessity. It is therefore reasonable to wonder, whether the changes in European agricultural production following the Eastern Enlargement and the MTR-reform will have significant impacts on the African countries through their trade with the EU.

In analyzing the European-African trade flows it is useful to distinguish between EU exports to Africa and EU imports from Africa, as these trade flows may to some extent be influenced

[12] In the GTAP database, other crops are a residual category of not elsewhere classified crops. Details of crops included in this category can be found on the GTAP home page www.gtap.agecon.purdue.edu under technical papers.

by different policy instruments and mechanisms. Figure 2 therefore shows the change in value of EU agricultural exports to Africa, while figure 3 shows the change in value of EU agricultural imports from Africa.[13] In order to distinguish between the effect of the Eastern Enlargement and the effects of the MTR-reform, the figures depict these changes in both the Agenda 2000 scenario and the MTR-scenario. As mentioned previously, the scenario of interest is the "realistic" MTR-enlargement scenario. However, the Agenda 2000 enlargement scenario shows us which part of the effect in the MTR-enlargement scenario that is attributable to the Eastern Enlargement, while the difference between the effects in the two scenarios is attributable solely to the MTR-reform.

FIGURE 2: CHANGE IN VALUE OF EU AGRICULTURAL EXPORTS TO AFRICA, MILL 1997 US$

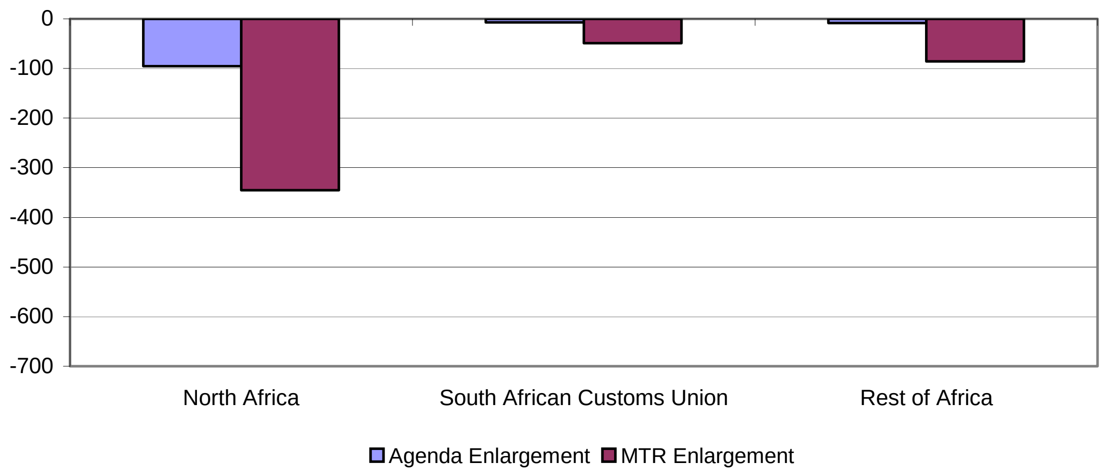
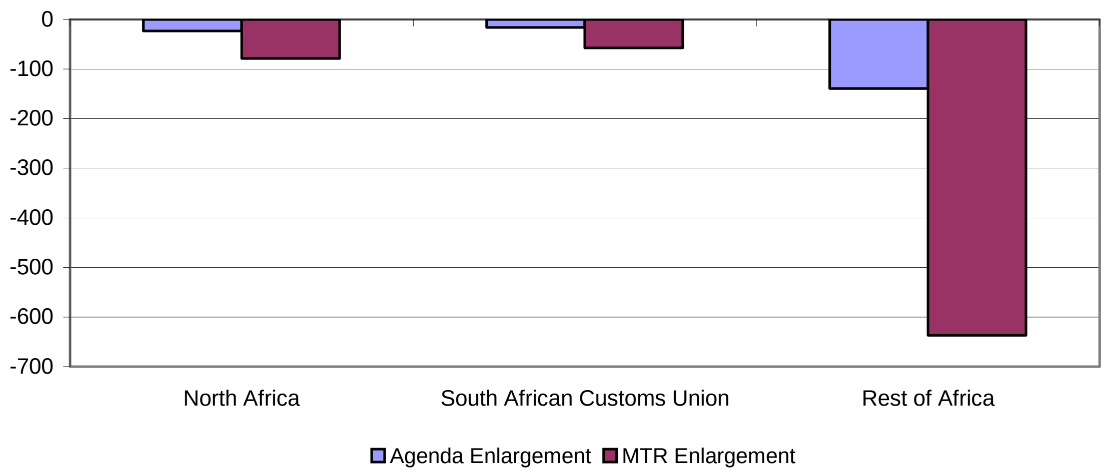


FIGURE 3: CHANGE IN VALUE OF EU AGRICULTURAL IMPORTS FROM AFRICA, MILLION 1997 US$



[13] Agricultural exports and imports are comprised of the commodities listed as primary agricultural commodities and secondary agricultural commodities in table 1.

The first thing to note, when looking at these two figures, is that in both scenarios we see a reduction in both EU agricultural exports to and EU agricultural imports from Africa. Furthermore, these reductions are larger in the MTR-enlargement scenario implying that both the Eastern Enlargement and the MTR-reform in itself lead to reductions in the value of EU trade with Africa. The fact that the MTR-reform effects are generally significantly larger than Eastern Enlargement effects mirrors the fact that the MTR-reform effect dominated the supply response results for EU25 in the previous section. The total effect in the MTR-enlargement scenario amounts to the EU reducing the value of its agricultural exports to Africa by 480 million 1997 US$ while reducing the value of its agricultural imports from Africa by 773 million 1997 US$. Following the Eastern Enlargement and the MTR-reform, the African agricultural trade balance *vis-à-vis* the EU25 thus deteriorates by 293 million 1997 US$.

In order to account for the differences in level of development across the African continent, Africa has been disaggregated into three regions – North Africa (consisting of Morocco, Algeria, Tunisia, Libya, and Egypt), the South African Customs Union (consisting of South Africa, Lesotho, Swaziland, Namibia, and Botswana), and Rest of Africa. Overall this categorization broadly reflects the level of development with the countries of North Africa and the South African Customs Union being middle-income countries, whereas most of the countries in the category Rest of Africa are low-income countries.

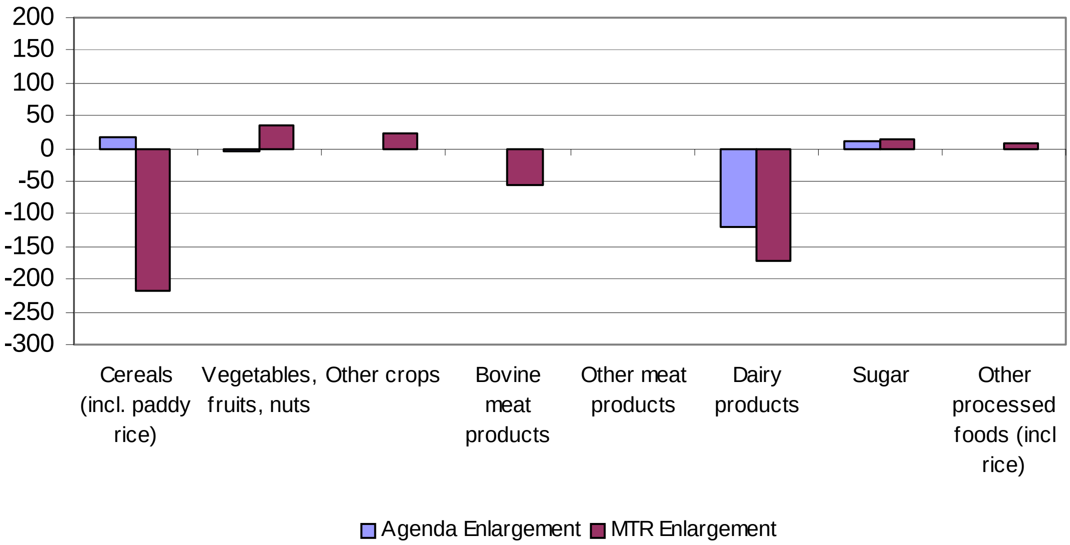
Given these differences in levels of development as well as differences in resource endowment across the three regions, we might expect the regions to be affected differently by the changes to EU agriculture and the figures confirm this suspicion. In terms of EU agricultural exports to Africa, the North African region is clearly more affected in absolute terms than the two other regions, whereas in the case of EU agricultural imports from Africa, the region Rest of Africa experiences the largest absolute impact. In the remaining part of this section we will consequently focus on these two examples starting with issue of EU exports to North Africa.

6.1 EU EXPORTS TO NORTH AFRICA

In order to further analyze the decline in the value of EU25 agricultural exports to North Africa, figure 4 shows the decomposition of the change in value of EU25 exports by commodities.

The figure shows that the changes in EU25 agricultural exports generally mirror the changes in EU25 agricultural production. The changes in value of EU25 agricultural exports are thus dominated by the effect of the MTR-reform, and in the MTR-enlargement scenario we consequently see a decline in the value of EU cereal exports and bovine meat exports, whereas the value of EU exports of other crops and vegetable, fruits, and nuts increase slightly. However, in the case of EU dairy exports, it is the Eastern Enlargement effect, which is primarily responsible for the decline in value of EU agricultural exports.

FIGURE 4: CHANGE IN VALUE OF EU25 EXPORTS TO NORTH AFRICA IN MILLION 1997 US$. SELECTED COMMODITIES

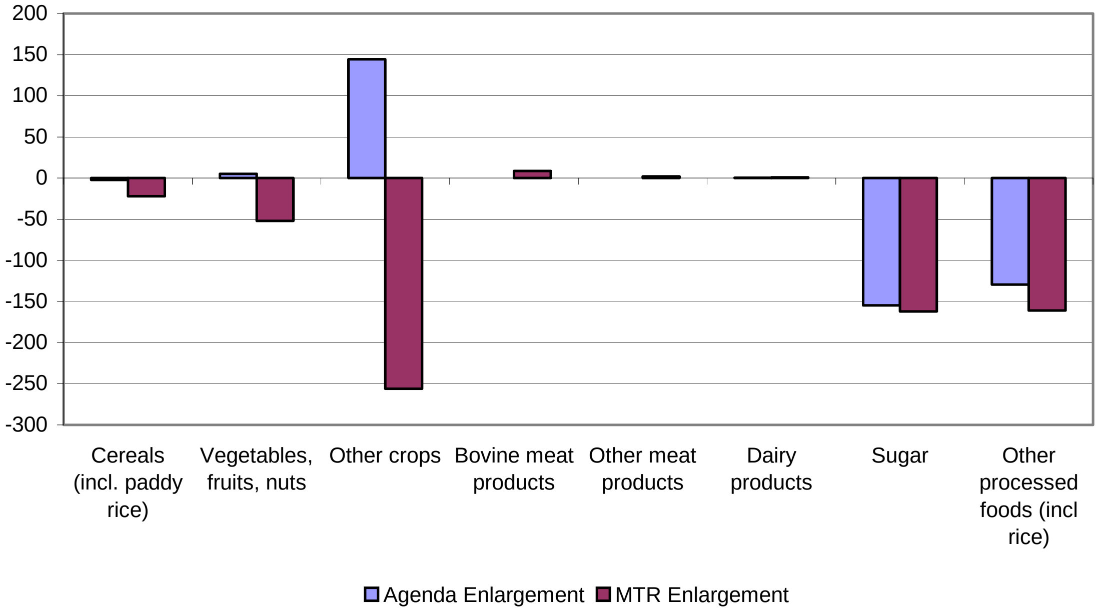


The decline in value of EU25 agricultural exports to North Africa in the MTR-enlargement scenario reflects a decline in the volume of EU25 agricultural exports to this region. This in turn means that North Africa’s import demand for these commodities from other countries increase, which raises the average North African import price on cereals, bovine meat products, and dairy products by respectively 0.7, 3.9, and 4.7 per cent. Following the Eastern Enlargement and the MTR-reform, North Africa will thus have to cover some of its import needs for cereal, bovine meat products, and dairy products from other sources and at higher prices or alternatively increase its own production of these commodities.

6.2 EU25 IMPORTS FROM REST OF AFRICA.

Figure 3 showed that the decline in value of EU25 agricultural imports from Africa stems primarily from the decline in value of EU25 imports from Rest of Africa. Figure 5 decomposes this latter trade flow by commodity.

FIGURE 5: CHANGE IN VALUE OF EU25 IMPORTS FROM REST OF AFRICA, MILLION 1997 US$. SELECTED COMMODITIES



Not surprisingly we once again see that the majority of the changes in the value of EU25 agricultural imports from Rest of Africa are concentrated in a few commodity groups, namely sugar, the category other food products and the category other crops.

In the case of other crops, the decline in the value of EU25 imports of 256 million 1997 US$ in the MTR-enlargement scenario (relative to the 2013 baseline scenario) is clearly more than 100 per cent attributable to the MTR-reform, as an Eastern Enlargement under Agenda 2000 would actually have produced a 144 million US$ increase in the value of EU25 imports of other crops. This change in the trade flow of other crops reflects the change in EU25 production of other crops, as an Eastern Enlargement under Agenda 2000 would result in declining EU25 production of these commodities, while the MTR-reform on the other hand causes an increase in the production of other crops due to the decoupling of direct payments for many of the other commodities.

However, we see a different pattern in the case of sugar and other processed food products. For these commodities, the decline in the value of EU25 imports from the Rest of Africa, which we see in the MTR-enlargement scenario, is due to the enlargement effect as this decline would also occur in the case of EU enlargement under the Agenda 2000 CAP.[14] It therefore appears that we have a case of trade diversion, which occurs when the formation – or in this case the extension – of a preferential trade agreement (PTA) causes a PTA-member to replace imports from non-members with imports from a less cost-effective PTA-member due to the PTA tariff preferences. The third country thus looses its export to the PTA-member, as the PTA tariff preferences provide other PTA-members with an artificial competitive advantage in the PTA-market (cf. Nielsen 2006, who provides a general discussion of PTAs).

However, as usual, reality is more complicated as we are in fact dealing with multiple PTAs in this case. The reason is that a number of countries in the region Rest of Africa are classified as least-developed countries (LDCs), and the EU's Everything But Arms initiative (EBA) entails a non-reciprocal removal of all EU restrictions on imports from LDCs (except for imports of arms) (cf. Yu and V. Jensen 2003). Prior to the Eastern Enlargement, the African LDCs consequently had better access to the old EU15 market than the new EU member countries did.

The EBA initiative grants the LDCs duty and quota free access to the EU markets for virtually all products (cf. Yu and Jensen 2006). Under the EBA scheme, "potential" EU tariff revenue is thus transferred to LDC exporters through their duty free access to the EU markets, which implies that these LDC exporters receive higher prices on their EU exports than non-preference receiving exporters.[15] However, the LDC exports are subject to rules-of-origin restrictions under the EBA scheme, which implies that not all exports coming out of the EBA countries will qualify for duty and quota free access to the EU (cf. Brenton 2003).

In the present analysis, the EBA agreement is modeled as duty free access for the LDCs to the EU internal market. Consequently, the LDC exporters are receiving higher prices (rents) for

[14] However, the results for other processed foods should not be overemphasized, as they are largely driven by increases in EU25 production of processed rice, which are exaggerated.

[15] Apart from the EBA preferential trading framework, the EU also grants preferential access to a number of developing countries under the Generalized System of Preferences (GSP) and the Cotonou agreement (which replaced the Lomé conventions). For further information on these preferential trading schemes and their relation to the EBA initiative see Yu and Jensen 2006.

their exports to the EU than their non-EBA competitors, as the EU imposes import tariffs on the exports of the latter thereby effectively reducing the export prices received by these non-EBA countries. In terms of trade volumes, the EBA agreement results in the LDCs exporting greater volumes than they otherwise would have, as receiving a higher export price than their competitors obviously affords them a competitive advantage in the EU markets.[16]
However, it should be noted that we have not accounted for the effects of rules-of-origin restrictions in our analysis, and we have implicitly assumed that the EBA preferences are fully utilized in the year 2013. Ceteris paribus this will tend to overemphasize the significance of the EBA scheme.

The special preference obtained by the LDCs under the EBA initiative obviously rests on the fact that non-LDCs generally do not have duty and quota free access to the EU markets. However, in the course of the Eastern Enlargement the LDCs' special preferences in the EU15 market are partly eroded, as the new member countries become part of the internal EU market. This implies that the LDC exports of e.g. sugar to the old EU member countries may be replaced by sugar from the new EU members. However, this would clearly not be due to the new EU members gaining an unfair advantage over the LDCs; rather it entails a leveling of the playing field for the LDCs and the new EU member countries in the old EU15 market.[17] On the other hand, the classic PTA trade diversion effects may arise for those African countries not classified as LDCs, if these countries do not enjoy other types of preferential access to the EU markets.

The decline in the MTR-enlargement scenario of EU25 demand for other crops, sugar, and other food products from Rest of Africa causes the regions export prices for these commodities to decline by respectively 1.0, 1.1 and -0.4 percent. As the following section will show, this in turn has consequences for the production of these commodities in the Rest of Africa.

[16] We have not included the Cotonou agreement in our analysis, as the trade component of the Cotonou agreement is merely a framework for the EU and African, Caribbean, and Pacific countries (ACP) to renegotiate the so-called Regional Economic Partnerships Agreements (REPAs), which will gradually enter into force after 2008 at the latest (cf. Yu and Jensen 2006). It is currently not clear what these REPAs will entail and therefore not possible to assess what effect they might have in the year 2013, in which our scenarios take place.
[17] It should also be noted that while the Eastern Enlargement results in an erosion of the special preferences enjoyed by LDCs in the old EU15 market, it also entails an extension of the EBA to the new EU member countries' markets, which should make it considerably easier for LDCs to export to these countries. The question is then whether the extended geographical coverage of the EBA can make up for the preference erosion in the old EU15 markets.

7. IMPACT ON PRODUCTION AND WELFARE IN NORTH AFRICA AND REST OF AFRICA.

As we have seen, the Eastern Enlargement of the EU and the MTR-reform of the CAP affects the EU's agricultural trade with Africa and this will subsequently affect not only the African agricultural production but also the overall measure of welfare in the African economies.

7.1 AGRICULTURAL PRODUCTION IN AFRICA

We first consider the MTR-enlargement scenario consequences for agricultural production in Africa. Table 2 shows the changes in volume of production in the two regions North Africa and Rest of Africa as well as the changes in value of EU25 exports to and imports from these regions, in order to clearly illustrate the connection between changes in trade flow and derived changes in production.

Starting with the results for the North African region, the table shows that as EU25 exports of cereals, bovine meat products, and dairy products to this region decline and the region's import prices of these commodities rise (by respectively 0.7, 3.9, and 4.7), domestic production becomes more profitable and the volume of domestic production increases by 0.9 percent for cereals, 16.7 percent for bovine meat products, and 7.1 percent for dairy products.[18] The table furthermore shows that changes in the EU-North African trade flow also results in a marginal decrease in the production of vegetables, fruits, and nuts, as the value of EU exports of these commodities to North Africa increases by 35 million 1997 US$, while the value of EU imports from North Africa declines by 47 million 1997 US$ (amounting to a net trade effect of –82 mill US$ for North Africa).

[18] The value of bovine meat product in North Africa is estimated to be 13 million US$ in 2013, which increases to 16 million after the enlargement of the EU. Compared to the value of primary agricultural production of bovine animals, which amounts to 10178 million US$ in 2013, the secondary industry of bovine meat production (commercially slaughtered animals) is a small industry in North Africa Therefore the relatively large percentage increase in bovine meat production in North Africa reflects a large percentage increase in a small industry.

TABLE 2: CHANGE IN VOLUME OF AGRICULTURAL PRODUCTION IN NORTH AFRICA AND REST OF AFRICA

	North Africa					Rest of Africa				
	Change in Value of EU25		Change in production			Change in Value of EU25		Change in production		
			MTR Enlarg.	Contributions				MTR Enlarg.	Contributions	
	Exports to	Imports from		Enlarg.	MTR	Exports to	Imports from		Enlarg.	MTR
	Mill. US$		*2013 = index 100*	*Change in index*		*Mill. US$*		*2013 = index 100*	*Change in index*	
Cereals (incl. paddy rice)	-218	5	100.9	-0.1	0.9	-63	-22	99.7	-0.4	0.1
Vegetables, fruit and nuts	35	-47	99.2	0.1	-0.8	13	-52	99.7	0.1	-0.4
Oil seeds	0	0	100.0	0.0	-0.1	0	2	100.5	-0.1	0.6
Sugar beet and cane	0	0	100.2	0.2	0.0	0	-1	98.4	-1.7	0.1
Plant based fibers	4	-2	99.8	0.1	-0.3	0	3	100.7	-0.4	1.1
Other crops	23	-5	97.6	0.3	-2.8	13	-256	98.8	0.7	-1.9
Bovine animals	8	-1	99.9	0.0	0.0	2	0	100.2	-0.1	0.3
Other animal products	0	0	99.9	0.0	0.0	0	-1	100.1	0.0	0.1
Raw milk	-1	4	100.5	0.4	0.1	-1	0	100.3	0.1	0.2
Wool	0	-1	99.1	-0.9	0.0	0	0	100.2	0.0	0.2
Bovine meat products	-55	0	116.7	-0.1	16.8	-23	9	102.9	0.1	2.8
Other meat products	0	0	98.8	0.3	-1.5	-3	2	100.3	0.1	0.2
Vegetables oils and fats	6	-7	99.0	-0.1	-0.9	-3	1	100.5	0.0	0.5
Dairy products	-171	1	107.1	5.0	2.1	-27	1	105.1	1.4	3.7
Sugar	14	-1	99.7	-0.1	-0.2	4	-162	97.5	-2.7	0.2
Other processed foods (incl. rice)	9	-25	99.8	-0.1	-0.2	2	-161	99.6	-0.4	0.0
Total	-345	-78	-	-	-	-86	-637	-	-	-

Turning to the results for Rest of Africa, we see that the decline in EU25 imports of other crops and the ensuing drop in the regions export price for these commodities of 1.0 percent results in the production of other crops declining by 1.2 percent in the region. In the case of sugar, we also see the decline in EU25 imports from Rest of Africa manifested in a 2.5 percent decline in production of processed sugar. Furthermore, this effect is transmitted to the regions primary production of sugar cane and beet, which declines by 1.6 percent. The decline in EU25 imports of other food products only results in a minute decline in Rest of Africa's production of these commodities of 0.4 percent.

In section 6 we focused on the effects of EU25 agricultural imports from Rest of Africa. However, changes in the regional volume of production stem from the combined effect of changes in the regions exports and imports. Table 2 shows that the value of EU25 exports of cereals, bovine meat products, and dairy products to Rest of Africa decline by respectively 63, 23, and 27 million 1997 US$ (parallel to the pattern we saw for North Africa although the magnitudes are smaller for Rest of Africa). In the case of bovine meat and dairy products, these changes translate into increases in domestic production of these commodities, whereas cereal production in the region is left virtually unchanged.

Summing up, the analysis shows that the changes in EU25 trade flows to and from the African regions translates into corresponding changes in African production of the affected commodities. However, it is also clear from table 2 that the Eastern Enlargement of the EU and the MTR-reform of the CAP are not going to cause dramatic changes in the African agricultural production patterns, as the changes in volume of production are indeed minor for most commodities.

7.2 WELFARE IMPLICATIONS FOR AFRICA.

So far we have considered how the Eastern Enlargement and the MTR-reform affects the African regions in terms of changes in the key variables relating to agricultural trade and production. But how do these changes affect the African economies overall?

One way of answering this question is to consider the impact, which the Eastern Enlargement and the MTR-reform have on economic welfare measured as the money metric value of the equivalent variation (EV).[19] Table 3 consequently shows the absolute changes in EV in the MTR-enlargement scenario as well as which part of the changes in EV that stem from the MTR-reform and which part that stem from the Eastern Enlargement. Furthermore, table 3 also shows the relative (i.e. percentage) change in EV in the MTR-enlargement scenario.

Table 3 shows that the enlarged EU stands to gain approximately 13 billion US$ in the MTR-enlargement scenario, while Africa as a whole will realize a minor welfare loss of 484 million US$. The Region Rest of Africa accounts for 49% of the African welfare loss, while North Africa accounts for 38%. As the results show, the EU would clearly be able to compensate the African economies for the welfare loss they will suffer as a consequence of the Eastern Enlargement and the MTR-reform of the CAP.

It is interesting to note that although the MTR-reform reduces some of the distortionary effects of the CAP, the effect of the MTR-reform itself accounts for over half of the African welfare loss (contributing to this welfare loss by 272 million US$), whereas an Eastern Enlargement under the old and more distortionary CAP only produces a welfare loss of 211 million US$ for Africa. However, looking at the decomposition of these changes in total EV we see that the majority of the African welfare losses in both cases stems from adverse terms of trade effects. These terms of trade effects result from a combination of changes in world market prices and changes in trade volumes following the Eastern Enlargement and the MTR-reform, which in turn translates into positive or negative welfare effects depending on the regions net trade positions. In the case of North Africa, the deterioration in the terms of trade are of course largely due to increases in the regions import prices for cereals, bovine meat products, and dairy products, while in Rest of Africa almost one third of the trade loss is linked to trade with other crops.

[19] For further information on EV and its decomposition, see Huff and Hertel 2000.

TABLE 3. CHANGE IN ECONOMIC WELFARE, MILLION 1997 US$

	MTR-enlargement scenario				Contributions from Enl.			Contributions from MTR.		
			of which			of which			of which	
	Percent change	Total EV	Allocative efficiency	Terms of trade	Total EV	Allocative efficiency	Terms of trade	Total EV	Allocative efficiency	Terms of trade
EU25	0.14	13099	11476	1793	7278	5832	1611	5821	5644	182
North Africa	-0.06	-182	-54	-127	-126	-52	-72	-57	-2	-55
Botswana	0.01	0	0	0	-3	0	-3	3	1	3
Rest of South African Customs Union	-0.04	-64	-35	-31	-22	-6	-18	-42	-29	-14
South African Customs Union	-0.04	-64	-34	-32	-25	-6	-21	-39	-28	-11
Malawi	-0.22	-8	-2	-7	2	0	1	-10	-2	-8
Mozambique	0.02	1	0	1	1	0	1	0	0	1
Tanzania	-0.13	-17	-5	-10	-12	-3	-6	-5	-2	-3
Zambia	-0.02	-1	0	-1	-1	-1	-1	0	0	0
Zimbabwe	-0.21	-17	-3	-14	1	1	0	-18	-3	-14
Other Southern Africa	-0.17	-38	-11	-34	-33	-10	-31	-4	-1	-3
Uganda	-0.03	-4	-1	-3	3	0	3	-7	-1	-6
Rest of Sub-Saharan Africa	-0.07	-153	-30	-108	-22	2	-18	-132	-31	-91
Rest of Africa	-0.08	-237	-50	-175	-61	-11	-50	-176	-40	-125
Africa	-0.06	-484	-139	-334	-211	-68	-143	-272	-70	-190
ROW	-0.01	-2934	-1502	-1502	-2550	-1110	-1509	-384	-392	8
Total	0.03	9681	9835	-42	4516	4654	-41	5165	5181	-1

Note: Economic welfare is measured as the money metric value of the Equivalent Variation (EV).

However, it must be noted that these changes in African welfare are small in relative terms. As shown in the first column of table 3, the relative change in total African welfare only amounts to –0.06 percent. Of the individual countries shown, Malawi and Zimbabwe are faced with the largest relative reductions in welfare, but these still only amount to respectively –0.22 and –0.21 percent. Furthermore the welfare gain to the EU following the Eastern Enlargement and the MTR-reform clearly leaves ample scope for compensating the African countries for their welfare losses.

8. QUALIFICATIONS.

As in all quantitative studies, the results naturally depend on the data and the assumptions applied in the model. When contemplating the implications of our simulation results, it is especially important to remember that the approach taken in modeling foreign trade is the Armington specification, which assumes incomplete substitutability between domestic and foreign commodities. This assumption is a key determinant of the size of the trade effects in the model. Furthermore, in the present parameter specification of the GTAP model version 5, the trade elasticities are based on a single value for agricultural products and one for food (originating from the SALTER model). This means that the analysis undertaken in this chapter does not model any difference between mass-trade in bulk products (e.g. wheat and soybeans), which may be expected to have very high trade elasticities, and non-standardized products (e.g. fresh fruits and processed goods), which may be expected to have lower trade elasticities. All in all, trade effects for products with very high trade elasticities may thus be underestimated, while trade effects for products with low trade elasticities may be somewhat exaggerated. Finally, the level of commodity and regional aggregation used here could also hide potentially smaller or larger trade effects than those found in the study. These caveats should of course be kept in mind when drawing conclusions based on the estimated effects on trade, production, and welfare.

9. CONCLUSION.

The fundamental question underlying the analysis in this chapter has been whether the Eastern Enlargement of EU and the MTR-reform of the CAP would be beneficial or detrimental to the African economies. While strictly speaking the results do indicate negative impacts on African welfare levels, the analysis also shows that the overall effects on the African economies are generally small. The Eastern Enlargement and the MTR-reform thus appear to be primarily European matters with only minor effects for third countries like the African economies.

The analysis also showed that in many cases the effects of the MTR-reform dominates the effects of the Eastern Enlargement. This may, however, not be that surprising considering that in our analysis the MTR-reform effect is defined as the difference between enlarging the EU under the old Agenda 2000 CAP and enlarging it under a new MTR-reformed CAP. Thus the MTR-reform effect does not only capture the liberalization gains from undertaking reforms in the old EU15, it also captures the effect of going from Agenda 2000 to the new MTR-reformed CAP in the new member countries. Of course Agenda 2000 is not actually going to be introduced in the new member countries so in this sense our MTR-effect may overestimate the impact of the MTR-reform. On the other hand, distortionary agricultural policy regimes had been established in many of the new member countries prior to the enlargement, meaning that the introduction of the MTR-reformed CAP in these countries will entail a significant degree of liberalization.

In the course of the former and the current WTO negotiation round there have been a constant pressure on the highly distortionary agricultural policy regimes in the developed countries. Part of the argumentation has emphasized how these policy regimes are detrimental to the developing world. It may therefore seem surprising at first that the MTR-reform apparently will not be beneficial to the African countries. However, this may actually not be that surprising when we consider that reducing the incentives for overproduction in the EU of e.g. cereals, bovine animals, and milk, will ceteris paribus benefit the other major producers of these commodities like the US, Australia, and New Zealand, while developing countries typically do not have comparative advantages in production of these commodities. Furthermore, while the MTR reform does entail reforms of domestic support in the EU, it does not encompass comprehensive reforms of EU border protection. Such elimination of one set of distortionary policies, while leaving another set of distortions in place, may lead to paradoxical welfare results. It should be noted, though, that while countries, like the North African economies might ceteris paribus benefit from reductions in EU border protection, those countries in Rest of Africa, which are covered by the EBA initiative, will not benefit from a reduction in EU border protection, as this would imply an erosion of the preferential access to the EU market they have been afforded by the EBA agreement.

The recent break-down in the WTO negotiations at the Cancun meeting has created a great deal of uncertainty regarding future changes to international agricultural. However, we do know the direction of change in one of the major players of world agriculture. The European leaders have decided in favor of both the Eastern Enlargement of the EU and the MTR-reform of the CAP, and the present chapter has explored the consequences of these developments. While these reforms entail major welfare gains for the enlarged EU, prospects for African countries may seem a little bleak, but the impacts are generally minimal. What remains to be seen now is whether the continuing WTO negotiations will succeed in furthering additional reforms – hopefully also to the benefit of the developing world.

CHAPTER 6

INTERNATIONAL TRADE AND THE NATIONAL WATER BALANCE[♣]

1. INTRODUCTION

The future conditions surrounding agricultural production in Egypt are not merely determined by domestic agricultural policies, but also by Egypt's international trade in agricultural commodities and changes in the world markets for these commodities. The previous chapter examined the impact of the Eastern Enlargement and the Mid-term Review of the Common Agricultural Policy on the EU's trading partners in Africa. To the extent that the results for the North African region are representative for Egypt, this analysis suggests that the two reforms will generally only have minor impacts on the crop producing sectors and the overall economy.

However, this does not imply that Egyptian crop production in general, and hence Egyptian irrigation issues, will be unaffected by international trade. The present chapter will consequently analyze the linkage between Egyptian crop production, the ensuing national water constraint, and international trade. The analysis will focus on how the national water constraint affects Egypt's international trade as well as how changes in trading conditions for key agricultural commodities will affect the Egyptian economy. The analysis is undertaken in a national CGE model for Egypt. The national CGE model is based on a modified version of the so-called ORANI-G CGE model using the International Food Policy Research Institute (IFPRI)'s 1997 disaggregated Social Accounting Matrix (SAM) for Egypt. Neither the ORANI-G model nor the IFPRI SAM features water use. The model has consequently been extended in order to capture crop water use and the national water constraint, and the SAM has been supplemented with additional data on land and water use.

Section 2 will present the background information on the Egyptian economy captured by the SAM and outline the design of the simulations. Section 3 details the extensions incorporated into the ORANI-G model, while section 4 documents the data work. Section 5 presents the

[♣] Advice and technical support from Lars-Bo Jacobsen, Philip Abbott, and Ken Pearson on various aspects of the modeling presented in this chapter and comments from Kenneth Baltzer on earlier drafts is gratefully acknowledged.

simulation specification and the results of the simulations. Section 6 features a discussion of the analysis and the conclusion.

2. BACKGROUND INFORMATION ON THE EGYPTIAN ECONOMY AND SIMULATION DESIGN.

The Egyptian economy was in 1997 characterized by a population of 63.5 million people and a GDP of 266 billion LE[1] in current prices (amounting to 78 billion US$). Agriculture accounted for 17% of GDP. GNI per capita (Atlas method) amounted to 1160 current UD$, which placed Egypt in the lower-middle-income country group. The labor force amounted to 18 million people, with 31 % of total employment in agriculture. GDP was growing by 5.5% annually, while the population was growing by 1.9% annually. Merchandise trade amounted to 21% of GDP (World Development Indicators 2006).

IFPRI's disaggregated SAM for Egypt provides a more detailed snapshot of the Egyptian economy in 1996/97. Following the approach of El-Said et al 2001, the structure of the Egyptian economy is presented in table 1 and 2, which are generated from the 1997 SAM data.

Table 1 shows the structure of sector outputs and sector costs in 1997.[2] Total agriculture accounts for 14.1% of total output. However, crop production only accounts for 10% of total output, while animal agriculture accounts for the remaining 4%. The most important crop sectors in terms of value of sector outputs are summer vegetables, fruits, and wheat, followed by other winter crops and maize-sorghum. Industry and services account for respectively 36.9% and 49% of total output. In terms of factor cost, agriculture accounts for 14.6% of total labor costs, 7.7% of total capital costs, and 100% of total land costs. However, the capital intensive animal agriculture sector once again distorts the picture of the agricultural sector, as the crop sectors only account for 3.5% of total capital costs while accounting for 12.8% of total labor costs and 100% of total land costs. The share of land in total factor costs varies significantly across crop sectors. In case of the fodder crop sectors long and short berseem land rents make up 76-82% of total factor costs, whereas in the case of fruit, legumes, other summer crops, and other winter crops land rents only amount to 30-32% of total factor costs.

[1] LE is an abbreviation for Egyptian pounds.
[2] In order to avoid ambiguous terminology, the present chapter will use the term "sector" in stead of "industry" when referring to the non-industrial activities.

TABLE 1: STRUCTURE OF SECTOR OUTPUT AND COSTS (1997)

	Value of sector output (bill LE)	Share of sector in total value of sector output	Share of sector in total factor costs			Share of factor in sector costs		
			Labor	Capital	Land	Labor	Capital	Land
Total agriculture	61.7	14.1%	14.6%	7.7%	100.0%	18.5%	17.6%	32.5%
Wheat	5.1	1.2%	1.4%	0.4%	12.3%	21.0%	11.6%	48.5%
Legumes	0.6	0.1%	0.2%	0.1%	1.0%	27.3%	13.0%	30.6%
LongBerseem	1.9	0.4%	0.2%	0.1%	7.7%	6.4%	5.3%	82.1%
ShortBerseem	0.4	0.1%	0.1%	0.0%	1.5%	10.4%	7.1%	75.6%
WinVeg	3.0	0.7%	0.6%	0.1%	6.6%	16.8%	4.7%	44.3%
OthWinCrp	4.8	1.1%	2.0%	0.4%	7.7%	32.6%	12.0%	32.1%
Cotton	3.2	0.7%	1.6%	0.2%	5.9%	38.0%	7.9%	37.1%
Rice	3.2	0.7%	0.9%	0.3%	7.0%	21.2%	12.7%	44.1%
MaizeSorg	4.3	1.0%	1.3%	0.3%	11.3%	23.9%	8.8%	52.4%
SumVeg	7.1	1.6%	1.1%	0.2%	21.8%	11.8%	3.4%	61.2%
OthSumCrp	3.4	0.8%	1.5%	0.3%	5.2%	33.7%	12.9%	30.5%
Fruit	6.1	1.4%	1.6%	1.1%	9.7%	20.1%	26.2%	31.8%
SugarCane	1.2	0.3%	0.4%	0.1%	2.3%	26.4%	9.8%	38.3%
AnimalAgr	17.3	4.0%	1.9%	4.2%	0.0%	8.3%	34.1%	0.0%
Total industry	161.0	36.9%	16.9%	32.5%	0.0%	8.2%	28.6%	0.0%
FoodProcess	51.0	11.7%	2.2%	4.0%	0.0%	3.4%	11.2%	0.0%
Oil	19.1	4.4%	0.9%	10.7%	0.0%	3.5%	79.4%	0.0%
CottonGin	3.9	0.9%	0.1%	0.0%	0.0%	1.2%	0.8%	0.0%
Textiles	30.4	7.0%	7.6%	5.4%	0.0%	19.4%	25.3%	0.0%
OthIndustry	56.7	13.0%	6.2%	12.3%	0.0%	8.5%	30.9%	0.0%
Total services	213.8	49.0%	68.5%	59.8%	0.0%	24.9%	39.6%	0.0%
Electricity	7.0	1.6%	1.5%	2.2%	0.0%	16.3%	44.2%	0.0%
Construction	33.8	7.7%	5.2%	6.2%	0.0%	11.9%	25.9%	0.0%
GovServ	25.6	5.9%	24.3%	0.0%	0.0%	73.9%	0.0%	0.0%
Transport	28.4	6.5%	4.1%	9.2%	0.0%	11.2%	45.9%	0.0%
OthServ	119.1	27.3%	33.4%	42.3%	0.0%	21.8%	50.2%	0.0%
Total economy	436.5	100.0%	100.0%	100.0%	100.0%	17.8%	32.5%	4.6%

Source: Own calcuations based on IFPRI’s 1997 disaggreated SAM.

Abbreviations of sector names: The agricultural sectors are wheat, legumes, long berseem, short berseem, winter vegetables, other winter crops, cotton, rice, maize-sorghum, summer vegetables, other summer crops, fruit, sugar cane, and animal agriculture. The industrial sectors are food processing, oil, cotton ginning, textiles and other industry. The service sectors are electricity, construction, government services, transportation, and other services.

TABLE 2: STRUCTURE OF DEMAND AND INTERNATIONAL TRADE (1997)

	Total domestic demands (bill. LE)	Share of commodity in total domestic demands	Distribution of imports across commodities	Share of imports in total domestic demands	Distribution of exports across commodities	Share of exports in total domestic output
Total agriculture	68.0	15.0%	9.3%	9.6%	0.5%	0.5%
Wheat	8.9	2.0%	5.4%	42.5%	0.0%	0.0%
Legumes	0.9	0.2%	0.4%	30.0%	0.0%	1.1%
Berseem	2.3	0.5%	0.0%	0.0%	0.0%	0.0%
OthWinCrp	4.8	1.1%	0.0%	0.0%	0.0%	0.0%
Cotton	3.2	0.7%	0.0%	0.0%	0.0%	0.0%
Rice	3.1	0.7%	0.0%	0.0%	0.1%	1.8%
MaizeSorg	5.9	1.3%	2.2%	26.1%	0.0%	0.0%
OthSumCrp	3.4	0.8%	0.0%	0.0%	0.0%	0.0%
Vegetables	10.0	2.2%	0.0%	0.0%	0.1%	0.8%
Fruit	6.1	1.4%	0.2%	2.3%	0.3%	2.3%
SugarCane	1.2	0.3%	0.0%	0.0%	0.0%	0.0%
AnimalAgr	18.2	4.0%	1.2%	4.6%	0.0%	0.0%
Total industry	195.8	43.3%	79.0%	28.3%	37.7%	12.9%
FoodProcess	52.6	11.6%	3.7%	4.9%	1.8%	1.9%
Oil	14.8	3.3%	8.2%	39.0%	18.4%	52.8%
CottonGin	3.6	0.8%	0.0%	0.0%	0.6%	8.0%
Textiles	28.0	6.2%	1.9%	4.8%	6.6%	12.0%
OthIndustry	96.8	21.4%	65.2%	47.3%	10.3%	10.0%
Total services	188.1	41.6%	11.6%	4.3%	61.8%	15.9%
Electricity	7.0	1.5%	0.0%	0.0%	0.0%	0.0%
Construction	33.8	7.5%	0.0%	0.0%	0.0%	0.0%
GovServ	25.6	5.7%	0.0%	0.0%	0.0%	0.0%
Transport	17.1	3.8%	1.4%	5.6%	22.2%	43.0%
OthServ	104.7	23.2%	10.3%	6.9%	39.5%	18.2%
Total economy	451.9	100.0%	100.0%	15.5%	100.0%	12.6%

Source: Own calcuations based on IFPRI’s 1997 disaggreated SAM.

Table 2 shows the structure of domestic demand and international trade in 1997. Total agricultural commodities account for 15% of total domestic demands, with crop commodities accounting for 11% of total domestic demands and animal agricultural commodities accounting for the remaining 4%. Industrial commodities and services account for respectively 43% and 42% of total domestic demands. Imports of all agricultural commodities account for 9.3% of total imports, with crop imports accounting for 8.1% of total imports. However, imports accounts for a large proportion of total domestic demands for the important cereal sectors. In the case of wheat imports thus account for 42.5% of total domestic wheat demands, while imports of maize account for 26.1% of total domestic maize-sorghum demands. Industrial imports amount to 79% of total imports. In terms of exports, primary agriculture accounts for less than 0.5% of the total value of exports. However, agriculture produces inputs for both the food processing sector and the cotton ginning and textiles sector. The latter two sectors account for 0.6% and 6.6% of total exports respectively. Services account for the majority of exports (61.8%), due in large part to the Suez Canal (El-Said et al 2001). Oil exports are also important, as they account for 18.4% of total exports. 52.8% of the Egyptian oil production is exported.

Given these features of the Egyptian economy and the Egyptian government's plan to expand agricultural production through large-scale reclamation of desert land, the linkage between Egyptian crop production, the ensuing water constraint, and international trade will be investigated through the following set of simulations. First the impact of a binding water constraint on the Egyptian trade balance will be investigated. This is done in two scenarios in which the agricultural land area is expanded. In the first of these scenarios, the supply of water is fixed at the same level as in chapter 4, and the expansion of the agricultural area consequently results in water becoming scarce. In the second land-expansion scenario, the water constraint is relaxed so that water does not become scarce following the land expansion. The implications of the water constraint for the Egyptian economy and the Egyptian trade balance can then be assessed by comparing the outcomes of the two scenarios.

The analysis in chapter 5 showed that the North African region is primarily affected by the EU Eastern Enlargement and Mid-term Review reform through declines in the region's imports from the EU. The decline in North African imports of cereals, bovine meat products, and dairy products from the EU was accompanied by rising import prices for these commodities. Assessing the significance of these results vis-à-vis the Egyptian trade structure, it is not entirely clear whether the bovine meat imports and the dairy imports would be categorized under the animal agriculture commodity or the processed food commodity in table 2. However, imports generally make up a relatively small percentile of total domestic demands for both commodity groups (in the case of animal agriculture imports accounts for 4.6% of total domestic demands, while in the case of processed foods imports accounts for 4.9% of total domestic demands). The impact of the EU reforms on the animal agriculture or the processed food sectors are thus not likely to be very significant. However, in the case of wheat and maize, imports account for 42.5% and 26.1% of total domestic demands. Increases in the prices of these commodities are therefore likely to have an impact on the Egyptian economy. Based on the updated database from the water-constrained scenario described above, a third scenario will consequently investigate how rising import prices for these cereals will affect the Egyptian economy in a setting where water is scarce.

3. Incorporating irrigation water into the ORANI CGE model

The national CGE model for Egypt, which is presented in this chapter, is based on the ORANI-G modeling framework ("G" stands for generic). The ORANI applied general equilibrium modeling tradition goes back to the 1970s, when the first ORANI model of the Australian economy was developed. Since then the ORANI model has been used extensively for policy analysis in Australia, and the ORANI modeling framework has been used to create national CGE models for a number of developed and developing countries, including China, Thailand, South Africa, Korea, Pakistan, Brazil, the Philippines, Japan, Ireland, Vietnam, Indonesia, Venezuela, Taiwan, and Denmark (CoPS 2006). The ORANI-based CGE model of Denmark is a good example of the ORANI framework being adapted and used for analysis of agricultural policy issues (cf. Lars-Bo Jacobsen 2001).

The ORANI-G model comes in several different versions. The version, which forms the basis of the present analysis, is the static multiple households model with no margins and no regional extensions.[3] The current general version of the ORANI-G model is documented in Horridge 2003, while the original version of the ORANI model from the 1970s is documented in Dixon et al 1997. The ORANI-G model is implemented using the GEMPACK software

[3] This version of the ORANI-G model, which is dated September 2004, can be found at the ORANI website: http://www.monash.edu.au/policy/oranig.htm. The general version of the ORANI-G model features a special treatment of marginal services (comprised of wholesale and retail trade services and transportation) as well as a regional extension facilitating the break down of national quantity results to the regional level. These features are not included in the version of the ORANI-G model used in the present analysis.

package (cf. Harrison and Pearson 1996). While many of the equations in the ORANI-G model are non-linear, the model is solved by representing it "as a series of linear equations relating percentage changes in model variables" (Horridge 2003 p 3).[4]

The theoretical structure of the ORANI-G model is typical for static CGE models. Demand and supply equations for private agents are based on the solutions to the optimization problems assumed to guide the behavior of agents in neoclassical microeconomics. Agents are assumed to be price-takers, implying that producers are prevented from earning pure profits. The model is comprised of equations describing the following aspects of the economy (Horridge 2003 p 2):

- Producers' demands for intermediary inputs and primary factors
- Producers' supplies of commodities
- Demands for inputs for capital formation
- Household demands
- Export demands
- Government demands
- The relationship of basic values to production costs and purchasers' prices
- Market-clearing conditions for commodities and primary factors
- Various macroeconomic variables and price indices

The modifications of the model, which were undertaken for the present analysis, relates to the production side of the economy. These changes to the production structure will be documented in the present section. Household demands and export demands, on the other hand, will be considered in the following data section, as these features of the model depend intimately on the parameter assumptions.

3.1 THE PRODUCTION STRUCTURE OF THE MODEL

The ORANI-G model is characterized by a multi-input, multi-output production structure. The model consequently allows each sector to produce multiple commodities using domestic

[4] There are several advantages to this linear approach to solving the CGE model. As percentage changes have no units, it is consequenlty not necessary to calibrate the model (since calibration amounts to an arbitrary choice of units). The linearized approach also offers free choice of which variables are to be exogenous and which variables are to be endogenous. Finally, the linear system makes it easy to substitute out matrix variables of large dimensions, which is often necessary in order to reduce CGE models to a manageable size. The model can consequently be specified in terms of the original behavioral equations in stead of in a reduced form (Horridge 2003).

and imported intermediates, different types of labor, as well as capital and land. Furthermore, the model also allows for commodities for export markets to be distinguished from commodities for local markets. To keep the multi-input, multi-output production specification manageable, a series of separability assumptions have been imposed on the production specification, yielding the nested production structure shown in figure 1 (Horridge 2003).

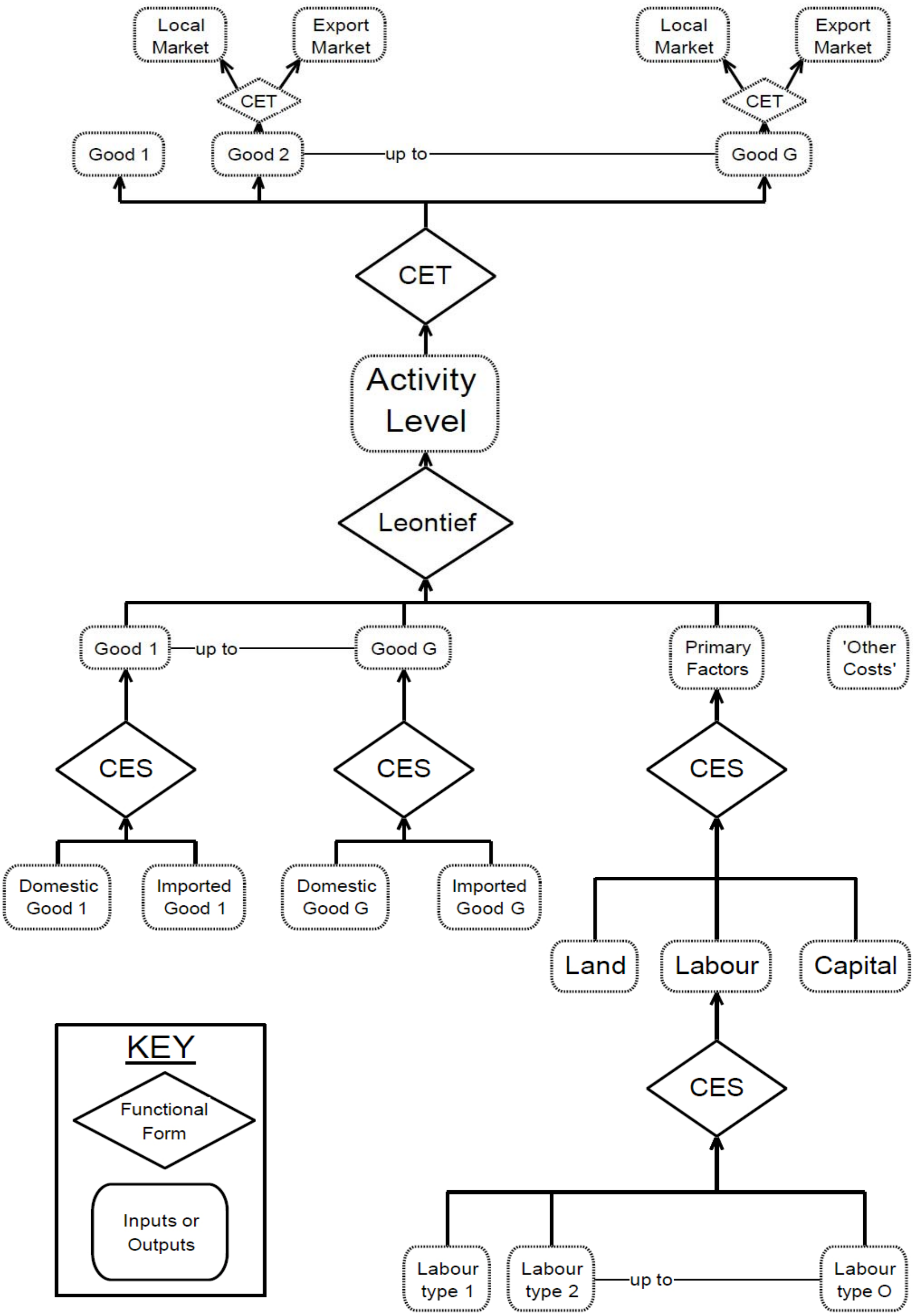
The upper part of figure 1 illustrates the output side of production. The figure shows how each sector is allowed to produce multiple commodities as well as how the commodities destined for export markets may be distinguished from the commodities destined for local markets. Each of these nests is governed by a constant elasticity of transformation (CET) function. The assumptions regarding the magnitudes of the elasticities and the ensuing implications for this part of the production structure will be outlined in the data section.

The lower part of figure 1 illustrates the input side of production. Intermediates are combined with the primary factor aggregate and the “other costs” item[5] through a Leontief function. Each intermediate input is thus used in fixed proportions with the other intermediate inputs as well as the primary factor aggregate. Each intermediate input may consist of the domestically produced and the imported version of this commodity. The mix between domestically produced and imported intermediate inputs is governed by a constant elasticity of substitution (CES) function.

The primary factor aggregate consists of a labor aggregate as well as capital and land, which are combined through a CES function. The labor aggregate in turn consists of different types of labor, which are also aggregated through a CES function.

[5] The ”other costs” item covers miscellaneous taxes on the firm like e.g. municipal taxes or charges (Horridge 2003).

FIGURE 1: STRUCTURE OF PRODUCTION IN THE ORANI-G MODEL



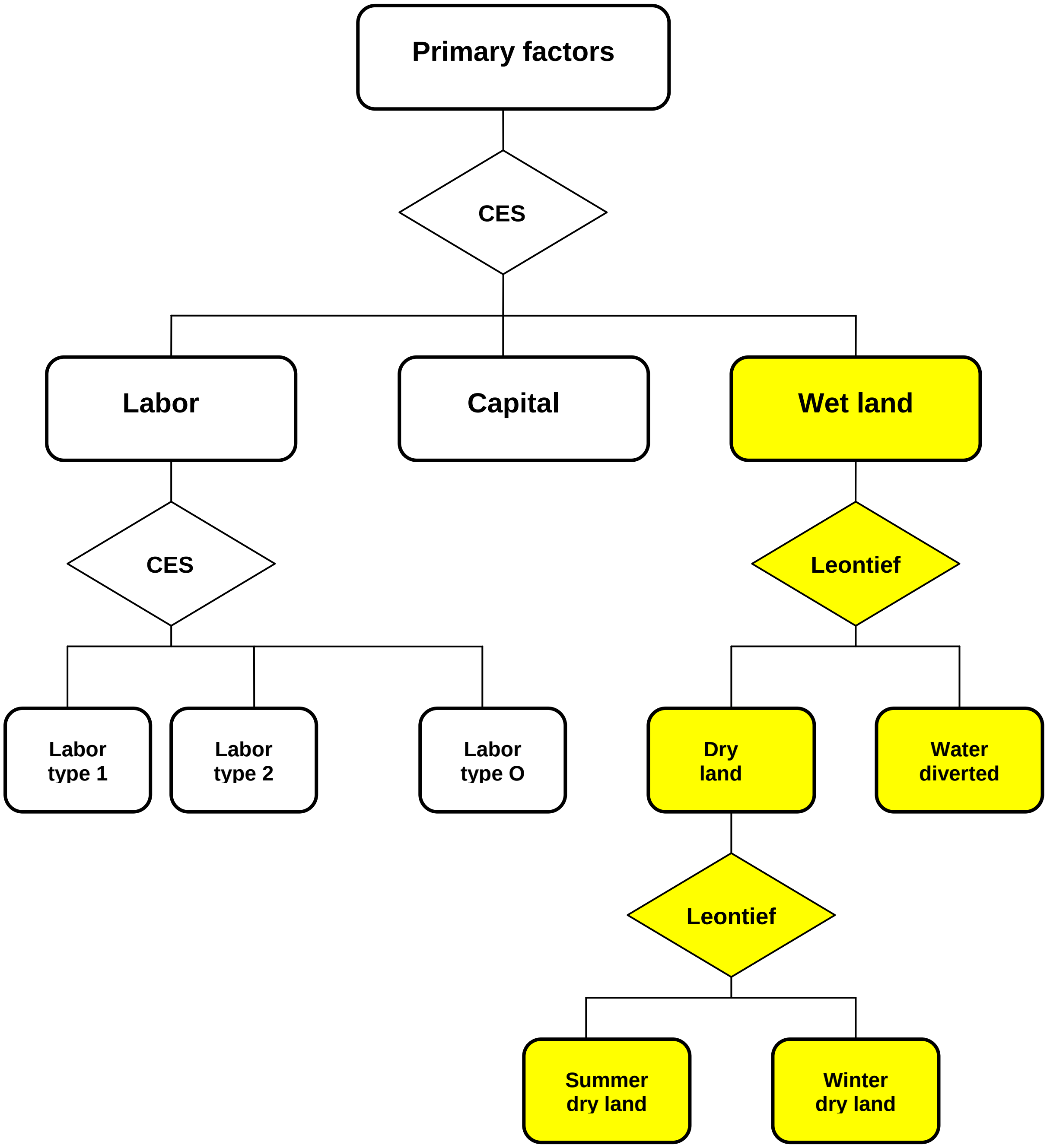
Source: Horridge 2003 p 18

As figure 1 shows, water does not enter the production structure of the ORANI-G model. In order to analyze the impact of the irrigation water constraint, it is thus necessary to first introduce irrigation water into the production structure of the model. The question is then, into which nest of the production structure water should be incorporated, and what functional form should be used? The approach adopted in this paper is to interpret the existing land variable as being land-with-water (or “wet land”). Wet land is assumed to be a function of dry land and water, which are used in fixed crop-specific proportions to produce wet land. Water is consequently incorporated into the production structure by adding a land-water nest with Leontief technology to the existing land variable. The notion of incorporating water into the production structure by introducing a land-water nest with Leontief technology is similar to the modeling of irrigation water in the works of Löfgren and El-Said (1999) and Robinson et al (2002), which also feature single-country CGE studies of Egyptian agriculture.[6]

The present specification of the model only allows for crops to be produced using the optimal amount of water per land unit. In the terminology of chapter 3 and 4, the model consequently only features one water-yield technique. The new structure of the primary factor nest is presented in figure 2. The details pertaining to the modeling of water and dry land will be presented in the following subsections.

[6] Incorporating water into the production structure by adding a land-water nest at the bottom of the production structure seems like the most appropriate solution for Egypt, as land in Egypt cannot be used for agricultural production without provision of irrigation water. However, there are examples of CGE models for other countries, where water is not incorporated into the production structure in this manner. One such example is the TERM model for Australia in which water is combined with a composite of all other inputs in irrigation sectors in a CES-nest at the very top of the production structure (Wittwer 2003). Another example is the GTAP-W model, where water is also included in the top industry nest along with the value-added-energy composite and intermediary inputs (Berrittella et al 2005).

FIGURE 2: PRIMARY FACTOR NEST AFTER INCLUSION OF LAND-WATER NEST



Source: Adapted and extended from diagram in Horridge 2003 p 18.

3.2 MODELING THE USE OF WATER AND THE WATER CONSTRAINT

The water variable, which enters the production function, is water diverted, as this is the water measure, which the farmer is assumed to have direct control over. As in chapter 3 and 4, it is assumed that the amount of water diverted can be determined based on the knowledge of the annual crop evapotranspiration coefficients, the field irrigation efficiency, and the amount of land used for production of each crop. Field irrigation efficiency is assumed to remain unchanged for each crop, and the amount of water diverted for production of a given crop consequently becomes directly proportional to the amount of land used for production of this crop.

Although it is water diverted, which enters the production function, it is still the amount of water consumed or irretrievably lost, which matters from society's point of view. The national water constraint is consequently specified in terms of the total amount of water consumed or lost. While the ORANI-G model is generally specified in terms of linearized equations, the national water constraint is specified in levels. The use of levels variables allows for specifying the water constraint as a complementarity constraint, meaning that the water constraint can not only be binding but also non-binding. This is necessary, as the IFPRI SAM for Egypt pertains to the year 1997, and the national water constraint was not strictly binding in Egypt in 1997.

In order to adequately capture the initial non-binding water constraint, the initial shadow price of water must be zero. The shadow price of water is captured by the basic price of water diverted.[7] As linear variables specified in percentage change terms cannot equal zero, the basic price of water diverted is specified as an absolute change linear variable (rather than a percentage change linear variable).

Although the water constraint is not binding initially, expansion of the agricultural area will eventually result in the water constraint becoming binding. When this happens, the cost to farmers of water diversions must become strictly positive in order to ensure that the water constraint is not breached. This could in principle be achieved by allowing the shadow price of water to increase. However, the shadow price of water is specified as a resource rent, which implicitly accrues to private agents. Keeping with the approach in chapter 3 and 4, the present study will assume that water demand is regulated through a tax mechanism. The tax instrument, which will be used to ensure that the water constraint is not breached, is a uniform tax on water applied. The tax instrument is thus used as the complementarity variable for the

[7] In the terminology of the ORANI-G model, "basic prices" is normally the price received by producers or importers. "Purchaser's prices", on the other hand, are the prices paid by users. The difference between basic prices and purchaser's prices is the indirect taxes and as well as the cost of margin services, if the model includes margins (Horridge 2003). However, in the present model the basic prices on water and land resources are interpreted as resource rents accruing to the private agents, which own these resources. As the government can place taxes on these resources, the total costs to farmers of using the resource are given by the purchaser's price of the resource. Purchaser's prices of water and land are thus comprised of the opportunity cost of using the resource as well as any taxes associated with using the resource.

complementarity constraint on water. The uniform tax on water applied is modeled as a quantity (as opposed to an ad valorem) tax on water applied. The farmer's purchaser's price of water thus consists of the shadow price of water, which is kept exogenous and equal to zero in the simulations, and the uniform tax on water diverted, which is endogenous and varies to ensure that the complementarity constraint on the total amount of water consumed or lost is not violated.[8]

3.3 MODELING THE USE OF DRY LAND AND THE LAND CONSTRAINT

As detailed in chapter 2, arable land is a scarce resource in Egypt. In 1997 the Egyptian agricultural sector thus faced a binding land constraint. Chapter 4 outlined how Egyptian crop production could be divided into winter crops, summer crops, as well as perennial crops. In order to adequately capture the Egyptian land constraint, the land constraint must be specified separately for the winter season and the summer season. The dry land variable in the land-water nest is consequently split into winter dry land and summer dry land. This is done by adding a seasonal land nest with Leontief technology to the dry land variable. The use of Leontief technology ensures that summer land cannot be substituted for winter land or vice-versa. Furthermore, the Leontief technology ensures that any changes in the amount of land used for perennial crops in one season translates into an equal change in the amount of land used for these crops in the other season.[9]

As was the case for the national water constraint, the land constraint for each season is specified in levels rather than linearized terms. However, unlike the water constraint, the

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[8] In the ORANI-G model the households and the government do not have explicit budget constraints, which link the total expenditures of the institution to its income. In stead, total household consumption and total government consumption is determined at the macro level through the closure of the model (cf. below on the closure used for the different simulations). The real production and consumption results from the simulations with a uniform tax on water applied would thus be identical to the results from simulations with optimal quotas on water applied. The only difference between these two sets of simulations would be for the variables capturing factor rents and tax revenue, as in the quota scenario the quota rents would accrue to the farmers, while in the tax scenario the tax revenue accrues to the government. However, this would not make a difference for real production and consumption as long as there is no direct link between expenditures and income for households and the government. The production results from the simulations in this paper could thus also have been produced through a set of optimal quotas on water applied. In earlier versions of the model I have also experimented with modeling of crop-specific land taxes as an instrument to regulate farmers' water use. However, it has not yet been possible to achieve a satisfactory implementation of these taxes.

[9] While land use must be considered on a seasonal basis, water use is calculated on an annual basis. The crop evapotranspiration coefficients for the perennial crop thus capture the annual crop water requirements of these crops. This in turn explains why water use and the water constraint can be separated from the seasonal aspects of land use. The present approach of having two seasonal land constraints and one annual water constraint is similar to the modeling approach in chapter 4.

seasonal land constraints are specified as binding at all times. The variables, which ensure that the seasonal land constraints remain binding, are the seasonal shadow prices of land.

Computing the land rents from the SAM shows that rents vary significantly across crops. As mentioned in chapter 4, land rents may vary across crops due agronomic constraints. According to Löfgren and El-Said (1999), land rents may also differ across crops due to differences in required skills or monitoring for producing these crops, differences in riskiness of crops, and differences in crop impact on soil fertility. However, none of these features are captured in the model, and the model can thus not in-and-of-itself explain the difference in land rents across crops. The question is then whether land rents should be homogenized across crops through some kind of data work (as was the case in chapter 4), or whether the model should be extended to explicitly allow land rents to differ across crops. Following the approach of Löfgren and El-Said (1999), the latter option is chosen for the present model, and land rents are consequently modeled as differentiated across crops on the basis of fixed ratios calculated from the base year data.

The differentiated land rents are implemented by setting a base land rent for each season. For the winter season, the base land rent is equated with the land rent of wheat, while the base land rent for the summer season is equated with the land rent of maize. The total land rents per area unit for each crop are then modeled as consisting of the base rent land rent, which is uniform across crops, and a crop-specific land rent wedge. The crop-specific land rent wedge is modeled in a similar fashion as an ad valorem tax, except that the "revenue" from this wedge is implicitly modeled as accruing to the land owner rather than the government. The ratios of land rents across different crops are then preserved by making the rent wedges exogenous (except in the cases described below).

In addition to the overall seasonal restrictions on total land availability, certain restrictions on individual crop land use have also been introduced in the model. The first of these restrictions takes the form of a crop rotation restriction. As outlined in chapter 4, the most prevalent crop rotations in Egypt are cotton crop rotations, which entail cultivation of short berseem in the winter followed by cotton in the summer. This restriction is included in the model by requiring the percentage change in area cropped with short berseem to equal the percentage change in area cropped with cotton. To enable the model to meet this constraint, the land rent wedge for short berseem is endogenized.[10]

The other crop land use restrictions, which are introduced, relates to the crop categories “other winter crops” and “other summer crops”. These crop categories are residuals, and examination of the SAM values for these sectors suggests that they encompass more than the “other crop” activities described in chapter 4. In order to prevent these residual crop categories from potentially dominating the simulation results, the amount of land allocated to these crops is specified as being exogenous. To enable the model to meet these sectoral land use constraints, the land rent wedges for other summer crops and other winter crops are endogenized.

3.4 TESTING MODIFICATIONS OF THE MODEL.

The preceding subsections have documented the extensions, which have been incorporated into the model in order to account for the irrigation water constraint and its implications for agricultural production. One way to ensure whether these extensions are functioning properly is of course to check the simulation results to see if these conform to expectations. However, there are additional tests, which can also be performed, in order to check whether the extensions to the model are consistent with key theoretical features of CGE models.

The ORANI-G documentation lists several types of simulations, which can be used to check formal model validity (cf. Horridge 2003 p 72-73):

- First of all, a price homogeneity test should be performed. The price homogeneity test is based on the property of neoclassical models that agents only respond to changes in relative prices and not changes in absolute price levels. The price homogeneity test is thus performed by shocking the numeraire (as well as any other exogenous price

[10] It should be noted that the total initial short berseem area is smaller than the total initial cotton area. This was also the case with the data set used in chapter 4. However, the present modeling of the crop rotation constraint ensures that the ratio of the total berseem area to the total cotton area remains unchanged. The introduction of the cotton-short berseem crop rotation in the model allows for the crop sectors long and short berseem to produce the same commodity berseem, which is in accordance with the input-output structure in the SAM. If the implied perfect substitutability between the outputs of the two berseem activities were to be maintained without introduction of some kind of restriction on one of the berseem sectors, it becomes difficult for the model to allocate berseem production between the two crop sectors in long run simulations, where all factors are mobile across sectors (cf. also Horridge 2003). Incorporating the crop rotation constraint solves this problem, as the production of short berseem is now linked to the production of cotton.

measured in domestic currency) and checking that this results in an identical percentage increase in all prices and flows, while leaving all real variables unchanged.

- Secondly, a real homogeneity test should be performed. The real homogeneity test is based on the notion that neoclassical models typically display constant returns to scale. This implies that a shock to all real exogenous variables should result in identical percentage changes in all endogenous real variables, while leaving prices unchanged.
- Thirdly, a real simulation should be run in which relative prices change. The results should subsequently be checked to see whether the change in nominal GDP calculated from the income side equals the change in nominal GDP calculated from the expenditure side. Furthermore, it should also be checked, whether the initial database used for the simulation is balanced. The ORANI-G model includes summary variables, which shows whether this is the case.
- Finally the real simulation should be run one more time, this time using the updated database from the previous real simulation as data input for the model. This is done in order to check whether the updated database produced by the first simulation is also balanced.

These four test simulations should be performed using both a single step and a multi-step solution method. In addition to checking simulation results to see whether these conform to expectations, the model has continuously been tested using these eight simulations in order to check the formal validity of the extensions to the model.

4. PREPARING THE DATA FOR THE SIMULATIONS.

The data work undertaken for the present analysis may be categorized according to three broad headings: fitting the SAM data to the ORANI-G data format, choosing elasticities for the model, and data work and parameters related to the land-water nest. The following subsections will consider each of these headings in turn.

4.1 FITTING THE SAM DATA TO THE ORANI-G DATA FORMAT.

The SAM, which constitutes the core part of the data set for this analysis, is IFPRI's 1997 disaggregated SAM for Egypt.[11] The original SAM features 12 institutions (5 rural households, 5 urban households, the government, and the rest of the world), 5 factors of

[11] Information about the SAM can be found at the following website: http://www.ifpri.org/data/egypt06.htm

production (agricultural and non-agricultural labor, agricultural and non-agricultural capital, and land), 28 activities / sectors (including 13 crop production activities), and 36 commodities (including 19 crop commodities). The SAM also includes information on the capital account, as well as indirect and direct taxes, tariffs, and commodity subsidies.

The original version of the ORANI-G model used in the present analysis requires 24 data matrices, which are all produced based on the SAM. The data format for the ORANI-G model differs from that found in the SAM, as the ORANI-G model generally requires a higher level of data disaggregation than that found in the SAM. Imports have consequently been disaggregated across users of imports, investments have been disaggregated across sectors, and commodity sales taxes have been disaggregated across sources of the commodities and taxpayers. On the other hand, the ORANI-G model only allows for one type of capital, so agricultural and non-agricultural capital has been aggregated into one type of capital.

As mentioned above, the SAM contains data on several commodity subsidies (bread subsidies, flour subsidies, as well as subsidies for sugar, cooking oil, electricity and transportation). Some of these commodity subsidies show up on the commodity accounts in the SAM, while others show up as income transfers to the consumers. As commodity subsidies are not the focus of the present study, the subsidies appearing on the commodity accounts of the SAM have been transformed into income transfers to the households.

As the above description of the SAM suggests, this data set features a high degree of disaggregation in terms of institutional accounts, activities, and commodities. As not all of these details are pertinent to the present study, the ORANI-G datasets are aggregated up to create a more manageable database:

- At the institutional dimension, the 5 rural and 5 urban households are aggregated to one household, as the present analysis does not focus on distributional issues.[12]
- At the sectoral dimension, the subsidized and non-subsidized flour and bread industries are aggregated with other processed foods to create one processed food industry.

[12] As mentioned previously, the households and the government in the ORANI-G model do not have explicit budget constraints, which link the total expenditures of the institution to its income. If the distributional implications of the water policies (like e.g. the direct implications of changing factor remuneration for household consumption) were to be analyzed, the model would need to be extended through inclusion of household and government budget constraints.

- At the commodity dimension, the subsidized and non-subsidized flour and bread commodities are also aggregated with the other processed foods commodity. The original commodity disaggregation also featured by-products for a large number of crop commodities, which serve as input into the animal agriculture sector, as well as a disaggregation of animal agriculture commodities. As animal agriculture is not the focus of this study, the crop by-product commodities have been aggregated with the corresponding crop commodities and the different animal agriculture commodities have been aggregated into one animal agriculture commodity.

These aggregations result in a new database with one household, 24 sectors, and 22 commodities. A schematic overview of the aggregations can be found in appendix A.

4.2 Elasticities and parameters for the ORANI-G model

In addition to the SAM data, the ORANI-G model also requires data for 13 elasticities and parameters. Four elasticities pertain to the production side of the model, one elasticity and one parameter relate to household demands, while six elasticities and one parameter pertain to international trade. The present section will detail the choice of elasticity values and the implication these values have for the model structure.

Elasticities related to production

The four elasticities in the production structure are:

- The sector-specific CES elasticities for substitution between different types of labor
- The sector-specific CES elasticities for substitution between the factors of production in the primary factor nest
- The sector-specific CET elasticities governing the production of multiple outputs by the same sector
- The commodity-specific CES elasticities controlling the degree of substitution between the output from two industries producing the same commodity

According to the SAM, no sector uses both agricultural labor and non-agricultural labor, which are the two types of labor in the data set. The CES elasticities for substitution between the different types of labor are consequently irrelevant in the present model, and are therefore set to zero. Furthermore, following the above-mentioned aggregation of the sector and the commodity dimensions of the database, no sector produces two outputs. The CET elasticities governing the production of multiple outputs by the same sector are therefore also set equal to zero.

The value for the CES elasticities for substitution between the factors of production in the primary factor nest are taken from the Löfgren and El-Said CGE study of food subsidies in Egypt (cf. Löfgren and El-Said 1999 p 36). These sector-specific elasticities range from 0.1 in oil production to 0.6 for most manufacturing and non-governmental services. The elasticities for all agricultural sectors are equal to 0.3. Compared to the CES-elasticities from the Australian version of the ORANI-G model, the Egyptian elasticities are very low, implying a low degree of substitutability between the different factors of production in the primary factor nest.

Following the aggregation of the sector and the commodity dimensions of the database, the CES elasticity governing the degree of substitutability between the outputs from two sectors producing the same output is only relevant for the commodities vegetables and berseem. In the case of berseem, there is no immediate reason to assume that the two winter crop activities short berseem and long berseem should produce outputs, which are imperfect substitutes. The CES elasticity for berseem is consequently set equal to 100 (an arbitrary high elasticity implying almost perfect substitutability). The vegetable commodity, on the other hand, is produced by the two crop activities winter vegetables and summer vegetables. As it does not seem reasonable to assume that winter vegetables and summer vegetables are perfect substitutes, the CES elasticity for vegetables is set equal to 5.

Elasticities related to household demands

In the ORANI-G model, the commodity composites of household demands are aggregated by a Klein-Rubin function, resulting in a linear expenditure system (Horridge 2003). This specification of household demands requires commodity- and household-specific expenditure elasticities and household-specific Frisch LES parameters. However, due to lack of data on such elasticity and parameter values for Egypt, the linear expenditure system is collapsed to a Cobb-Douglas function by setting household expenditure elasticities equal to 1 and the Frisch parameter equal to -1 (cf. ORANI-G short course 2005 slides). While a Cobb-Douglas representation of household demands is rather simplistic, the focus of the present study is on agricultural production and not household consumption as such.

Elasticities related to international trade

The elasticities related to international trade can be divided into elasticities pertaining to imports and elasticities pertaining to exports. Starting with the elasticities relating to imports, the ORANI-G mode requires data on the commodity-specific CES elasticities governing the substitution between imports and domestically produced commodities (also known as Armington elasticities). The Armington elasticities need to be specified for the use of intermediate inputs in production, for commodity demands for investments, and for household demands. The values for the Armington elasticities are taken from Löfgren and El-Said's CGE study of Egypt (Löfgren and El-Said 1999 p 36). Armington elasticities are equal to 0.3 for all commodities except oil (for which the Armington elasticity equals 2), maize (for which the Armington elasticity equals 1.6), and wheat (for which the Armington elasticity is set to 100, as imported and domestically produced wheat are assumed to be perfect substitutes).[13] Compared to the Armington elasticities from the Australian version of the ORANI-G model, elasticities of 0.3 are quite low, indicating that changes in world market prices for these commodities have relatively small effects on the Egyptian economy. In the case of wheat, on the other hand, the opposite is clearly the case as even small changes in world market prices of this commodity will have a substantial impact on the Egyptian wheat sector.

Three elasticities and one parameter relate to exports in the ORANI-G model:

- The commodity-specific CET elasticities governing the production of commodities for local and export markets respectively.
- A parameter indicating whether a given commodity belong to the so-called "individual exports" group (which have individual export demand curves, meaning that exports of these commodities are directly related to their own price) or the "collective exports" group (which have a shared export demand curve).[14]
- Commodity-specific export demand elasticities for commodities belonging to the individual exports group
- Shared demand elasticity for all commodities belonging to the collective exports group

[13] In the Löfgren and El-Said study, the Armington elasticity for non-subsidized flour is equal to 3. However, following the aggregation of the commodity dimension of the database, non-subsidized flour is a minor part of the processed food commodity, and the Armington elasticity for this commodity is set equal to 0.3.

[14] The commodities in the collective exports group are those commodities for which export volumes do not seem to depend primarily on the corresponding price. The commodity composition of the collective export group is determined by a Leontief function (Horridge 2003).

Starting with the issue of individual vs. collective exports, all export commodities are classified as individual exports in the present study. The shared demand elasticity of collective exports is consequently irrelevant.

This leaves the CET elasticities governing the production of commodities for local and export markets and export demand elasticities for all the individual export commodities. These two elasticities are connected as different combinations of the two elasticities signify different traditions in CGE export modeling. In the American tradition, export demand curves are assumed to be highly elastic. In order to prevent over-specialization in the long-run, when all factors are mobile between sectors, the production of commodities for export markets is made less than perfectly elastic through the CET elasticity governing the mix between commodities for exports and commodities for local markets. In the Australian tradition, on the other hand, the production of commodities for export markets is assumed to be perfectly elastic (i.e. an infinite CET elasticity), whereas the export demand is assumed to be less than perfectly elastic. This difference in modeling of exports may in part be explained by a difference in time horizon. While the American tradition tends to focus on the long-run, the Australian tradition is more focused on the short run.[15]

The approach for modeling exports adopted in this paper follows the American tradition.
The CET elasticities and the export demand elasticities are again taken from Löfgren and El-Said's CGE study of Egypt (Löfgren and El-Said 1999 p 36). This implies a CET elasticity of 2.0 for all non-agricultural exports, and 0.8 for all agricultural exports, except in the case of legumes, for which the CET elasticity is set to 0.5. As for the export demand elasticities, Egypt is assumed to face perfectly elastic export demand curves for all commodities except vegetables, for which the export demand elasticity is 3.0, and transportation and other services, for which the export demand elasticity is 1.0. In the case of export demands, the

[15] Each approach has important implications for the export properties of the model. The American approach of using a CET elasticity to govern the mix between commodities for local and export markets implies that the version of the commodity destined for the export markets and the version of the commodity destined for the local markets become joint by-products. A rise in the foreign demand for the export commodity will consequently also imply an increase in the supply of the commodity to the domestic market. The export price will subsequently rise, while the domestic price of the commodity will fall (cf. ORANI-G short course 2005 slides). The use of the CET elasticity to govern the mix between commodities for export and domestic markets thus imply that an increase in export demand will result in a decrease of the domestic price of the commodity, and this does not seem plausible. Using the Australian approach, on the other hand, this result will not arise. However, the Australian assumption of export demand being less than perfectly elastic carries with it the implication of an optimal tariff.

perfectly elastic demand is approximated by an elasticity of 50 (rather than 100 as usual), as the model has difficulties solving for export demand elasticities of 100. Although a demand elasticity of 50 does not entail perfectly elastic export demand, it nonetheless implies highly elastic export demand, and is thus judged to be sufficient for the present study.

4.3 DATA WORK AND PARAMETERS FOR THE LAND-WATER NEST

Apart from the SAM data and the parameters, the model also requires data on land and water use. As in chapter 4, water use by each crop is calculated based on the cropping pattern as well as the water parameters for crop evapotranspiration, field irrigation efficiency, and return flow recoverability. The present sub-section will first document the data work undertaken with respect to the cropping pattern and secondly present the data for the water parameters.

Cropping pattern.

The base year for the SAM is the same as the base year for the analysis in chapter 4. In principle, the cropping pattern underlying the SAM should thus correspond fairly closely to the initial cropping pattern in chapter 4 (with the exception of land use for perennial fruit production, which was underestimated in the chapter 4 data set).[16] However, as outlined in Löfgren and El-Said 1999, the SAM is based on a number of different data sources, including data from other years (Löfgren and El-Said 1999). There is consequently no guarantee that the cropping pattern underlying the SAM will match the ASME / FAOSTAT cropping pattern.

There are several ways in which the cropping pattern implicitly underlying the SAM may be derived. One approach would be to calculate it based on the land rents in the SAM. However, as noted in chapter 4, land rents do in reality differ across sectors (due to e.g. crop rotations or differences in riskiness across crops), and this makes it difficult to derive a cropping pattern simply based on these rents. Furthermore, land rents are notoriously difficult to estimate, as they will typically have to be imputed. Given the general challenges of reconciling many different types of data in a SAM, as well as the need to allocate production costs over a limited number of factors and inputs in the SAM, SAM land rents are consequently not likely to be a good tool for deriving the crop land allocation.

[16] In order to obtain an estimate for the total area used for perennial fruit production, the complete FAOSTAT core production data set on area usage in Egypt in 1997 (cf. http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340) was used to produce a cropping pattern with the same crop categories as the SAM. Comparing this cropping pattern data set with the initial cropping pattern in chapter 4 showed that these were either identical or very similar for all crops except for the amount of land used for perennial fruits, which was almost three times larger in the FAOSTAT data set than in the initial cropping pattern in chapter 4.

Another more promising approach is to derive the land allocation based on the value of sector output and knowledge of crop prices and yields. Using the crop prices from chapter 4 as well as the actual national yields for 1997 from the ASME data (cf. Mohamed 2001 p A64), a cropping pattern is derived from the SAM values of sector output.[17] Comparing the resulting SAM cropping pattern to the cropping pattern derived from the complete FAOSTAT data set on land use (cf. footnote on previous page) shows almost identical land allocations for the two large cereal sectors wheat and maize as well as for the perennial fruit sector. There are minor deviations between the SAM cropping pattern and the FAOSTAT cropping pattern for the crops sugar cane (-9%), cotton (12%), and legumes (-12%). However, the deviations for rice, summer and winter vegetables, and short and long berseem are substantial, as the SAM cropping pattern underestimates the use of land for rice by 21% and the amount of land used for long berseem and short berseem by 46% and 45%, while the amount of land used for summer vegetables and winter vegetables is overestimated by 57% and 49% respectively. The amount of land used for other summer crops and other winter crops is very overestimated by the SAM, when compared with the FAOSTAT cropping pattern.

Using the cropping pattern produced by the original SAM values for sector outputs and the prices and yields from chapter 4 is not reasonable, as this implies a significant increase in the amount of winter and summer land compared to the FAOSTAT cropping pattern. On the other hand, simply using the FAOSTAT cropping pattern with the original SAM values for sector outputs would amount to implicit assumptions about changes in either crop prices or yields compared to those used in chapter 4. Rather than implicitly changing prices and yields in order to arrive at the FAOSTAT cropping pattern, the approach adopted for the present analysis assumes that the crop prices and actual yields are correct and that the value of sector output should consequently be adjusted in order to produce the FAOSTAT cropping pattern.

SAM values of sector output are adjusted by using a special levels version of the ORANI-G model designed for updating or balancing complex CGE databases.[18] This levels version of

[17] As noted earlier, the SAM contains not only the main crop commodities but also the by-products of these crops. As the prices from chapter 4 only refer to the main commodities, the value of the by-products is first subtracted from the value of industry output for each crop sector, before dividing by price and yields to obtain the cropping pattern.

[18] This model and its documentation can be found at the following website: http://www.monash.edu.au/policy/archivep.htm_item_TPMH0058. The model is designed for another type of ORANI-G database with margins and a single household. As outlined in section 4.1, the database for the present

the ORANI-G model uses a proportional scaling approach to adjust database values to specified targets. The proportional scaling approach implies that flows are changed proportionally to their original values and zero flows continue to equal zero. Furthermore, cost and sales shares are altered as little as possible. Maximum entropy, which is a popular method for data transformation, is a type of scaling (Horridge 2004).

In this special level version of the ORANI-G model, the value of a given sector's output can be adjusted by exogenizing the value of this sector's output and endogenizing the multiplier for the sector's inputs. The value of the sector's output is subsequently shocked to the desired level. This procedure is performed simultaneously for the sectors summer and winter vegetables, long and short berseem, rice, legumes, cotton, and sugar cane.

As mentioned above, the SAM also appears to overestimate the value of sector output for other summer and other winter crops. However, as the analysis in chapter 4 showed, these are very heterogeneous crop categories, and as they are the residual crop categories it is not clear exactly what activities they cover. In order to prevent these crop categories from potentially dominating the simulations, the amount of land allocated to these crops is specified exogenously (cf. section 3.3). As the adjustments to value of sector output for these crop sectors would be very drastic, resulting in inaccurate data transformations, the amount of land used for other summer and other winter crops is simply fixed at the levels indicated by the FAOSTAT cropping pattern without adjusting the value of sector output for these sectors.

Once the value of sector output have been adjusted, the cropping pattern implicit in the new SAM is calculated by dividing the values of sector outputs with the 1997 crop prices and actual yields for the different crops. The resulting cropping pattern is presented in appendix B. This cropping pattern is virtually identical to the one calculated from the FAOSTAT data. Note that the total amount of summer land and the total amount of winter land now equals 7.2 million feddans, which is higher than the total amount of land in the analysis in chapter 4 due to the increase in the amount of land used for perennial fruit production.

The land rents are also calculated by dividing the SAM value of land for each crop with the land allocations for each crop. Comparing these land rents to the land rents used in the

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analysis has been aggregated to one single household, but it contains no margins. The model for adjusting the database is consequently modified to disregard margins.

analysis in chapter 4 shows that the land rents from the SAM are several times higher than the land rents from chapter 4. The reason for this may be that the data set in Mohamed 2001, which is the source of the land rents for the analysis in chapter 4, has a more detailed cost structure. The SAM land rents may thus cover other land related cost items, which are specified separately in the data set in Mohammed 2001. However, the land rents calculated from the SAM also suggest different relative magnitudes of land rents across crops. Land rents for summer and winter vegetables are thus significantly higher than land rents for the other crops, and so are the land rents for long berseem, while land rents for legumes are noticeably lower than land rents for other crops.[19] These differences in land rents across crops may be commensurate with the notion of SAM land rents covering more than imputed returns to land, and according to Löfgren and El-Said differences in SAM land rent across crops is "a reflection of real-world phenomena that are not modeled explicitly" (Löfgren and El-Said 1999 p 8). However, these differences in land rents across crops also have implications for simulation results. This issue will be discussed in more detail in the results section.

Water parameters

The water parameters needed for the land-water nest and for calculating initial water use are the crop-evapotranspiration coefficients, the crop-specific field irrigation efficiency coefficients, and the return flow recoverability coefficients. These parameters are all taken from the analysis in chapter 4 and aggregated across regions to produce national averages. This results in national field irrigation efficiency coefficients of 0.79 for all crops except rice for which the field irrigation efficiency coefficient is 0.553. The national return flow recoverability coefficient is 0.51. The national evapotranspiration coefficients are shown in appendix C. These water coefficients all reflect the characteristics of the Egyptian agricultural sector in the base year 1997 and hence before the expansion of the New Lands. As such, the field irrigation efficiency coefficients and the return flow recoverability coefficient will tend to overestimate the national efficiency in water use after the expansion of the New Lands. Likewise the evapotranspiration coefficients will tend to underestimate the crop water requirement after the expansion of the New Lands. However, as these are parameters, they cannot be updated in the course of the CGE simulations. The final water parameter needed for the model and data work is the total amount of water available for crop water consumption

[19] The land rents for other winter and other summer crops are also very high compared to the land rents for the other crop categories. This is not surprising given the fact that values of industry output were not adjusted for these crops. However, as mentioned above, steps have been taken to minimize the effect of these crops on simulation results, as the land allocation for these crop categories is kept fixed.

and irretrievable losses from irrigation. As in chapter 4, this amount of water is set equal to 47 billion cubic meters (BCM).

5. Simulation scenarios and results.

As outlined in section 2, the present analysis will feature three different simulations. The first set of simulations examines the trade implications of expanding the agricultural area and encountering the national water constraint. The third simulation will investigate the consequences of increasing import prices for cereals. The following subsections present each of these simulations and their results.

5.1 Trade implications of expanding the agricultural land area

In order to examine the implications of the water constraint for international trade, two land expansion scenarios are run. In the first scenario, the amount of water available for consumption or loss in irrigation is 47 BCM. In this scenario, increasing the amount of summer and winter dry land by 10% results in the water constraint becoming binding.[20] In the second scenario, summer and winter dry land is also increased by 10%, but the amount of water available to agriculture is set so high as to ensure that the water constraint does not become binding. As the only difference between the two scenarios is the water availability for agriculture, the implications of the water constraint for Egyptian international trade can be assessed by comparing the results from these two scenarios.

The model closure used for the two land expansion scenarios is a long run closure. While there is no standard ORANI-G long run closure, the model documentation does provide a possible long run closure, which is used in the present study with a few modifications. The long run closure presented in the ORANI-G model documentation implies the assumption of an open capital market, where sectoral capital stocks adjust to maintain fixed rates of return in each sector. Aggregate employment (which is aggregated across sectors using wage bill weights)[21] is fixed and the real wage is endogenous. Labor is thus implicitly assumed mobile

[20] In chapter 4, the amount of land was increased by 15%. However, as outlined in the previous section, the initial amount of land cropped and hence also the initial amount of water consumed or lost is higher in the present data set than in the data set used in chapter 4. Increasing the amount of land in the present data set by 15% would thus almost drive land rents to zero. As the land constraint is required to remain binding in the present model specification, model solutions become inaccurate as land rents approach zero.

[21] Using wage bill weights reflects different workers' relative marginal product. Other options for aggregating employment across sectors include using number of workers or hours worked as weights (Horridge 2003). Considering that agriculture accounted for 31% of total employment in 1997 but – according to the SAM – only 14.6% of total labor costs (cf. section 2), there appears to be significant differences between wages in

between agricultural and non-agricultural sectors. Sectoral land allocation is assumed to be fixed. On the expenditure side of the economy, the nominal balance of trade as a fraction of GDP is assumed to be exogenous, as the rest of the world is not likely to be willing to fund an increased trade deficit in the long run. Household expenditure and government expenditure move together to accommodate the trade balance constraint, while aggregate investment follows the aggregate stock of capital (Horridge 2003). Demand curves for exports are fixed, as are also foreign prices of imports. The nominal exchange rate is the numeraire.

The long run closure used in the present analysis corresponds to the ORANI-G long run closure except for the fact that land is assumed to be mobile across crop sectors. As it may take 10 or 20 years to reach a long run equilibrium (Horridge 2003), it would not make sense to assume that farmers would not adjust their cropping pattern in the course of this time span. Total amount of summer dry land, winter dry land, and water available for irrigation is assumed to be exogenous. As outlined earlier, the basic price of water diverted is set to be exogenous, while the uniform tax on water diverted is endogenized to ensure that the water constraint is not breached. The base land rents on summer land and winter land are also endogenous, whereas the land rent wedges are exogenous for all crops except short berseem, “other winter” crops, and “other summer” crops (cf. section 3.3 on restrictions on land use for these crops). The percentage changes in land rents for all summer crops will thus be identical (with the exception of the land rent for “other summer” crops). The same is true for all winter crops (with the exception of the land rents for short berseem and “other winter” crops) as well as for all perennial crops. The consumer price index is used as numeraire in stead of the nominal exchange rate, as this provides for a more intuitive interpretation of the trade related results.

Results for water-constrained land-expansion scenario.

The results for the scenario in which the expansion of the summer and winter dry land area by 10% results in the water constraint becoming binding are presented in tables 3 to 6. Table 3 shows the percentage changes in output and input quantities in the different sectors, while table 4 shows the percentage changes in the corresponding input and output prices. Note that the results for tax on water diverted in table 4 are specified as absolute changes rather than percentage changes. Table 5 presents the percentage changes in quantities and prices for

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agricultural and non-agricultural employment. Using numbers of workers instead of wage bill wage may thus be more appropriate. However, this would require additional data on employment in Egypt.

household demands, imports and exports, while table 6 presents the macro results for the scenario.

Land and water is only used by the agricultural sectors, and these are therefore the sectors most immediately affected by the increase in the amount of summer and winter dry land. As shown in table 6, an increase in the amount of summer and winter dry land by 10% results in an increase in agricultural employment of 3.74%. Total employment in the economy is assumed to be fixed in the long run and this pull of labor into the agricultural sector thus results in rising wages. The agricultural capital stock also increases by 4.00%. In the long run, the capital market is assumed to be open and rates of return on capital are fixed for each sector. With the expansion of land and labor employed in agriculture, it is thus not surprising that the agricultural capital stock increases in order to maintain the fixed rates of return to capital in each sector.

The amount of irrigation water consumed or irretrievably lost also increases following the increase in the amount of summer and winter dry land. However, while the amount of dry land was increased by 10%, the amount of water consumed or lost can only increase by 5.41% due to the water constraint. As the water constraint becomes binding, the uniform tax is levied on water diverted in order to assure that the water constraint is not violated (cf. column 5 in table 4).

The increase in the amount of dry land and the onset of water scarcity results in declining land rents. Summer dry land rents decline more than winter dry land rents, which is partly attributable to the fact that summer crops tend to be more water intensive than winter crops. This is shown in column 4 in table 4. The first six crops in the table are winter crops, while the five subsequent crops are summer crops, and the last two crops are perennial crops. For all winter crops (except short berseem and other winter crops) the dry land rents decline by 49.86%, while for all summer crops (except other summer crops) the dry land rents decline by 67.73%. The reason why the changes in dry land rents for short berseem, other winter crops, and other summer crops differ from the general changes in seasonal land rents is that these crops are subject to land allocation restrictions as outlined in section 3.3. Perennial dry land rents decline by 59.08%, which is basically the average of the changes in summer and winter dry land rents.

TABLE 3: CHANGES IN PRODUCTION AND INPUT QUANTITIES IN WATER CONSTRAINED SCENARIO (PERCENTAGE CHANGE)

	Sector activity level	Effective labor input	Capital stock	Dry land	Water diverted	Wet land
Wheat	33.01	31.83	32.53	33.64	33.64	33.64
Legumes	-2.60	-1.64	-1.12	-4.03	-4.03	-4.03
LongBerseem	2.40	-1.78	-1.26	3.00	3.00	3.00
ShortBerseem	3.38	-0.78	-0.25	4.37	4.37	4.37
WinVeg	-46.45	-50.47	-50.21	-44.09	-44.09	-44.09
OthWinCrp	0.04	-0.08	0.45	0.00	0.00	0.00
Cotton	1.26	-1.13	-0.61	4.37	4.37	4.37
Rice	-17.78	-11.24	-10.78	-21.94	-21.94	-21.94
MaizeSorg	3.60	1.14	1.67	5.14	5.14	5.14
SumVeg	77.76	50.19	50.98	87.66	87.66	87.66
OthSumCrp	-0.01	-0.16	0.37	0.00	0.00	0.00
Fruit	1.98	0.57	1.10	3.68	3.68	3.68
SugarCane	0.01	5.76	6.32	-4.67	-4.67	-4.67
AnimalAgr	2.56	2.13	2.67	-	-	-
FoodProcess	0.00	-0.81	0.24	-	-	-
Oil	-8.14	-8.29	-8.13	-	-	-
CottonGin	1.23	0.80	1.86	-	-	-
Textiles	0.29	-0.30	0.75	-	-	-
OthIndustry	-0.23	-1.06	-0.01	-	-	-
Electricity	-0.16	-0.67	0.03	-	-	-
Construction	-0.31	-1.03	0.02	-	-	-
GovServ	0.74	0.74	-	-	-	-
Transport	-0.27	-1.11	-0.07	-	-	-
OthServ	-0.47	-1.20	-0.15	-	-	-

TABLE 4: CHANGES IN OUTPUT AND INPUT PRICES IN WATER CONSTRAINED SCENARIO (PERCENTAGE CHANGE)

	Average input / output price	Price of labor composite	Rental price of capital	Dry land rents	Tax on water diverted (absolute change)	Cost of wet land
Wheat	-0.33	2.54	0.76	-49.86	0.17	-2.01
Legumes	4.83	2.54	0.76	-49.86	0.17	11.30
LongBerseem	-10.37	2.54	0.76	-49.86	0.17	-12.49
ShortBerseem	-10.38	2.54	0.76	-44.44	0.17	-13.38
WinVeg	-19.64	2.54	0.76	-49.86	0.17	-31.52
OthWinCrp	1.86	2.54	0.76	-4.91	0.17	2.28
Cotton	-4.51	2.54	0.76	-67.73	0.17	-14.41
Rice	28.38	2.54	0.76	-67.73	0.17	57.30
MaizeSorg	-4.58	2.54	0.76	-67.73	0.17	-9.90
SumVeg	-36.78	2.54	0.76	-67.73	0.17	-51.20
OthSumCrp	1.73	2.54	0.76	-12.23	0.17	2.00
Fruit	-1.90	2.54	0.76	-59.08	0.17	-7.34
SugarCane	19.28	2.54	0.76	-59.08	0.17	44.96
AnimalAgr	-1.90	2.54	0.76	0.00	0.00	0.00
FoodProcess	0.72	2.54	0.76	0.00	0.00	0.00
Oil	0.87	2.54	0.76	0.00	0.00	0.00
CottonGin	-3.15	2.54	0.76	0.00	0.00	0.00
Textiles	0.39	2.54	0.76	0.00	0.00	0.00
OthIndustry	0.92	2.54	0.76	0.00	0.00	0.00
Electricity	1.09	2.54	0.76	0.00	0.00	0.00
Construction	1.02	2.54	0.76	0.00	0.00	0.00
GovServ	2.01	2.54	0.00	0.00	0.00	0.00
Transport	1.03	2.54	0.76	0.00	0.00	0.00
OthServ	1.14	2.54	0.76	0.00	0.00	0.00

TABLE 5: CHANGES IN QUANTITIES AND PRICES OF HOUSEHOLD DEMANDS, IMPORTS AND EXPORTS FOR WATER CONSTRAINED SCENARIO (PERCENTAGE CHANGE)

	Household use of domestic / imported composite	Household price of domestic / imported composite	Total supplies of imported goods	Duty-paid, basic price of imported goods (local currency)	Export basic demands	Purchaser's price of export goods (local currency)
Wheat	0.74	0.00	-40.90	0.54	-	0.00
Legumes	-2.77	3.61	-1.73	0.54	-4.57	0.64
Berseem	0.00	0.00	0.00	0.54	-	0.00
OthWinCrp	0.00	0.00	0.00	0.54	-	0.00
Cotton	0.00	0.00	0.00	0.54	-	0.00
Rice	-21.53	28.38	0.00	0.54	-100.00	28.38
MaizeSorg	5.58	-4.58	0.00	0.54	-	0.00
OthSumCrp	0.00	0.00	0.00	0.54	-	0.00
Vegetables	51.66	-33.57	0.00	0.54	66.31	-15.14
Fruit	2.69	-1.90	1.17	0.54	3.94	0.46
SugarCane	0.00	0.00	0.00	0.54	-	0.00
AnimalAgr	2.57	-1.79	1.46	0.54	-	0.00
FoodProcess	0.03	0.72	0.06	0.54	-0.34	0.55
Oil	0.00	0.74	0.16	0.54	-14.99	0.87
CottonGin	0.00	0.00	0.00	0.54	8.73	0.37
Textiles	0.36	0.38	0.21	0.54	0.57	0.53
OthIndustry	-0.02	0.77	-0.03	0.54	-0.95	0.56
Electricity	-0.34	1.09	0.00	0.54	-	0.00
Construction	-0.27	1.02	0.00	0.54	-	0.00
GovServ	0.00	0.00	0.00	0.54	-	0.00
Transport	-0.30	1.05	-0.01	0.54	-0.41	0.96
OthServ	-0.36	1.11	-0.27	0.54	-0.55	1.10

TABLE 6: MACRO ECONOMIC RESULTS FOR WATER CONSTRAINED SCENARIO (PERCENTAGE CHANGE)

Agricultural winter land	10.00	Nominal GDP	0.83
Agricultural summer land	10.00	Real GDP	0.44
Consumption or loss of irrigation water	5.41	GDP price index (expenditure side)	0.39
Agricultural employment	3.74	Aggregate real household consumption	0.74
Non-agricultural employment	-0.54	Aggregate consumer price index	0.00
Total employment (wage bill weights)	0.00	Aggregate real government demands	0.74
Agricultural capital stock	4.00	Nominal trade balance as share of nominal GDP (absolute change)	0.00
Non-agricultural capital stock	-0.82	Nominal exchange rate	0.54
Total capital stock	-0.65	Terms of trade (export price index - import price index)	0.35
		Real devaluation (import price index - GDP price index)	0.15
		Export volume index	-3.15
		Import volume index	-2.22

The increases in total amount of summer and winter dry land and the ensuing changes in factor rents have differing impacts of the cropping sectors depending in part on the water intensity of the crop and the magnitude of the land rents in the crop sector. The first column of table 3 shows the percentage changes in sectoral activity levels, and the impact on agricultural production clearly centers around four sectors: the winter crops wheat and winter vegetables and the summer crops rice and summer vegetables. Wheat and rice are both very trade-exposed, as wheat imports and rice exports are basically perfectly substitutable with domestically produced wheat and domestically produced rice for the local market. Wheat is not a water intensive crop, and the decline in winter dry land rents consequently dominates the increase in water taxes for this crop. As the sixth column of table 4 shows, the cost of wet land (i.e. the combined price / opportunity cost of dry land and water) consequently drops by 2.01% for wheat. Despite the increases in labor and capital costs (cf. column 2 and 3 in table 4), the total unit costs of production in the wheat sector thus declines by 0.33% (cf. column 1 of table 4).[22] As domestically produced wheat is assumed to be a perfect substitute for imported wheat, this drop in domestic wheat production costs is accompanied by an increase in domestic wheat production of 33.01%, while imports of wheat decline by 40.90% (cf. column 3 in table 5).

Rice, on the other hand, is a highly water intensive crop, partly because crop water consumption is high for rice and partly because rice production requires extra water for soaking the paddy fields. Despite the decline in summer dry land rents, the cost of wet land for rice production consequently increases by 57.30% due to the water taxes. This results in a relative increase in the labor and capital intensity of the sector (cf. column 2-5 in table 3 how the use of labor and capital in the rice sector only declines by 11.24% and 10.78%, while land and water use declines by 21.94%). However, the unit cost of production in the rice sector still increases by 28.38%. This in turn results in rice production declining by 17.78%, while direct sales of rice to households decline by 21.53% (cf. column 1 in table 3 and column 1 in table 5). Furthermore, as rice for the domestic market and rice for export markets are perfect

[22] The variable capturing the unit costs of production, which are shown in the first column of table 4, is labeled the “average input / output price” in the ORANI-G model code. The reason for this terminology is that the model’s constant returns to scale in production imply that the percentage change in unit costs is also the percentage change in marginal costs. Furthermore, the competitive “zero pure profits” condition is enforced by assuming that the percentage change in marginal (and unit) costs is equal to the average price received by each sector (Horridge 2003).

substitutes and as export demands for rice are highly elastic, this increase in unit costs of production results in a complete collapse of rice exports (cf. column 5 of table 5).[23]

Rice is one of the major summer land crops and the combination of a 10% increase in total summer land and a decline in the area devoted to rice of 21.94% implies that other summer crops sectors will be expanding considerably. As table 3 shows, the summer vegetable sector expands significantly as production increases by 77.76% and the area devoted to summer vegetable production increases by 87.66%. Part of the explanation for the large increase in the production of summer vegetables is that vegetables are water extensive. The other part of the explanation is that in the present data set land rents for summer vegetables are substantially higher than land rents for other crops. The combination of these two features implies that the decline in summer dry land rents strongly dominates the increase in water taxes for the summer vegetable sector. As shown in table 4, the cost of wet land for the summer vegetable sector consequently declines by 51.20%. This large decline in land-water costs for the summer vegetable sector results in a substitution away from the more expensive labor and capital inputs towards the less expensive land-water input. As shown in table 3, labor and capital inputs into the summer vegetable sector thus only increase by 50.19% and 50.98% respectively, while land and water use increase by 87.66%. All in all, unit costs for the summer vegetable sector declines by -36.78%.

The increase in the amount of land devoted to wheat production is larger than the increase in the total amount of winter land, and other winter crop sectors thus have to contract not only in relative but also in absolute terms. The winter crop sector, which accommodates the expansion of the wheat sector, is winter vegetables. As table 3 shows, production of winter vegetables declines by 46.45%. This happens despite the fact that the cost of wet land for winter vegetables declines by 31.52% (due to the high initial land rents for winter vegetables and the low water intensity of this crop). Apart from the expansion in wheat production, the large decline in winter vegetable production is also a result of the fact that the summer and winter vegetable sectors both produce the same commodity – vegetables. Summer and winter vegetables are assumed to be imperfect substitutes (cf. section 4.2), but the large increase in

[23] The reason why total rice production declines less than direct sales of rice to households and rice exports is that while 64% of rice production is sold directly to the households, 34% of rice production is sold as inputs into other sectors. 42% of these rice inputs go to the food processing industry. As intermediate inputs enters the production structure through a Leontief nest and as the food processing industry is virtually unaffected by the land shock, rice inputs into the food processing industry are also unchanged.

production of summer vegetables still facilitates a substantial contraction in the winter vegetable sector. Total vegetable production thus only increases by 36.99%. A reinforcing factor for the contraction of the winter vegetable sector is the fact that 64% of the vegetable production is sold directly to the households. As household demand is characterized by a Cobb-Douglas function, the increase in household consumption of vegetables by 51.66%, due to the large expansion in production of summer vegetables, is accompanied by a drop in the household price of vegetables of 33.57% (cf. column 1 and 2 in table 5). Exports of vegetables increase by 66.31%. As a combination of the fact that production costs for vegetables have gone down and that Egypt faces a less elastic demand curve for vegetable exports (cf. section 4.2), the export price of vegetables in local currency drops by 15.14% (cf. column 6 in table 5).

There are only minor adjustments in land allocation and production for the other agricultural sectors. As total land area is increased by 10%, this implies that the importance of these sectors decline in relative terms and in some cases also in absolute terms. The production of legumes declines by 2.60% despite the fact that legumes are water extensive crops. The reason for this is that the initial land rents for legumes are so low that the increase in water costs dominates the fall in land prices, resulting in an increase in the cost of wet land for legume of 11.30% (cf. table 4). The initial land rents also drive the result for production of the water intensive crop long berseem, as the high initial land rents for this crop implies that the drop in land prices dominates the increase in water costs, leading to a fall in the cost of wet land for long berseem production of 12.49%.

The amount of land allocated to short berseem, on the other hand, is determined by the cotton sector, as short berseem precedes cotton in the crop rotation. The amount of land allocated to cotton (and short berseem) increase by 4.37%. Cotton is a relatively water intensive crop, but returns to cotton land tend to be high and the drop in land prices thus dominate the increase in water costs. As shown in table 2, cotton is a quite labor intensive crop sector with labor costs accounting for 38% of total sector costs. Not surprisingly, the combination of a fall in the cost of wet land and an increase in the price of labor (and also in the price of capital) results in the cotton sector becoming less labor and capital intensive. The amount of labor and capital in the cotton sector thus actually decline by 1.13% and 0.61% respectively, while the amount of land and water used increase by 4.37%, resulting in a mere increase of 1.26% in total cotton production. The amount of land allocated to the major summer crop maize increases by

5.14%, as maize is a relatively water extensive crop. The amounts of land allocated to the categories other winter crops and other summer crops are unchanged as they are specified exogenously. This implies that these crops become relatively less important in the cropping pattern following the enlargement of the agricultural area by 10%.

Sugar cane is a highly water intensive crop. Following the enlargement of the agricultural area and the onset of water scarcity, the cost of wet land for sugar cane production consequently increases by 44.96%. However, the amount of land allocated to sugar cane only decreases by 4.67%, and production of sugar cane is virtually unchanged, as the sector's use of labor and capital increases by 5.76% and 6.32% respectively. All in all, the unit costs of producing sugar cane increases by 19.28%, which raises the question why sugar cane production can remain unchanged in the face of such increases in costs? The explanation for this observation is the fact that sugar cane is neither imported nor exported, and 86% of sugar cane production ends up in the food processing industry. However, sugar cane only accounts for 3% of intermediate inputs into the food processing industry, so an increase in the price of sugar cane of 19.28% does not have a significant impact on the food processing sector. Production of processed food is virtually unaffected in the present simulation, and the production of the water intensive crop sugar cane is thus kept up by demands from the domestic food processing industry.

Production in the animal agriculture sector expands by 2.56%. Intermediary inputs account for 59% of total costs in animal agriculture, primarily in the form of fodder, and berseem accounts for 36% of the intermediary inputs into animal agriculture. As the long berseem sector supplies the majority of the berseem commodity, production in the animal agriculture sector is thus quite dependent on the development in the long berseem sector. As outlined above, the long berseem sector expands due to the high initial land rents, and this facilitates an expansion in the animal agriculture sector despite the increase in labor and capital costs.

Cotton ginning expands marginally following the expansion of the cotton crop sector. Intermediary inputs account for 94% of total costs in cotton ginning and cotton accounts for 78% of the intermediary inputs into cotton ginning. As cotton was not imported in 1997 according to the SAM, and as cotton for the domestic market and cotton for the export markets are assumed to be imperfect substitutes (cf. section 4.2), an increase in domestic cotton production also results in an increase in domestic cotton ginning.

The only non-agricultural sector, which is significantly affected by the expansion of agricultural land, is the highly trade-exposed oil industry. Total production of oil thus decreases by 8.14%. 53% of domestic oil production is exported (cf. section 2), and the decline in oil production is a result of oil exports declining by 14.99%. The decline in oil exports is a result of the fact that local sales and exports of domestically produced oil are assumed to be perfectly substitutable and oil export demand is assumed to be highly elastic. The oil industry is highly capital-intensive, with capital costs accounting for 79% of total sector costs. Even a minor increase in the price of capital of 0.76% (combined with an increase in labor costs of 2.54%) thus results in unit costs of oil production – and hence also export prices - increasing by 0.87% in local currency and 0.33% in foreign currency.[24]

In terms of export revenue and import expenditures, the only commodities for which export revenue or import expenditures change significantly in absolute terms is oil (exports) and wheat (imports). As it turns out, the decline in oil export revenue matches the decline in wheat import expenditures fairly closely. This is in accordance with the long run closure, which requires the nominal trade balance as a fraction of nominal GDP to be unchanged, as the rest of the world is assumed to be unwilling to fund an increasing trade deficit.

Turning to the remaining macro results in table 6, we see that total employment (aggregated across sectors using wage bill weights) is fixed in accordance with the long run closure, and the pull of labor into agriculture consequently results in a decline in non-agricultural employment of 0.54%. As for the capital markets, the long run closure entails that the gross rate of return for capital in each sector is assumed to be exogenous, which results in identical changes in the rental rate of capital (cf. table 4).[25] While the agricultural capital stock increases by 4.00%, the non-agricultural capital stock decreases by 0.82%, which results in a

[24] The price of exports in foreign currency is calculated by subtracting the change in the nominal exchange rate from the change in the export price in local currency.

[25] In ORANI-G model, the gross rate of return on capital is defined as the rental price of capital divided by the price of new capital. In the long run closure, the gross rate of return on capital in all sectors is set exogenously. The rental price of capital is consequently determined by the price of new capital in the long run. As the SAM only contained one investment commodity, this commodity was distributed proportionally across all sectors (by assuming that each industry's share of aggregate investment is proportional to the industry's share of total capital rent). The investment profile in all sectors is thus identical. This is not a realistic assumption, but data was not available for differentiating investment profiles across sectors. The fact that each sector has identical investment profiles results in the price of new capital being identical across sectors, which in turn results in changes in rental prices of capital being identical across sectors in the long run. As the sector "other industry" account for 52.3% of the investment good, and as 47% of the total supply of other industry goods are imported, the price of new capital and hence also the long run rental price of capital is sensitive to changes in the exchange rate.

decrease of the total capital stock of 0.65%. The decrease in the non-agricultural capital stock is attributable to the contracting, capital-intensive oil industry, which accounts for 10.7% of total capital costs in the economy (cf. table 1).

As outlined in section 2, the cropping sectors only account for 10% of the value of total sectoral output. The cropping sectors thus only amount to a minor share of the total economy, and as table 6 shows, the increase of summer and winter dry land by 10% only results in an increase in real GDP of 0.44%. Real household and real government consumption increase by 0.74. The nominal exchange rate depreciates by 0.54% and export volumes and import volumes decline by 3.15% and 2.22% respectively. Despite the significant impact on the agricultural sector itself, the expansion of summer and winter land by 10% thus only has minor impacts on the economy-wide level.

Results for the water-abundant land-expansion scenario.

In order to determine the impact of the water constraint on agricultural production and international trade a second scenario is run featuring a 10% increase in the amount of summer and winter dry land. However, this time the water constraint is relaxed so as not to become binding despite the expansion of the land area. In all other respects the scenario is identical to the previous water constrained scenario.

The production, trade, and macro economic results for the non-water constrained scenario are presented in tables 7 to 10. Similarly to the presentation of the results in the water-constrained scenario, table 7 shows the changes percentage changes in output and input quantities in the different sectors, while table 8 shows the percentage changes in the corresponding input and output prices. Table 9 presents the percentage changes in quantities and prices for household demands, imports and exports, while table 10 presents the macro economic results for the scenario.

As table 10 shows, the expansion of summer and winter dry land by 10% results in consumption or loss of irrigation water increasing by 11.6%. The increase in agricultural employment of 4.79% is larger than in the water-constrained scenario and so is the expansion in the agricultural capital stock of 5.95%.

The fact that the agricultural sector does not become water constrained has significant implications for land rents. In the previous scenario, the onset of water scarcity following the land expansion resulted in general summer and winter dry land rents declining by 68% and 50% respectively. In the current water abundant scenario, the expansion of dry land only results in general summer and winter dry land rents declining by 10.53% and 2.44% respectively, while perennial dry land rents decline by 6.61%. As the water constraint does not become binding, the tax on water diversions remain zero. The cost of wet land is consequently identical to the price of dry land, and the cost of wet land thus declines for all crop sectors (except the two "other crop" categories) (cf. table 8). This in turn has significant implications for the allocation of land between crop sectors.

As shown in table 7, expanding the amount of dry land in a water-abundant setting once again primarily affects the winter crop sectors wheat and winter vegetables and the summer crop sectors rice and summer vegetables. As was the case in the previous scenario, the decline in the price of wet land and unit costs of production for wheat results in a drop in wheat imports by 34.44% and an increase in domestic production of wheat by 27.83%. Both the drop in wheat imports and the expansion in domestic wheat production is smaller in this water-abundant scenario than in the previous water-constrained scenario. This may in large part be explained by the changes in the nominal exchange rate. The water-constrained scenario was thus characterized by a devaluation, which would make wheat import more expensive, whereas the present water-abundant scenario produces a minor appreciation of the nominal exchange rate (cf. tables 6 and 10).

The decline in the cost of wet land for rice production results in unit cost of rice production declining by 4.76%, which in turn translates into a decline of 4.76% in the export price of rice in local currency and a decline of 4.71% in the export of rice in foreign currency. As rice for domestic markets and export markets are perfect substitutes and export demands for rice are highly elastic, rice exports subsequently increase ten-fold by 1016%(!) However, as rice exports only amounted to 2% of rice production prior to the expansion of agricultural land, the massive increase in rice exports is "only" accompanied by a 24.34% increase in rice production.

TABLE 7: CHANGES IN PRODUCTION AND INPUT QUANTITIES IN WATER ABUNDANT SCENARIO (PERCENTAGE CHANGE)

	Sector activity level	Effective labor input	Capital stock	Dry land	Water diverted	Wet land
Wheat	27.83	26.76	27.37	28.43	28.43	28.43
Legumes	0.58	-0.07	0.41	1.25	1.25	1.25
LongBerseem	0.83	-0.35	0.13	0.96	0.96	0.96
ShortBerseem	2.70	1.51	1.99	2.93	2.93	2.93
WinVeg	-15.07	-15.84	-15.43	-14.73	-14.73	-14.73
OthWinCrp	0.15	0.13	0.61	0.00	0.00	0.00
Cotton	0.74	-1.01	-0.53	2.93	2.93	2.93
Rice	24.34	21.58	22.16	26.42	26.42	26.42
MaizeSorg	3.20	0.74	1.23	4.75	4.75	4.75
SumVeg	13.24	9.76	10.29	14.13	14.13	14.13
OthSumCrp	0.12	0.07	0.55	0.00	0.00	0.00
Fruit	1.75	0.52	1.01	3.19	3.19	3.19
SugarCane	0.16	-1.22	-0.75	1.40	1.40	1.40
AnimalAgr	1.13	0.74	1.23	-	-	-
FoodProcess	0.18	-0.56	0.40	-	-	-
Oil	-10.77	-10.90	-10.76	-	-	-
CottonGin	0.73	0.34	1.30	-	-	-
Textiles	0.00	-0.54	0.42	-	-	-
OthIndustry	-0.40	-1.15	-0.20	-	-	-
Electricity	-0.17	-0.64	0.00	-	-	-
Construction	-0.34	-0.99	-0.04	-	-	-
GovServ	0.39	0.39	-	-	-	-
Transport	-0.31	-1.07	-0.12	-	-	-
OthServ	-0.49	-1.15	-0.20	-	-	-

TABLE 8: CHANGES IN OUTPUT AND INPUT PRICES IN WATER ABUNDANT SCENARIO (PERCENTAGE CHANGE)

	Average input / output price	Price of labor composite	Rental price of capital	Dry land rents	Tax on water diverted (absolute change)	Cost of wet land
Wheat	-0.77	1.91	0.29	-2.44	0.00	-2.44
Legumes	-0.20	1.91	0.29	-2.44	0.00	-2.44
LongBerseem	-1.92	1.91	0.29	-2.44	0.00	-2.44
ShortBerseem	-1.94	1.91	0.29	-2.73	0.00	-2.73
WinVeg	-1.63	1.91	0.29	-2.44	0.00	-2.44
OthWinCrp	1.59	1.91	0.29	2.35	0.00	2.35
Cotton	-3.29	1.91	0.29	-10.53	0.00	-10.53
Rice	-4.76	1.91	0.29	-10.53	0.00	-10.53
MaizeSorg	-5.13	1.91	0.29	-10.53	0.00	-10.53
SumVeg	-7.13	1.91	0.29	-10.53	0.00	-10.53
OthSumCrp	1.46	1.91	0.29	2.13	0.00	2.13
Fruit	-1.92	1.91	0.29	-6.61	0.00	-6.61
SugarCane	-2.16	1.91	0.29	-6.61	0.00	-6.61
AnimalAgr	-0.64	1.91	0.29	0.00	0.00	0.00
FoodProcess	0.02	1.91	0.29	0.00	0.00	0.00
Oil	0.39	1.91	0.29	0.00	0.00	0.00
CottonGin	-2.35	1.91	0.29	0.00	0.00	0.00
Textiles	0.15	1.91	0.29	0.00	0.00	0.00
OthIndustry	0.41	1.91	0.29	0.00	0.00	0.00
Electricity	0.56	1.91	0.29	0.00	0.00	0.00
Construction	0.48	1.91	0.29	0.00	0.00	0.00
GovServ	1.46	1.91	0.00	0.00	0.00	0.00
Transport	0.51	1.91	0.29	0.00	0.00	0.00
OthServ	0.64	1.91	0.29	0.00	0.00	0.00

TABLE 9: CHANGES IN QUANTITIES AND PRICES OF HOUSEHOLD DEMANDS, IMPORTS AND EXPORTS FOR WATER ABUNDANT SCENARIO (PERCENTAGE CHANGE)

	Household use of domestic / imported composite	Household price of domestic / imported composite	Total supplies of imported goods	Duty-paid, basic price of imported goods (local currency)	Export basic demands	Purchaser's price of export goods (local currency)
Wheat	0.88	-0.49	-34.44	-0.05	-	0.00
Legumes	0.55	-0.16	0.49	-0.05	0.64	-0.07
Berseem	0.00	0.00	0.00	-0.05	-	0.00
OthWinCrp	0.00	0.00	0.00	-0.05	-	0.00
Cotton	0.00	0.00	0.00	-0.05	-	0.00
Rice	5.41	-4.76	0.00	-0.05	1016.61	-4.76
MaizeSorg	5.82	-5.13	0.18	-0.05	-	0.00
OthSumCrp	0.00	0.00	0.00	-0.05	-	0.00
Vegetables	6.39	-5.64	0.00	-0.05	7.30	-2.37
Fruit	2.36	-1.92	1.12	-0.05	3.25	-0.12
SugarCane	0.00	0.00	0.00	-0.05	-	0.00
AnimalAgr	1.01	-0.62	0.63	-0.05	-	0.00
FoodProcess	0.38	0.02	0.18	-0.05	0.03	-0.05
Oil	0.18	0.22	0.23	-0.05	-19.82	0.39
CottonGin	0.00	0.00	0.00	-0.05	5.31	-0.16
Textiles	0.22	0.17	0.13	-0.05	-0.39	-0.05
OthIndustry	0.18	0.22	-0.16	-0.05	-1.27	-0.03
Electricity	-0.17	0.56	0.00	-0.05	-	0.00
Construction	-0.09	0.48	0.00	-0.05	-	0.00
GovServ	0.00	0.00	0.00	-0.05	-	0.00
Transport	-0.15	0.54	0.01	-0.05	-0.48	0.43
OthServ	-0.21	0.60	-0.25	-0.05	-0.62	0.57

TABLE 10: MACRO ECONOMIC RESULTS FOR WATER ABUNDANT SCENARIO (PERCENTAGE CHANGE)

Agricultural winter land	10	Nominal GDP	0.35
Agricultural summer land	10	Real GDP	0.07
Consumption or loss of irrigation water	11.6	GDP price index (expenditure side)	0.28
Agricultural employment	4.79	Aggregate real household consumption	0.39
Non-agricultural employment	-0.69	Aggregate consumer price index	0
Total employment (wage bill weights)	0	Aggregate real government demands	0.39
Agricultural capital stock	5.95	Nominal trade balance as share of nominal GDP (absolute change)	0
Non-agricultural capital stock	-1.23	Nominal exchange rate	-0.05
Total capital stock	-0.98	Terms of trade (export price index - import price index)	0.41
		Real devaluation (import price index - GDP price index)	-0.34
		Export volume index	-2.86
		Import volume index	-1.94

The rice area expands by 26.42%, which amounts to about half of the expansion in the summer dry land area. The remaining part of the new summer dry land is primarily used for summer vegetables and maize-sorghum. Production of summer vegetables thus expands by 13.24%, while production of maize-sorghum expands by 3.20%. The increase in production of summer vegetables leads to a decline in the production of winter vegetables of 15.07%. As the summer vegetable sector is initially more than twice as large as the winter vegetable sector, total vegetable production still increases by 4.44%.

The only non-agricultural sector, which is significantly impacted by the land expansion, is once again the oil industry. In the present water-abundant scenario, oil production decreases by 10.77%, which is 2.6 percentage points more than in the water-constrained scenario. Again the contraction in the oil industry is driven by a drop in oil exports, this time in the order of 19.82%. The larger decline in oil exports is a result of the massive increase in rice exports. While the nominal exchange rate depreciated by 0.54% compared to the consumer price index (i.e. the numeraire) in the previous water constrained scenario, the nominal exchange rate in the present water abundant scenario appreciates by 0.05% compared to the consumer price index.

Turning to the macro economic results, we see that an expansion of summer and winter dry land by 10% in a water-abundant setting only results in an increase in real GDP of 0.07%, while the same increase in summer and winter dry land in a water-constrained setting resulted in an increase in real GDP of 0.44%. Extra water resources consequently do not appear to be beneficial to the Egyptian economy, which seems puzzling. However, a significant part of this result derives from the development in the rice sector.

As outlined earlier, rice produced for the domestic markets is assumed to be a perfect substitute for rice produced for local markets, and export demands for rice are also highly elastic. This resulted in large swings in rice exports, as these were basically eliminated in the water-constrained land-expansion scenario, while they increased ten-fold in the water-abundant land-expansion scenario. The appreciation of the exchange rate in the latter scenario is driven by this massive increase in rice exports. The appreciation of the nominal exchange rate in the water-abundant scenario corresponds to a real appreciation of 0.34% compared to a real depreciation of 0.15% in the water-scarce scenario (cf. table 6 and table 10). Tests of the model in which rice for domestic markets and rice for export markets are turned into imperfect substitutes using the same CET value as that for other crop commodities show that the appreciation is harmful to the Egyptian economy in the sense that real GDP in the water-abundant scenario increases more when the rice export response is tempered and the exchange rate depreciates leading to a real depreciation. However, even with rice exports being imperfect substitutes for rice for local markets, real GDP in the water-constrained scenario still increases more than real GPD in the water-abundant scenario (0.42% vs. 0.30%).[26]

One factor, which may explain at least part of this remaining gap between real GDP in the two scenarios, is the differences in land rents across sectors. As outlined in section 4.3, land rents in the two vegetable sectors are significantly higher than land rents in most other sectors. In the water-constrained scenario, land use in the summer vegetable sector expands by 88%, while land use for winter vegetables declines by 44%. However, as the summer vegetable sector was initially twice as large as the winter vegetable sector, and as summer vegetable land rents are almost 50% higher than winter vegetable land rents, these changes in the cropping pattern imply that significant amounts of “cheap” land used for production of other crops is converted into “expensive” land for vegetable cultivation in the course of the simulation. This conversion of cheap land for normal crops into more valuable land for vegetable crops comes free of charge, as land is assumed to be perfectly mobile between sectors. In the water-abundant scenario, vegetable production does not expand nearly as much as in the water-constrained scenario – land for summer vegetable production thus only increase by 14.13%, while land for winter vegetable production decreases by 14.73%. Given these differences in the cropping patterns in the two scenarios, Egypt thus gets more of the valuable vegetable land in the water-constrained scenario than in the water-abundant scenario.

The notion that this conversion of normal crop land into more valuable vegetable crop land may explain why real GDP is higher in the water-constrained scenario than in the water-abundant scenario seems to be supported by the results for change in the aggregate amount of wet land. Wet land is aggregated across sectors using basic wet land prices, which are equal to dry land rents, as the basic price of water is zero (cf. section 3.2). In the water-constrained scenario, the results show that the aggregate amount of wet land increases by 13.14%, while it only increases by 8.37% in the water-abundant scenario. Comparing the increases in the

[26] In these scenarios where rice exports are imperfect substitutes for rice for domestic markets, the changes in the aggregate capital stock are approximately the same (-0.67% in the water-constrained scenario vs. -0.63% in the water-abundant scenario), which suggests that the lower GDP in the latter scenario is not explained by a lower aggregate capital stock.

aggregate amount of wet land in the two scenarios with the fact that the aggregate physical amount of dry land increases by 10% in each scenario suggests that the high vegetable land rents make is appear as though the economy is gaining more land in the water-constrained scenario than in the water-abundant scenario, which in turn would explain why real GDP is higher in the former scenario.[27]

5.2 Impact of increasing cereal import prices

Changes in international commodity markets can affect the import and export prices of the Egyptian economy. Whether such changes will have noticeable effects on the Egyptian economy depend in part on the Egyptian trade structure and the degree of openness of the Egyptian markets. The analysis in chapter 5 showed that the impact of the European Eastern Enlargement and the Mid-term Review of the CAP on EU trade with North Africa is most pronounced in absolute terms for cereals, bovine meat products, and dairy products. As outlined in section 2, the Egyptian trade structure suggests that the increases in import prices of bovine meat products and dairy products are not likely to have a substantial impact on the Egyptian economy. In the case of cereals, on the other hand, rising import prices may affect the Egyptian economy, as Egypt covers a substantial fraction of its wheat and maize demands through imports. The present scenario will consequently analyze the effect of rising import prices for wheat and maize on the Egyptian economy.

The implications of rising cereal import prices are analyzed in the long run version of the model. The model closure is thus identical to the long run model closure used in the previous scenarios. The starting point for the simulations is a situation, where water is scarce following the expansion of the agricultural area. The initial database for the present scenario is thus the updated database from the water-constrained scenario. While it would have been relevant to construct a scenario in which Egyptian cereal import prices were changed by the same magnitude as that produced by the Eastern Enlargement and the Mid-term Review in chapter 5, it is not possible to transfer the results from that model directly to the present one for a number of reasons.[28] First of all, the two models refer to different years and different factor

[27] Apart from aggregate labor, aggregate capital, and aggregate wet land, the decomposition of GPD from the income side also includes taxes and technical changes. The technical change term is zero in both scenarios, as the simulations feature no technical changes. As for the contribution from taxes, the results show that this amounts to -0.022 percentage points in the water-constrained scenario and -0.019 percentage points in the water-abundant scenario, despite the significant increase in water taxes in the former scenario.

[28] For general information about how to transfer trade shocks from the GTAP model to a single country model see Horridge and Zhai (n.d.).

endowments – while the model in chapter 5 was based on a baseline to the year 2013, the present model simply features an expansion of the land area in the 1997 economy under due observation of the ensuing water constraint. Secondly, the numeraire in the two models are different. As all prices are measured relative to the numeraire, the price changes from chapter 5 would have to be recalculated in order to be meaningful in the present model set-up. Furthermore, the two models are based on different assumptions regarding trade elasticities and the preceding sections have shown that the trade elasticities are highly important for model results. Instead of emulating the trade results from chapter 5, the general effects of increasing cereal import price are therefore investigated by simply shocking the C.I.F. foreign currency import price of both wheat and maize by 5%. While the scenario does not capture the exact effects of the Eastern Enlargement and the Mid-term Review on Egypt, it will illustrate general long run implications for the Egyptian economy of rising cereal import prices.

The long run consequences for the Egyptian economy of increasing import prices for wheat and maize by 5% are presented in tables 11 to 14. Once again table 11 shows the percentage changes in output and input quantities in the different sectors, while table 12 shows the percentage changes in the corresponding input and output prices. Table 13 presents the percentage changes in quantities and prices for household demands, imports and exports, while table 14 presents the macro economic results for the scenario.

As table 13 shows, the increase in import prices of wheat and maize results in imports of wheat declining by 19.58% while imports of maize only decline by 0.75%. Due to appreciation of the nominal exchange rate by 0.39% (cf. table 14), the import prices of wheat and maize in local currency only increase by 4.59%. All other import prices decline by 0.39%.

TABLE 11: CHANGES IN PRODUCTION AND INPUT QUANTITIES IN IMPORT PRICE SCENARIO (PERCENTAGE CHANGE)

	Sector activity level	Effective labor input	Capital stock	Dry land	Water diverted	Wet land
Wheat	5.18	6.97	6.83	4.03	4.03	4.03
Legumes	-2.01	-0.92	-1.06	-3.26	-3.26	-3.26
LongBerseem	-2.11	0.64	0.50	-2.52	-2.52	-2.52
ShortBerseem	0.63	3.40	3.25	-0.04	-0.04	-0.04
WinVeg	-20.49	-18.38	-18.49	-21.74	-21.74	-21.74
OthWinCrp	-0.70	-1.15	-1.29	0.00	0.00	0.00
Cotton	-0.01	0.03	-0.11	-0.04	-0.04	-0.04
Rice	0.43	0.25	0.11	0.57	0.57	0.57
MaizeSorg	-0.43	-0.40	-0.54	-0.43	-0.43	-0.43
SumVeg	1.66	2.17	2.03	1.46	1.46	1.46
OthSumCrp	-0.67	-1.06	-1.19	0.00	0.00	0.00
Fruit	-1.28	-0.65	-0.79	-2.11	-2.11	-2.11
SugarCane	-0.70	-0.29	-0.43	-0.97	-0.97	-0.97
AnimalAgr	-1.66	-1.55	-1.69	-	-	-
FoodProcess	-0.75	-0.54	-0.81	-	-	-
Oil	-2.08	-2.04	-2.08	-	-	-
CottonGin	0.02	0.13	-0.14	-	-	-
Textiles	0.03	0.19	-0.09	-	-	-
OthIndustry	-0.19	0.02	-0.25	-	-	-
Electricity	-0.05	0.08	-0.10	-	-	-
Construction	-0.08	0.10	-0.17	-	-	-
GovServ	-0.28	-0.28	-	-	-	-
Transport	-0.07	0.15	-0.12	-	-	-
OthServ	-0.07	0.12	-0.16	-	-	-

TABLE 12: CHANGES IN OUTPUT AND INPUT PRICES IN IMPORT PRICE SCENARIO (PERCENTAGE CHANGE)

	Average input / output price	Price of labor composite	Rental price of capital	Dry land rents	Tax on water diverted (absolute change)	Cost of wet land
Wheat	4.30	-0.74	-0.28	20.59	-0.01	8.93
Legumes	2.35	-0.74	-0.28	20.59	-0.01	7.47
LongBerseem	8.53	-0.74	-0.28	20.59	-0.01	10.39
ShortBerseem	8.50	-0.74	-0.28	19.14	-0.01	11.10
WinVeg	5.95	-0.74	-0.28	20.59	-0.01	14.19
OthWinCrp	-1.93	-0.74	-0.28	-4.60	-0.01	-4.51
Cotton	-0.49	-0.74	-0.28	4.06	-0.01	-0.52
Rice	-1.21	-0.74	-0.28	4.06	-0.01	-1.78
MaizeSorg	-0.53	-0.74	-0.28	4.06	-0.01	-0.65
SumVeg	0.87	-0.74	-0.28	4.06	-0.01	1.57
OthSumCrp	-1.71	-0.74	-0.28	-4.34	-0.01	-4.19
Fruit	1.25	-0.74	-0.28	13.87	-0.01	4.29
SugarCane	0.47	-0.74	-0.28	13.87	-0.01	1.56
AnimalAgr	1.80	-0.74	-0.28	0.00	0.00	0.00
FoodProcess	0.58	-0.74	-0.28	0.00	0.00	0.00
Oil	-0.31	-0.74	-0.28	0.00	0.00	0.00
CottonGin	-0.47	-0.74	-0.28	0.00	0.00	0.00
Textiles	-0.42	-0.74	-0.28	0.00	0.00	0.00
OthIndustry	-0.36	-0.74	-0.28	0.00	0.00	0.00
Electricity	-0.39	-0.74	-0.28	0.00	0.00	0.00
Construction	-0.39	-0.74	-0.28	0.00	0.00	0.00
GovServ	-0.59	-0.74	0.00	0.00	0.00	0.00
Transport	-0.37	-0.74	-0.28	0.00	0.00	0.00
OthServ	-0.35	-0.74	-0.28	0.00	0.00	0.00

TABLE 13: CHANGES IN QUANTITIES AND PRICES OF HOUSEHOLD DEMANDS, IMPORTS, AND EXPORTS FOR IMPORT PRICE SCENARIO (PERCENTAGE CHANGE)

	Household use of domestic / imported composite	Household price of domestic / imported composite	Total supplies of imported goods	Duty-paid, basic price of imported goods (local currency)	Export basic demands	Purchaser's price of export goods (local currency)
Wheat	-4.46	4.37	-19.58	4.59	-	0.00
Legumes	-1.84	1.58	-1.21	-0.39	-3.30	-0.32
Berseem	0.00	0.00	0.00	-0.39	-	0.00
OthWinCrp	0.00	0.00	0.00	-0.39	-	0.00
Cotton	0.00	0.00	0.00	-0.39	-	0.00
Rice	0.94	-1.21	0.00	-0.39	51.19	-1.21
MaizeSorg	0.25	-0.53	-0.75	4.59	-	0.00
OthSumCrp	0.00	0.00	0.00	-0.39	-	0.00
Vegetables	-1.79	1.54	0.00	-0.39	-2.44	0.43
Fruit	-1.52	1.25	-0.75	-0.39	-2.52	-0.34
SugarCane	0.00	0.00	0.00	-0.39	-	0.00
AnimalAgr	-1.95	1.70	-1.13	-0.39	-	0.00
FoodProcess	-0.83	0.55	-0.40	-0.39	-2.55	-0.34
Oil	0.06	-0.34	-0.05	-0.39	-4.03	-0.31
CottonGin	0.00	0.00	0.00	-0.39	0.17	-0.39
Textiles	0.13	-0.42	0.02	-0.39	0.08	-0.39
OthIndustry	0.09	-0.37	-0.18	-0.39	-0.24	-0.39
Electricity	0.11	-0.39	0.00	-0.39	-	0.00
Construction	0.11	-0.39	0.00	-0.39	-	0.00
GovServ	0.00	0.00	0.00	-0.39	-	0.00
Transport	0.10	-0.38	-0.09	-0.39	-0.04	-0.35
OthServ	0.07	-0.36	-0.07	-0.39	-0.05	-0.34

TABLE 14: MACRO ECONOMIC RESULTS FOR IMPORT PRICE SCENARIO (PERCENTAGE CHANGE)

Agricultural winter land	0.00	Nominal GDP	-0.41
Agricultural summer land	0.00	Real GDP	-0.26
Consumption or loss of irrigation water	0.00	GDP price index (expenditure side)	-0.15
Agricultural employment	0.44	Aggregate real household consumption	-0.28
Non-agricultural employment	-0.07	Aggregate consumer price index	0.00
Total employment (wage bill weights)	0.00	Aggregate real government demands	-0.28
Agricultural capital stock	0.43	Nominal trade balance as share of nominal GDP (absolute change)	0.00
Non-agricultural capital stock	-0.45	Nominal exchange rate	-0.39
Total capital stock	-0.42	Terms of trade (export price index - import price index)	-0.23
		Real devaluation (import price index - GDP price index)	0.03
		Export volume index	-0.76
		Import volume index	-0.84

The large decline in wheat imports results in an expansion of domestic wheat production by 5.18%, while the amount of land allocated to wheat production increases by 4.03%. As wheat already takes up 42% of winter dry land prior to the changes in import prices, expanding wheat land by 4% results in a significant increase in general winter dry land rents of 20.59% as well as contractions in land use in other winter crop sectors. The long berseem sector and the perennial fruit sector account for 21% and 13% of winter dry land prior to the import price shock. Following the import price shock, dry land use in these sectors decline by respectively 3.26% and 2.11%. In the case of the winter vegetables sector (which already contracted significantly under the water-constrained land-expansion scenario), the use of winter dry land declines by 21.74%, and output from the winter vegetable sector contracts by 20.49%. The drop in total vegetable production is countered by an expansion of the summer vegetables sector (which already expanded significant under the water-constrained land expansion scenario) by 1.66%. However, total vegetable production still declines by 1.59%.

The fact that maize imports only decline by 0.75% following the increase in maize import prices of 4.59% is due to the fact that imported maize is an imperfect substitute for domestically produced maize. The Armington elasticity for maize is thus only 1.6 compared to the Armington elasticity for wheat of 100. Following the decline in maize imports, one might expect an increase in domestic maize production, but the domestic maize sector actually contracts by 0.43%. The reason why domestic maize production declines relates to the domestic demands for maize. 50.6% of domestically produced maize is thus used as intermediary inputs, and 65.1% of these intermediary maize inputs go to the animal agriculture sector. Production in the animal agriculture sector declines by 1.66% due to the decline in berseem production (cf. discussion under water-constrained land-expansion scenario for the importance of berseem to animal agriculture). As all intermediary inputs are used in fixed proportions, the decline in animal agriculture also implies a decline in demands for maize as intermediary input into the animal agriculture sector. However, due to the decline in the maize price of 0.53%, household demands for maize increase marginally by 0.25.

The increase in the amount of land used for summer vegetable production exceeds the decline in the amount of land used for maize production and this leads to an increase in general summer dry land rents of 4.06%. On the other hand, the decline in the amount of water needed for production of long berseem, fruits, and winter vegetables marginally exceed the increased water needs of the wheat sector. This in turn results in a minor relaxation of the water constraint and hence also a minor drop in the uniform tax on water diverted (cf. column 5 of table 12). The combination of the moderate increase in summer dry land rents and the decline in water taxes results in a decline in the costs of wet land for rice production of 1.78%. Use of dry land for rice production consequently expands marginally by 0.57% and production of rice expands by 0.43%. The decline in the domestic output price of rice of 1.21% results in a comparable drop in the export price of rice in local currency and a drop in the export price of rice in foreign currency of 1.6%. This subsequently leads to an increase in rice exports of 51.19%. However, given that rice exports were virtually eliminated in the water-constrained land-expansion scenario, rice exports are for all practical purposes still zero.

The only non-agricultural sectors, which are noticeably affected by the increase in cereal import prices, are food processing and the oil industry, which contract by 0.75% and 2.08% respectively. In the case of the food processing industry, this is attributable to the developments in the wheat sector. 89% of the total wheat supply is used as intermediary inputs and 80% of these intermediary wheat imports go to the food processing industry. As the combination of a 19.58% drop in wheat imports and 5.18% increase in domestic wheat production amounts to a decline in total wheat supply for the local market of 1.03%, the food processing sector contracts following the increase in wheat import prices.

In the case of the oil industry, the contraction is a result of the appreciation of the exchange rate. Despite the fact that the domestic output price of oil declines by 0.31%, due largely to the drop in the rental price of capital by 0.28%, the appreciation of the exchange rate by 0.39% results in an increase in the export price of oil in foreign currency of 0.08%. Exports of oil consequently decline by 4.03% resulting in the contraction in total domestic oil production of 2.08%.

Turning to the macro economic results in table 14, we see that the increase in the cereal import prices results in a decrease in the total capital stock of 0.42%. This is largely the result of the non-agricultural capital stock decreasing by 0.43% due in part to the contraction in the oil industry. Employment in agriculture increases by 0.44%, while non-agricultural employment decreases by 0.07%. The fact that this shift in labor allocation is associated with a decline in the price of labor of 0.74% suggests that labor may be pushed out of the non-agricultural sectors more so than it is being pulled into agriculture. Looking at the labor use in the non-agricultural sectors shows that the only sectors in which labor use declines is the food processing sector, the oil industry, and government services. Neither the food processing sector nor the oil industry are labor intensive (cf. table 1), and in both of these sectors the decline in the capital stock exceeds the decline in labor use suggesting that the labor intensity in these sectors actually increases. The government sector, on the other hand, is highly labor intensive and accounts for 24.3% of total labor costs in the Egyptian economy. The sector is characterized by being the only sector in the SAM, which does not use capital and hence also does not benefit from the decline in the rental price of capital. As labor is the only primary factor input in government services, a decline in total output of government services necessarily translates into a comparable decline in the amount of labor used for the production of government services. Intermediary inputs account for 26.1% of total costs in the government sector, and other industry goods account for 28% of the intermediary inputs in the government sector. The contraction in the other industry sector may thus contribute to the contraction in the government sector.

All in all, the increase in wheat and maize import prices of 5% in foreign currency results in a decline in real GDP of 0.26% and a decline in real household and government demands of 0.28%. Not surprisingly, rising prices of cereal imports thus have a negative impact on the Egyptian economy. The results are mostly driven by the developments in the wheat sector as this sector is much more trade-exposed than the maize sector.

6. DISCUSSION AND CONCLUSION.

The present analysis has investigated the linkages between Egyptian crop production, the ensuing national water constraint and international trade. The first two scenarios investigated the impact of the water constraint on the Egyptian economy and Egyptian international trade, when agricultural land was expanded by 10%. The third scenario investigated the implications for Egypt of rising import prices for wheat and maize.

The first two scenarios illustrated the impact of the water constraint on Egyptian international trade in a situation where summer and winter dry land were expanded by 10%. Where most of the Egyptian crop sectors were assumed to be relatively sheltered from the developments in the international agricultural markets through low degrees of substitutability either between imports and domestically produced commodities or between commodities destined for export and commodities destined local markets, this was not the case for the wheat and rice sectors.

Imports of wheat were thus assumed to be perfectly substitutable for domestically produced wheat, while rice destined for exports were assumed to be perfectly substitutable with rice destined for local markets and export demands were assumed to be highly elastic. Given the relative magnitudes of these sectors – wheat accounts for 35% of winter land use and rice accounts for 22% of summer land use – as well as the degree of trade exposure for wheat and rice commodities, the developments in the wheat and rice sector tended to dominate the results in the two scenarios.

As wheat is not a particularly water-intensive crop, the onset of water scarcity only appeared to have minor impacts on this sector. It should be noted, though, that the difference in the resulting exchange rate between the two scenarios may have masked some of the impacts of the water constraint. Unlike wheat, rice is a highly water-intensive crop, and accounting for the water constraint consequently had very pronounced effects for exports of this trade-exposed commodity. In the water-constrained scenario, rice exports were thus eliminated, while rice exports in the water-abundant scenario increased ten-fold. Although rice exports only amounted to 0.1% of total exports in the initial database, the massive increase in exports of this commodity in the water-abundant scenario still brought about an appreciation of the nominal exchange rate, which had a negative impact on the economy and real GDP, although it did not explain all of the difference between real GDP in the two scenarios. The remaining difference between GDP in the two scenarios appears to be driven by the massive shift of land into the summer vegetable sector in the water-constrained scenario, as this implies a costless conversion of normal land into high value land.

The analysis in chapter 5 suggested that Egypt in the future might be faced with rising prices of cereal imports. The third scenario therefore analyzed the impact of a general 5% increase in the foreign currency import price of wheat and maize. Not surprisingly, the results were once again driven by the trade-exposed wheat sector, and the increase in cereal import prices had a minor negative impact on the economy and real GDP. However, comparing the magnitude of the real GDP impact in the cereal import price scenario with the magnitude of the GDP impact in the two land expansion scenarios underscores that rising import prices of the important cereal crops do matter for the Egyptian economy.

The fact that the expansion of agricultural land apparently has relatively small effects on GDP in the land-constrained Egyptian economy raises some questions as to what degree the present simulations illustrate the future conditions of the Egyptian economy. The important thing to note here is that the present simulations merely increase the amount of dry land in the economy without considering changes in population and labor force, the capital stock, and general productivity. In order to fully capture the future realities of the Egyptian economy and the implications of expanding the land area in this economy, it would be necessary to construct a baseline of the Egyptian economy for the time period over which the land expansions will take place.

Further investigation of the land rent issues would also be an area for future work. While the differences in land rents may reflect real-world phenomena, the results from the two land-expansion scenarios showed that it would be relevant to study the implications of either having more homogenous land rents or limiting substitution in and out of sectors with high land rents, both in terms of the resulting cropping patterns and in terms of the implications for GDP.

Parameter assumptions are clearly also very important for model results as the discussion of the trade results have shown. A set of model parameters, which it would be desirable to update, is the household demand parameters, as household demands are not likely to conform to a Cobb-Douglas function. Combining such parameters with additional model extensions to close the income-expenditure circuits for the households and the government, the model could subsequently also be used for analysis of the distributional aspects of the water constraint.

All in all, the analysis in the present chapter has demonstrated some of the key implications for Egyptian agricultural trade of accounting for the ensuing water constraint as well as how this can be done using CGE models and SAMs, which do not initially account for agricultural water usage. As the degree of water scarcity in Egypt becomes more pronounced in the coming years, accounting for agricultural water usage in the national economic models will only become more important.

APPENDIX A: HOUSEHOLD, INDUSTRY AND COMMODITY AGGREGATIONS

HOUSEHOLD AGGREGATIONS

Aggregated household	SAM households
Household	Rural household quintile 1 - 5, urban household quintile 1 - 5

SECTORAL AGGREGATIONS

Aggregated industries	SAM industries
Wheat	Wheat
Legumes	Legumes
LongBerseem	Long berseem
ShortBerseem	Short berseem
WinVeg	Winter vegetables
OthWinCrp	Other winter crops
Cotton	Cotton
Rice	Rice
MaizeSorg	Maize-sorghum
SumVeg	Summer vegetables
OthSumCrp	Other summer crops
Fruit	Fruit
SugarCane	Sugar cane
AnimalAgr	Animal agriculture
FoodProcess	Subsidized bread, non-subsidized bread, subsidized flour, non-subsidized flour, other food processsing
Oil	Oil
CottonGin	Cotton ginning
Textiles	Textiles
OthIndustry	Other industry
Electricity	Electricity
Construction	Construction
GovServ	Government services
Transport	Transportation
OthServ	Other services

Commodity aggregations

Aggregated commodities	SAM commodities
Wheat	Wheat, wheat byproducts
Legumes	Legumes, legumes byproducts
Berseem	Berseem
OthWinCrp	Other winter crops, other winter crops byproducts
Cotton	Cotton, cotton byproducts
Rice	Rice, rice byproducts
MaizeSorg	Maize-sorghum, maize-sorghum byproducts, yellow maize
OthSumCrp	Other summer crops, other summer crops byproducts
Vegetables	Vegetables
Fruit	Fruit
SugarCane	Sugar cane
AnimalAgr	Animal agriculture, animal labor, manure
FoodProcess	Subsidized bread, non-subsidized bread, subsidized flour, non-subsidized flour, other food processsing
Oil	Oil
CottonGin	Cotton ginning
Textiles	Textiles
OthIndustry	Other industry
Electricity	Electricity
Construction	Construction
GovServ	Government services
Transport	Transportation
OthServ	Other services

Appendix B: Cropping pattern for 1997 (million feddan)

	Summer land	Winter land
Wheat		2.52
Legumes		0.42
LongBerseem		1.59
ShortBerseem		0.70
WinVeg		0.47
OthWinCrp		0.27
Cotton	0.86	
Rice	1.55	
MaizeSorg	2.31	
SumVeg	1.01	
OthSumCrp	0.23	
Fruit	0.96	0.96
SugarCane	0.29	0.29
Total	7.21	7.23

Source: Own calculations based on a modified version of IFPRI's 1997 SAM, FAOSTAT core production data (http://faostat.fao.org/site/340/DesktopDefault.aspx?PageID=340) , and data from Mohamed 2001.

APPENDIX C: NATIONAL CROP EVAPOTRANSPIRATION COEFFICIENTS (000 CUBIC METERS PER FEDDAN)

	Summer crop ET	Winter crop ET	Annual ET
Wheat		2.12	2.12
Legumes		1.44	1.44
LongBerseem		2.97	2.97
ShortBerseem		1.02	1.02
WinVeg		1.67	1.67
OthWinCrp		1.87	1.87
Cotton	2.97		2.97
Rice	4.46		4.46
MaizeSorg	2.55		2.55
SumVeg	2.18		2.18
OthSumCrp	2.93		2.93
Fruit	3.08	1.66	4.74
SugarCane	5.24	2.82	8.06

Source: Own calculations based on data from Mohamed 2001 p A39-A40.

CONCLUSION.

Water scarcity and the questions it raises about how best to allocate this resource will become more important in the years to come. The recently published Human Development Report 2006 entitled “Beyond scarcity: Power, poverty and the global water crisis” is a testimony to the intensified struggle for water in many parts of the developing world, whether in the form of water for human consumption, sanitation, or agricultural production. The report argues that “scarcity is the product of public policies that have encouraged overuse of water through subsidies and underpricing” (UNDP 2006 p 2-3).

Egypt is one of the countries, which will have to face the issue of water scarcity in the near future. The growth of the Egyptian population and the government’s ambitious plans to expand the agricultural area by reclaiming large amounts of desert land will lead to water demands exceeding the fixed supplies from the Nile. As agriculture is the largest water user in the Egyptian economy, and as domestic and industrial water needs are typically given preference over agricultural water needs, the water demands of the 100% irrigation dependent agricultural sector have to be adjusted. The question, which has been the main focus of this Ph.D. thesis, is how agricultural water demands can be regulated efficiently given the specific features of the Egyptian irrigation system and hydrology.

The Egyptian irrigation system is characterized by large differences between the traditional irrigation system in the Old Lands and the more modern irrigation systems in the New Lands. In the traditional system, it is not yet possible to meter individual farmers’ water appropriation, but large-scale renovations of the irrigation infrastructure imply that it may be possible in the future. Farmers use the inefficient flood irrigation technique, which results in substantial return flows from irrigation. However, these return flows typically end up in drains or shallow aquifers from which they are readily recoverable. In the New Lands, on the other hand, return flows tend to be non-recoverable. Farmers are therefore required by law to use the modern and more efficient sprinkler and drip irrigation techniques. The use of modern irrigation techniques implies that water can in principle be metered at the point of delivery.

The institutional and hydrological set-up of the Egyptian irrigation system implies the presence of two key externalities in irrigation economics. The fact that individual farmers’ water appropriations are not effectively regulated suggests that some farmers will have access to appropriate scarce water resources at other farmers' expense, and that water resources will consequently not be distributed in a socially efficient manner across farmers. This is the classical head-end tail-end externality problem of irrigation canals. The low irrigation efficiency and high return flow recoverability in the Old Lands also signifies the presence of the recoverable return flows' externality. Indeed calculations show that water is already being used more than once in Egypt.

The implications of the externality associated with farmers' appropriation of water are well-understood, and there is a substantial literature on the policy instruments, which can be used to alleviate this externality. These policy options range from volumetric water pricing (or taxes) over non-volumetric taxes to water quotas, establishment of water markets and user-based allocations. The implications of the recoverable return flow externality, on the other hand, have not been as widely recognized. Possibilities considered in the literature for alleviating this type of externality include water markets and water pricing, but there is a need for more research on the issue of how to most efficiently handle recoverable return flows. This topic has therefore been investigated in the present PhD thesis.

Rather than merely studying the recoverable return flow externality in isolation, it is important to also study it in conjunction with the irrigation water diversion externality, as the two externalities have different implications for the importance of field irrigation efficiency. As part of this thesis, a theoretical model was consequently constructed to study the efficiency properties of different water regulating policy instruments in a setting where both externalities are present simultaneously. The tax policy instruments under consideration were:

- Taxes on water applied and credits on recoverable return flows
- Only taxes on water applied
- Crop-specific land taxes
- Crop-specific output taxes

In addition to these tax instruments, the efficiency properties of the corresponding quota instruments were also analyzed.

The theoretical analysis showed that it would in principle be possible to achieve a first-best allocation of land and water in the presence of the two externalities through use of the policy instrument of taxing water applied and crediting for recoverable return flows. However, this policy instrument is not implementable in a real-world setting, as it will generally not be possible to meter or deduce the amount of return flows generated by individual farmers. Due to the presence of the return flow externality, only taxing water applied cannot yield a first-best allocation of land and water, as long as return flows are at least partially recoverable. Crop-specific land taxes and crop-specific output taxes also result in second-best allocations of land and water. However, unlike the first-best instrument, all three types of second-best policies are in principle implementable. Volumetric water taxes (or alternatively water quotas) will, though, require the ability to meter individual farmer water appropriations. As outlined above, this is not yet possible in the Old Lands, but it might become possible in the future following the implementation of the Irrigation Improvement Project. Crop-specific land taxes, on the other hand, are implementable under the current system and are typically not too expensive to administer. Crop-specific output taxes would tend to be substantially more difficult and costly to implement than crop-specific land taxes.

The relative efficiency properties of the second-best instruments depend on the values of various water parameters, and it is consequently not possible to rank these three instruments based solely on the theoretical analysis. In order to ascertain the relative efficiency of the second-best instruments in an Egyptian setting and determine "what difference the difference makes", the theoretical analysis was implemented empirically in a regional non-linear programming model of Egypt. The empirical model is a result of joint work with Philip Abbott. The analysis showed that the policy instruments produced significantly different cropping patterns driven in part by regional differences in the key water parameters. The analysis also suggested that a single tax on water applied would achieve a more socially efficient allocation of land water in Egypt than crop-specific land taxes and crop-specific output taxes. However, the differences in welfare between the different policy instruments were generally small, including the difference in welfare between the first-best and the second-best instruments.

All of the tax policy instruments analyzed in the empirical model had a similar and significantly negative impact on farmer profits. This is not likely to be well-received in the Egyptian country-side, where the notion of charging for irrigation water itself is generally not accepted. The option of using water quotas may consequently be politically more appealing. However, unlike the present system of allocating water to large segments of the irrigation system, the water quotas would have to be allocated to each individual farmer. Determining the optimal quota sizes may be difficult for the authorities and enforcing such a water quota system would also require the ability to meter individual farmer water diversions. The upgrade of the irrigation infrastructure would consequently have to be completed before a quota system could be effectively implemented. In the mean time, crop-specific land taxes may prove to be the best instrument for regulating the use of irrigation water in the Old Lands. However, the issue of the negative impact on farmer profits remains.

All models and analyses rests on simplifying assumptions and this is also the case for the present policy studies. Two areas of future work are thus water quality and the cost of providing irrigation water. Although the analyses have generally focused on water quantities, the degree and implications of water scarcity cannot be fully assessed without including considerations of water quality. Water quality is also important with respect to recoverable return flows, as each additional water use cycle tends to result in a decline in the water quality. As outlined in the theoretical analysis, there are features in the theoretical model, which can be used for including the notion of water quality. However, there is still a significant gap between introducing water quality measures in the theoretical analysis and operationalizing these measures in empirical analysis.

Recovery of the costs associated with providing irrigation water is also an important issue in irrigation economics. The costs of operating and maintaining a large-scale irrigation system can be substantial, and these costs should be included when calculating the socially optimal price of water. The costs of providing irrigation water are also affected by the recoverability of return flows, as recovering these water flows may result in additional pumping costs. However, accounting adequately for these costs of recovering return flows in empirical analyses requires detailed data on the hydrological properties of the irrigation system.

The models developed for these analyses have been based on the characteristics of the Egyptian irrigation system. However, although the specific results of the empirical analysis pertain to Egypt, the general lessons from the analysis are relevant to many other developing countries. Recoverable return flows will thus be a feature in most major river irrigation systems. In order to achieve the best use of scarce irrigation water resources, the generation and recoverability of return flows should thus be considered when analyzing the properties of the irrigation systems in question. Furthermore, many developing countries' irrigation systems will also be characterized by the inability to meter individual farmer water diversions. The present analysis has demonstrated how non-volumetric water policies like crop-specific land taxes or possibly crop-specific output taxes may be used to achieve a more efficient allocation of land and water resources in the presence of both irrigation externalities. These developing countries may thus be able to reap the benefits of more efficient allocation of irrigation water resources without having to devote substantial amounts of government funds or development aid to implement volumetric metering in their irrigation infrastructure.

International trade in agricultural commodities is often important to developing countries both in terms of potential export earnings and as a means to cover a domestic food-deficit. The European Union is one of the most important trading partners for Egypt, and the Common Agricultural Policy has recently undergone substantial changes in terms of the Eastern Enlargement of the EU and the Mid-term Review of the CAP. In order to determine to what extent these changes to EU agriculture will affect the EU's African trading partners, a study was done on the impacts of the reforms on EU-African trade and African production and welfare using the multi-country CGE model GTAP. The study was co-authored by Hans Grinsted Jensen. The results of the analysis suggest that although the enlargement of the EU and the reform of the CAP have significant implications for EU agricultural production and trade, the effects on the African regions will typically be neglible. The North African region will primarily be affected through declining imports and rising import prices of cereals, bovine meat products, and dairy products, but the overall impact on the North African region tend to be minor.

The focus of the final analysis in this PhD thesis was the relationship between international trade and the national water balance in Egypt. Using a national CGE model of Egypt, based on a modified version of the so-called ORANI-G model and IFPRI's 1997 SAM of Egypt, the impact of the national water constraint on Egyptian international trade was investigated. The analysis showed how the onset of water scarcity had significant implications for Egyptian production and trade, especially in the case of the highly water-intensive and trade-exposed rice sector. As Egypt is highly dependent on imports for covering the domestic cereal demands, the analysis also investigated the consequences for the Egyptian economy of rising cereal import prices.

One of the lessons for other developing countries is that it is important to include water scarcity considerations when evaluating the impact of developments in the international agricultural markets. In the irrigation-dependent economies, the onset or intensification of water scarcity may have substantial implications for these countries' agricultural potential. Some water measures have already been included in a small-scale version of the GTAP model and database (cf. GTAP-W in Berrittella et al 2005). While it would probably be a fairly demanding task to include water use for all countries and sectors in the large GTAP database, results for countries which are water-constrained should at least be evaluated with these water constraints in mind.

The focus in this Ph.D. thesis has mainly been on the efficiency implications of the impending water scarcity in Egypt. An important area for future work will be to investigate the distributional implications of the binding water constraint, both in the Egyptian setting and in other water constrained economies. The rural sector is often home to a disproportionally large fraction of the poor in developing countries. It is consequently important to take the distributional implications of a given set of water policies into consideration. Tax policy instruments like the ones considered in the theoretical and empirical models in this thesis will have a negative impact on farmer incomes. However, the tax revenue could be used to at least partially alleviate adverse distributional implications of these policies. The use of quota instruments would allocate the water rents to the farmers. However, enforcing water quotas will often be costly and great care must be exercised to ensure that the poor segments get their fair share of the water.

Water scarcity is likely to become more pronounced in the coming years in many areas of the world. The mounting pressure on the fresh water resources makes it more important not only to treat water as a general economic good, but to focus on the special characteristics of this good such as the difficulties in regulating access to water in many places and the fact that water will often be used more than once due to presence of recoverable return flows. In order to maximize the economic value of each drop, it is important to use policy instruments, which are designed with these issues in mind. Imposing the national water constraints on individual citizens through taxes, quotas, and the like will often have noticeable impacts on relative prices and production structures. Furthermore, real world policy reforms tend to produce not only winners but also losers, at least in the short run. Efforts must thus be taken to ensure that the poor are not further marginalized in the course of reforms. However, despite these policy challenges and political hurdles, water management reforms must still be pursued, as these reforms are needed in many places if we are to make the most of the precious fresh water resources in the water constrained regions of the world.

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