UNIVERSITÁ CATTOLICA DEL SACRO CUORE PIACENZA

Scuola di Dottorato per il Sistema Agro-alimentare

Doctoral School on The Agrofood System

Cycle XXII

S.S.D.: SECS P/02

MODELING WATER REALLOCATION POLICIES IN A CGE FRAMEWORK: THE IMPACT OF DROUGHT ON THE KENYAN ECONOMY

Candidate: Adriano Spinelli
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INTRODUCTION

Framing the Problem: the Importance of Water and Its Main Economic Features

Water is used in almost all production activities present in our economies, of which very often is an essential input. Currently our societies are facing problems of water scarcity, which are tightly related to climate change, urban growth, and the dynamics of population and pollution which are becoming increasingly challenging issues for policy makers. There is a rising call for an improved management of water demand rather than just increasing its supply[1].

Therefore, the issue of water shortages makes *efficient allocation* a pivotal goal to be reached. To ensure availability of the resource in the long term, such an objective should be subject to an environmental protection strategy. There is a need to re-assess our current unsustainable production and consumption patterns to ensure the *sustainability* of water management. Hence, the need for decoupling economic growth from increased environmental pressure. However, *equity* is a fundamental concern too, since water is such a crucial resource for human life and activities. As provided by Millennium Development Goals[2] living standards and gender equality must be enhanced. Therefore, water allocation mechanisms must conjugate efficiency with the equity and the environmental sustainability paradigm.

Targeting such an objective for water management policies is desirable from the social point of view; it is not an easy task though. Thus, there is a call for an improved governance at regional, national and local levels. Indeed, none of the

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[1] This is true in general. However for Kenya we will see the crucial role of increasing supply even in agriculture where the irrigation potential is not jet entirely developed.

[2] Millennium Development Goals: 1- Eradicate extreme poverty and hunger; 2- Achieve universal primary ducation; 3- Promote gender equality and empower women; 4- Reduce child mortality; 5- Improve maternal health 6- Combat HIV/AIDS, malaria and other diseases; 7- Ensure environmental sustainability; 8- Develop a Global Partnership for Development. (http://www.undp.org/mdg/basics.shtml).

previous objectives are reachable without more efficient governance and stakeholders' active participation. For instance, the implementation of a given water pricing scheme would be a failure if it did not target the needs of people - namely investing in infrastructures, knowledge and skills; establishing anticorruption measures; reducing transaction costs; enabling an investor-friendly environment for private sector's investment; and promoting gender equality.

The importance of water as the most fundamental constituent of life needs no further explanation. Water is essential for agriculture, household consumption, the industrial, and tourism sector, and for its role in sustaining earth's ecosystem. Historically, water has been playing a fundamental role in enhancing food production – especially for the Less Industrialized Countries (LIC) – e.g. during the Green Revolution[3] - through irrigation, which accounted for 80% of total (and 86% of LIC's) water consumption in 1995 (Rosegrant *et al.*, 2002). While irrigation ensured food security, it raised several environmental issues: water depletion, water quality reduction, water logging, and salinization. Regarding domestic consumption of water, it is mostly used for drinking, cooking, cleaning and gardening. Even if domestic uses (as well as industrial ones) are far less water demanding than agriculture, they are particularly critical in terms of health especially in LIC. An ancillary use of water is worth being mentioned: the recreational one. The latter is often a crucial sector in those economies in which tourism is an important share of GDP and where there is a huge amount of unskilled workers. However, it is never an easy task to differentiate among domestic and irrigation uses especially in rural and peri-urban areas. Moreover, owing to a growing population, exhaustion of groundwater, water pollution and waste, the problem of scarcity is more and more affecting this fundamental resource.

[3] The Green Revolution refers to the transformation in agriculture which involved the use of both high yield intensive crop and improved agricultural technology. Initially started in Mexico around 1945, the Green Revolution had its highest success in India along 60's providing sufficient food for an increasing population.

Consequently, the different sectors of an economy or of a certain territorial entity are increasingly competing for the provision of this input.

Water has been officially recognized as a scarce resource by the International Community since the 1992 *Dublin Statement on Water and Sustainable Development* which clearly pointed out that water resources are both finite and "vulnerable"[4].

In broad terms, water can be considered as a merit good – the consumption of which must be guaranteed on needs, more than on willingness to pay. In fact, it is essential for human life. The importance of water from an economic point of view descends among the others from two aspects: its "relative" and "local" scarcity and the competition among different agents and/or activities using it.

Concerning the first point, the scarcity is "relative" because sometimes water would exist in a certain area if only it could be either self provided by farmers – i.e. by means of a rain water harvesting systems - or provided by a certain authority - through an appropriate infrastructure (i.e. irrigation scheme, piping system). However, sometimes provision is too costly. Moreover, scarcity is a "local" issue because often availability of water is quite uneven in a given territorial/administrative unit (i.e. Nation, Region, County, ...). In many cases, though, the problem of local scarcity can be better tackled using water more efficiently than trying to increase the supply of such an important input (Tirado *et al.*, 2004).

From a different perspective, the problem of water shortage is strongly related to the quality of water, to the efficiency of its management and to the different ends of use. Hence, institutional arrangements to promote "higher value" of water use become primordial. In order to reach efficiency and fairness, there is a

[4] Principle No. 1 - Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment (http://www.wmo.ch/pages/prog/hwrp/documents/english/icwedece.html)

call for a proper *allocation mechanism*[5] among different uses. An instrument which has been considered allowing for optimal allocation is a pricing scheme (For example Decaluwé *et al*, 1999 and Dinar and Mody, 2004). Water pricing plays two main roles: recovering the investment and the operating costs of water system and signalling the level of scarcity value and the opportunity cost of water when driving allocation decision (Dinar and Mody, 2004). It is important to bear in mind that the first best allocation cannot be reached, given that the water market is far away from being perfectly competitive.

The second point is an effect of the first one and directly comes from a crucial feature of water: the difficulty to assign property rights. In fact, it falls from the sky and evaporates with no regard to boundaries or property regimes. Water is overwhelmingly non excludable. And its consumption is rival. Thus, this natural resource has been classified as common pool resource. There is a tendency to free ride and then to over consume the resource, reaching the well known *"tragedy of common"*[6] (Dalhuisen et al., 1999). It is generally the case that private costs of use do not reflect social costs, giving the premises for *externality* problems. This latter stem from the absence of a certain market for goods, whose use in a production/consumption process positively/negatively affect other economic agents that do not pay/receive a compensation. Subsequently, its infrastructure can be both not excludable and not rival. In general, water supply is classified as a *natural monopoly* possessing the following features: high fixed costs related to transportation and delivery of water; inefficiency in building more than one delivering network, although some experiment of supplying different quality of water has been made[2]; sunk costs[7]; transportation costs are high due to water being heavy and scarcely valuable; consumption

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[5] An allocation mechanism can be defined as sets of institutions and predefined rules that determine the quantity (and sometimes the quality) of water that individual (or groups of) users are allowed to use.

[6] rational agents according to their private incentives reach Pareto-inefficiency over-consumption and eventual resource exhaustion.

[2] For example in UK: a double pipeline system used to provide to households both drinkable and others domestic destination uses water.

[7] For example building a dam.

and production areas must be located relatively close each other – this latter being an element contributing to ensure the quality of delivering.

All these features are pivotal in order to properly model water. Besides, they affect the agents' strategic behaviour. The last two points, for instance, lead to the conclusion that water management at a local level assumes a central stage.

It is finally worth to mention that water is both an input in production functions of several economic activities and an output of the water production sectors[8].

With these premises, we can state that water is an essential input and often a local scarce resource. It results in different sectors competing in order to satisfy their demand. Therefore it is pivotal to assess the problem from an inter-sectoral point of view.

Economic models of water use have generally been applied to study the direct effects of water policies - typically water pricing or quantity regulations - on the reallocation of water resources (among the others Tirado, 2004 and Decaluwe, 1999). In order to obtain insights from alternative water policy scenarios on water resources' reallocation both partial and general equilibrium models have been used. The formers focus only on the sector affected by a policy measure disregarding the rest of a given economy, whereas the latter consider also other regions and/or sectors to determine the economy-wide effect. The general equilibrium approach allows for a richer set of economic feedbacks – with respect to a partial equilibrium analysis - and for a complete assessment of welfare implications, but this evidently comes at the price of a cruder resolution (Berrittella *et al*, 2007a).

The Objectives of the Work

In this broad context, the main objectives of this work are

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[8] As we will see in the section 3, there are some studies not considering water productive sector (for example Berck et al, 1999 & Seung, 1998) whereas some others do (among the others, Decaluwe, 1999 and Tirado, 2004), allowing for more complication.

1. To describe the Computable General Equilibrium (CGE) model approach applied to studies of water allocation issues. The study of water allocation within a general equilibrium framework seems to be appropriate for several reasons. In particular, studying effects of resource scarcity, tariff reforms or the introduction of a water market, through this approach, takes into account the interdependences among different sectors of an economy. Given the importance of water as an economy wide input, CGE models for water management seem well suited to compare alternative policy scenarios.

2. To review critically the main contributions found in the literature.

Even if these analytical tools cannot be used for forecasting purposes, they are well suited to: (i) assess water reallocation problems; (ii) indicate the likely economy wide effects of water policies and (iii) to rank alternative policy measures. Moreover, CGE models are extremely useful instruments in assessing water related problems as for example, sustainable water use, social welfare effects, climate change and pollution.

3. To analyze the implications of a limited/augmented availability of water for the Kenyan economy: is water scarcity an important constraint to the agricultural sector growth in Kenya? Prior to answer this question, I will present the peculiarity of Kenyan Economy –with a focus on agriculture as the main water user. Three scenarios will be considered: i) perfectly elastic supply of water, ii) constrained supply within two different settings: a) either water is sector specific or b) water is transferable between sectors. The interest towards simulating the progressive reduction of water endowment is justified by the problems related to the ever worsening droughts that are affecting Kenya – as we will see in more detail further below. On the other hand, for Kenya it is relevant to simulate how the economy would react to an increase in water availability. Indeed, according to AQUASTAT[9] the physical irrigation potential[10] of Kenya is far from fully exploited.

4. To evaluate the implementation of a system of resource taxation and redistribution of extra revenue collected. Levying a per user lump-sum tax on water might increase government revenues. Those latter might be used either for recycling the extra-revenue back to the economy in favor of the poorest [11], for financing targeted activities - i.e. rehabilitation of forests, water related transboundary conflicts management, etc., or for ensuring the self sustainability of the system through investments in infrastructure promoting a technological change - i.e. financing new water facilities or ameliorating factors' productivity in targeted sectors (section 8).

5. To assess the impact of droughts on the Kenyan economy – the model seems to underestimate the range of the effects of droughts – i.e. water endowment reductions if not associated with other adjustment - I decided to carry out another set of simulations. Therefore, I consider that the lack of water reduces the resilience of land – the capability of land to recover its nutrients and properties; and heavily undermines production capacity of many productive rural sectors. For instance, the production of maize – the main Kenyan staple crop - is projected to reduce by 26-40 percent, due to drought during the cropping season in 2009, according to the Kenyan Ministry of Agriculture. Besides, pastoralists' production - one of the main economic activities in ASAL

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[9] AQUASTAT is FAO's global information system on water and agriculture developed by the Land and Water Division. It collects, analyses and disseminates data and information by country and by region. Its aim is to provide users interested in global, regional and national analyses with comprehensive information related to water resources and agricultural water management across the world, with emphasis on countries in Africa, Asia, Latin America and the Caribbean. http://www.fao.org/nr/water/aquastat/main/index.stm

[10] The area which can potentially be irrigated depends on the physical resources 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate. According to AQUASTAT the area equipped for irrigation as percentage of irrigation potential is 19.15% (the 94.19% of which is actually irrigated).

[11] A study by Letsoalo *et al.* (2006) explores the plausibility of achieving a tax on water and energy and recycling the revenue back to the economy by allowing for a reduction in the other forms of taxation for South Africa. The interesting idea behind the double dividend refers to the achievement of both environmental and economic objectives through the same instruments.

(Arid and Semi-Arid Lands) - will be also drastically reduced[12] being the ASAL the areas which first suffer from lack of water. Therefore, I will consider along with water scarcity, the degradation of land endowment and shocks in the production of maize (the main staple food in Kenya) and of the pastoralists' activities.

6. **To simulate a possible policy response offered by the implementation of the UN-FAO and World Bank "Arid Land and Resource Management Project" (ALRMP) in Kenya.** The ALRMP is focused on mitigating the negative effects of droughts on pastoralists' communities living in ASAL. In particular the implementation of an *Early Warning System* would allow to preserve/ameliorate the productivity of pastoralists' activities. This intervention would be fundamental mainly for three reasons: i) favour food security **-** by improving the productivity and sustainability of land use systems in selected watersheds; ii) sustain the livelihood of pastoralists' communities whose role and traditions go well beyond the numbers of livestock sectors through which they produce the main sort of income; and iii) limit another possible negative effect of drought, i.e. migration from rural marginal areas to urban slums.

The Structure of the work

The present study is divided into five further sections.

In the *next* section, I will first briefly introduce the evolution of the multi-sectoral approaches: Input Output (IO) analysis, Social Accounting Matrix (SAM), Linear Programming (LP) and CGE models. In particular, I will focus on the SAM and CGE approaches. On one side, the SAM is a comprehensive, disaggregated, consistent and complete data system. Moreover it can be seen and used as a conceptual framework for modelling. On the other side, I will

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[12] An assessment carried out by Oxfam following the 2005 drought in northern Kenya, revealed that over 70% of the livestock had been lost (Oxfam, 2006 and Orindi *et al.*, 2007).

also consider more into detail the CGE approach. Furthermore, I will introduce some classification criteria for CGE models. An original classification is proposed and based on the objective of the analysis: *(i)* competition between sectors; *(ii)* water pricing policies and tariffs; *(iii)* water and trade issues; *(iv)* CGE and other models. Moreover, I will propose some methodological approaches to introduce water in a SAM and in a CGE framework**.** In the *second* section, I will examine a review of the application of CGE model approaches to study water allocation issues. The survey conducted takes into account the work of Dudu and Chumi (2008) which discuss analytical models dealing with water allocation issues. The authors consider both partial as well as general equilibrium models dealing with water issues. However, in the present work, the focus will be more on CGE models and on an original classification of the main contributions found in the literature.

Since Kenya has been chosen to be the focus country of the present study, in the *third* section, I will introduce: *(i)* an overall description of geographic, hydrologic, demographic and economic profile in Kenya; *(ii)* a brief description of agriculture in Kenya's economy with a focus on maize production (largely the main staple food) and livestock sectors (the most important in the ASAL); *(iii)* the role of water availability in Kenya, with a focus on agricultural uses in rural areas; *(iv)* a description of the water sector reform process recently implemented in Kenya with particular consideration for the Water Act (2002) - establishing a new institutional set up within the water sector; and *(v)* Key policy concerns focusing on possible remedies to the intensification of droughts tremendously undermining agricultural yields and food security;

In the *fourth* section, the first issue dealt with will be the main data source: *(i)* the 2003 SAM of Kenya (Kiringai *et al.*, 2006). A pivotal change in the original SAM must be introduced: the inclusion of the water factor. This way of modelling allows to properly treat water as a non man made input, i.e. a factor. Moreover, considering water as a factor - which is called "primary water" –

allows for substitutability among this very resource and the other factors of production (typically capital, labor and land), and for simulating a reduction/increase of the water endowment. Therefore, *(ii)* an adaptation of the SAM of Kenya and the CGE model to include water as a factor is proposed. Whereas, in previous works using CGE models there is a lack of consideration for the description of this adaptation procedure[13]. Furthermore the last part of chapter *(iii)* describes the model. The behaviour of agents – households, enterprises, government and the rest of the world (RoW) – is described along with features of the productive sectors. Besides closure rules[14] for factors and in particular for "primary water" will be also described.

In the *fifth* section will be dedicated first to *(i)* the description of the simulations: exogenous shocks on available water simulating either scarcity or abundance scenarios, and the drought scenarios; fiscal policies taxing either the water factor or the different water commodities (irrigation, industrial and domestic water); a further set of simulations considers both shocks on water endowment and policy measures. The extra-revenue obtained with the different taxation schemes will be either reinvested for project of public utility (i.e. rehabilitation of forest areas, management of water related conflicts, etc.) or redistributed to the poorest rural households. Secondly, *(ii)* the simulations' results will be presented and discussed. Moreover, *(iii)* I tested a possible remedy to mitigate the effects of droughts in ASAL; the ALRMP[15] which would allow to increase the productivity of agricultural factors in some of the smallholders' activities.

Finally, some policy implications and conclusions will be drawn.

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[13] A recent tentative has been done by Sahlén (2008) in a CGE model applied on Namibia.

[14] From a mathematical point of view the model to give a solution must be squared - i.e. the number of the equation must be equal to the number of variables. In this regards, closure rules define which variables have to be considered as exogenously fixed and which ones have to be treated as endogenous.

[15] The project has been proposed and implemented by World Bank and the Investment Centre Division of UN-FAO,

1. THE MULTI-SECTORAL APPROACHES

1.1. The Evolution of Multi-sectoral Models

The aim of this paragraph is to describe the different multi-sectoral models: IO, SAM, LP and the CGE models.

The general equilibrium basic theoretical framework is represented by the Arrow, Debreu and Hahn model[16]. The key issues in structuring a multi-sectoral model are presented in Greenaway *et al.* (1993):

- *Dimensionality* – the level of sectoral desegregations of total economic activity.

- *General specification of key relationships* (including functional form) – supply and demand equations (including the interdependencies and interactions between sectors).

- *Consideration of benchmark case* – the starting point from where simulation should be run.

- *Calibration* – choosing one or the other approach to CGE modeling will affect the choice of specifying functional form for production or cost functions (Claus, 2001). Note that this classification works for a wide range of multi-sectoral modeling approaches: from IO models, to SAM based models, to LP, to CGE models.

Developed since 1950s, The IO models present simple technological and behavioural assumptions based on straightforward accountability relations between production activities. Notwithstanding their simplicity, IO models are very useful because such linear models capture major element of interdependency in the productive sectors of an economy. From 1960s, the

[16] Here the essential result is that an equilibrium exists and it is unique under given assumptions. However, general equilibrium models are not restricted to the conventional Walrasian assumption of universal perfect competition. According to this latter, three conditions must hold: exhaustion of product (no economic profit in any production sectors), market clearance (no excess of demand in any markets), and income balance (consumption cannot exceed income from endowment).

evolution of computer programming gave the opportunity to solve LP models. The LP approach can be seen as a system of inequalities, which introduces a certain degree of flexibility, still in a linear formulation. Through those models it has been introduced choice and optimization into policy models and also offered the possibility of setting up prices explicitly - still in an exogenous fashion - into the analysis (Robinson, 1989). In a following work by Bruno (1979) the treatment of price improved. The idea was not to explicitly simulate market prices but rather to use shadow prices[17] for policy analysis. However, according to Robinson (1989), linearity assumption tends to lead to unrealistic specialization and extreme behaviour, in particular for dynamic models. For those latter in particular there is a problem of specifying appropriate terminal constraints. Moreover, there are difficulties in the interpretation of shadow prices generated by LP models. In addition, both IO and LP models are not well suited to describe price adjustments and substitution possibilities within an economy (Timpano, 1996).

Furthermore, an extension of IO models is the SAM based approach, a comprehensive, economy-wide data framework, typically portraying the economy of a certain administrative unit (typically a nation, but also a region, district, village, etc.) and capturing the transactions and transfers between all economic agents in the system (Round, 2004). SAM framework brings together data from many disparate sources that allow to describe the structural characteristics of a given economy. In particular, the use of SAMs has been motivated by the National Income and Product Accounts (NIPA) and IO accounts in a comprehensive statistical framework . It represents a generalization of the IO one since it captures the circular interdependences characterizing any economic system, not just in terms of (i) the production activities, but also (ii) framing the factorial income distribution, and (iii) the income distribution among institutions (particularly among different

[17] In the context of a maximization problem with a constraint, the shadow price on the constraint represents the value that the objective function of the maximization would increase by if the constraint were relaxed by one unit.

socioeconomic household groups), which, in turn, determines the expenditure pattern of institutions. Alternatively, if a number of conditions are met – e.g. excess in capacity, unemployment/underemployed labor resources – the SAM can be used as a conceptual framework (see figure 1) to explore the impact of exogenous changes in such variables as exports, certain categories of government expenditures, and investment on the whole interdependent socioeconomic system (e.g. the production structure, factorial and household income distributions) (Thorbecke, 2000). However, the SAM multiplier analysis is based on some limiting assumptions - namely that excess capacity prevails and unused resources are available (Thorbecke, 2000). Therefore, any exogenous increase in demand can be fulfilled by a corresponding increase in supply, at constant prices. Nevertheless, in any real market economy, some factors are fully allocated and therefore prices can no longer stay constant.

In the CGE models - developed by 1970s - prices are endogenous and any exogenous shocks simulated determines changes in prices and in turn production, consumption and income variations. Nevertheless, both SAM multipliers and CGE frameworks share a concept: what matters in a socio-economic system – especially from the policy analysis point of view - are interactions, interdependences and the economic structure, where they take place and that they modify. The SAM provides the underlying taxonomy of the CGE. Moreover, it represents the initial conditions for the CGE to start with running the benchmark, and also the calibration base for the parameters and the coefficients of the model. The issue of using the benchmark year for the model calibration raises the question if the year is a “normal” one. If the answer is no, it is clear that the parameters derived from it do not represent a good picture of the underlying framework.

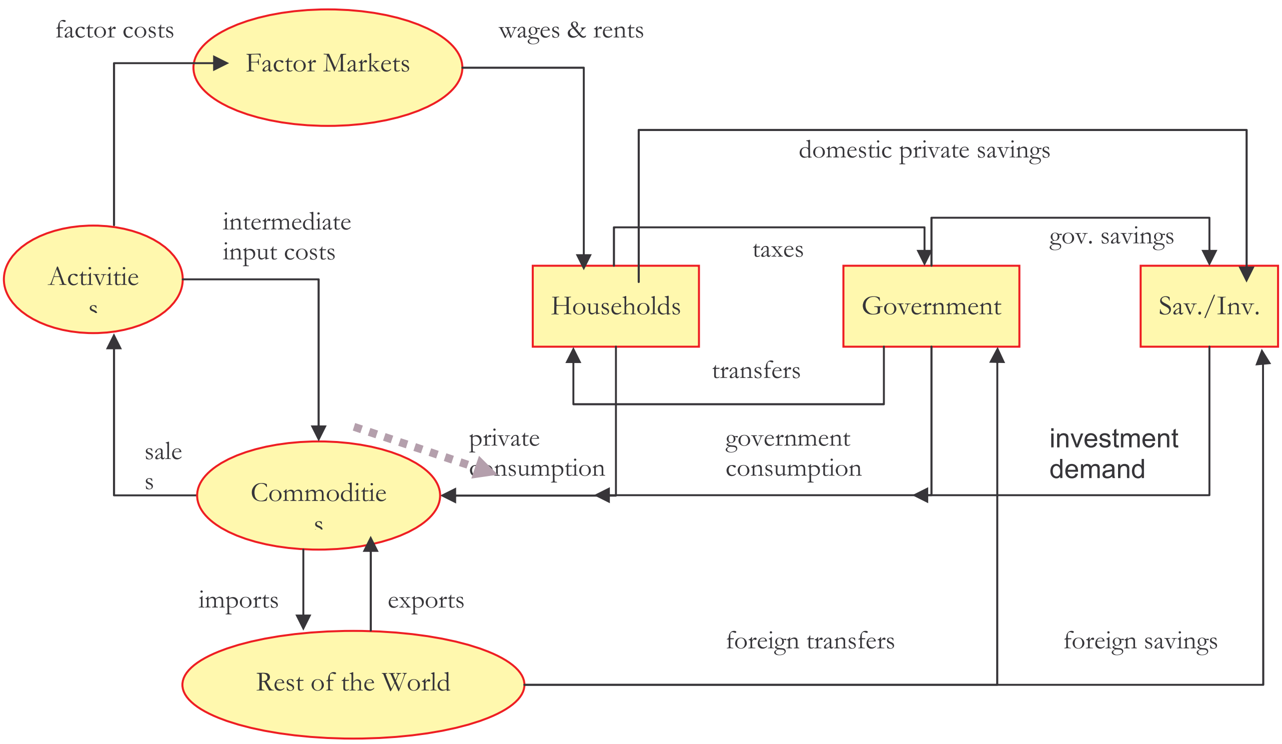
The CGE models represent a natural evolution of the previous approaches adding neoclassical substitutability in production and demand functions as well as non linearity, an explicit system of market prices and a complete specification of the income flows in the economy. CGE models are well suited to explicitly capture market dynamics solving for both market prices and quantities simultaneously. There are utility maximizing consumers whose decisions determine the demand for goods and the supply of labour. There are profits maximizing producers whose decisions determine supply of goods and demand for primary and intermediate inputs. There is International trade. The role of the Government is introduced: collecting taxes and tariffs and providing transfers, subsidies and services (it also may set exchange rates). The market clearing conditions specifies supply-demand balance which determines equilibrium prices.

The basic structure of a Neoclassical CGE model consists of four main parts (Robinson, 1989): (1) the agents – i.e. Households, Producers, the Government and the Rest of the World; (2) the behavioural rules – e.g. producers profit maximizers; (3) decision based on signal observed – typically price; the urles of the game – i.e. perfect market competition; (4) the specification of the "rule of the game".

Likewise, the CGE may be set-up in a dynamic setting looking at the capital accumulation. There is large use of dynamic models in environmental CGE modelling (for example) and also in water CGE models (Chapter 2). However, it is worth to mention in advance that dynamic CGE models do not deal with seasonal variations: there is no CGE model considering peak water demand depending on seasons (drought/water abundance). This may be due to the characteristics of the SAMs – annual data set – the data sets used the most to calibrate CGE models. Water CGE models deal rather with longer periods (typically multi-years) assessing the effects of water stock and flows variations.

The neoclassical partition proposed by Robinson (1989) fit also for describing the hypotheses behind the the structuralist approach to CGE modeling. For instance, regargarding "the agents", structuralist approach makes hypothesis for some agents or groups to be price makers. Regarding "the behavioural rules" agents do not follow a maximizing behaviour. Concerning the "rule of the game", the neo-classical assumption of fully factor employment is abandoned; moreover the role of the financial market in the accumulation process is considered – i.e. the role of interest rate charged by banks has an impact on private capital formation (Lance, 1990). Structuralist models are not set up in "real" terms in terms of relative prices. They explicitely consider nominal prices and income flows.

Figure 1: Conceptual Framework: Flow Diagram of SAM Transactions



Source: Löfgren *et al.*, 2002.

1.1.1 Multi-sectoral Models and Policy Objectives

Any SAM based model is aimed at capturing the most relevant effects of policy changes and/or external shocks on a given economy and household. In order to be useful for policy analysis, it should have a number of desirable features:

(i) Policy relevance – the models should link values of policy variables to economic outcome of interest to policy makers and useful in economic discussions. *(ii) Transparency* – the connections between policy variables and outcomes should be easy to trace and explain. *(iii) Timeliness* – models must be based on real consistent and recent data if they are to be used in ongoing policy decision making processes. *(iv) Validation and Estimation* - estimated model parameters (i.e. share and elasticity parameters) and model behaviour need to be validated for the "domain of application" of the model. In other words, the model must be determined in order to achieve accurate results. *(v) Diversity of approaches* – validation results from policy models is greatly strengthened by analysis using a variety of models and at different levels of aggregation. Such diversity tests the robustness of the results and the importance of assumption made in various approaches (Devarajan and Robinson, 2002).

In general, structural models seem to be more appropriate to deal with the first three criteria than reduced form models. In fact, usually, those latter do not explicitly consider links between policy variables and economic outcomes. Even if IO and LP are frameworks simpler to comprehend, they may not be transparent enough with respect to policy evaluations if compared to CGE models[18]. Being based on expenditure/input structure, IO and LP are rather well suited for decomposition analysis (Pyatt and Round, 1985). Also validation argues for structural models whose domain of applicability depends on the pertinence of structural relations and on the stability of its parameters in the period of analysis.

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[18] However transparency call for stylized models.

Furthermore, IO and LP approaches seek to address issues of sectoral allocation of investment, international trade and the implication of different development strategies in the medium long term. Moreover, while those models are useful tools to analyze growth (not in a dynamic fashion) and structural change in production and foreign trade, they are not well suited to study mixed market economies in which autonomous agents' behaviour and market mechanisms largely determine resources' allocation[19]. IO and LP do not capture market mechanisms through which incentive instruments (i.e. taxes and subsidies) affect the economy. In other words, while they represent a consistent economy wide framework, they do not help in linking solution variables to actual policy decisions.

Concerning SAM multipliers approach, it is worth recalling that the SAM framework has been extensively used to analyze a wide range of different questions at different levels of geographical aggregation. At national level, it has been used in order to assess the impacts of alternative allocation of government expenditure to certain groups of households, several tariff structure on the patterns and composition of imports and exports. At provincial/district level, it may be useful for studying regional targeted development programs (e.g. Special Economic Zones[20]) and the possible related inter-regional effects with the rest of the country and rest of the world (migrations of labor forces, industrial delocalization, etc.), or the shared used of an aquifer by several countries (Roe and Diao, 1994). Finally, at village level with a number of studies investigating various issues as for example the impact of remittances of workers living abroad or in metropolis to villages' livelihood in Mexico (Adelman *et al.,* 1988) and more recently in Nepal (Aryal, 2006).

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[19] The neoclassical assumption of perfect competition, perfectly functioning markets with flexible prices and free mobility of products and factors are not realistic in actual economies. Instead, modellers have incorporated a variety of "structural" rigidities allowing for a better description of the reality. In particular here we refer to macro imbalances, institutional and market rigidities characteristic of less industrialized countries.

[20] SEZ are targeted areas where a special financial/legal framework is in use as an exemption with respect to the national rules and regulations. For further reading on SEZ are Aggarwal (2007) and Ishida (2009).

Instead, CGE models are effective tools in implementing simulations mapping out "policy response" relationships. The idea is to look for empirically important effects and indirect general equilibrium links[21].

1.2. The CGE Models: Some Classification *Criteria*

Given this, it is important to introduce several different ways of grouping CGE models. I look at three different categorizations: *(i)* static and dynamic; *(ii)* single country and multi country/global; and *(iii)* for the main shocks and policy objectives.

(i) The *static* (or comparative static) models generate the equilibrium specifying the functional forms through a calibration process using the matrixes. In this setting, consumers and producers make "optimal" decisions within a single period, with no thought given to the future. Comparative static - within this approach – can be implemented modifying the assumptions at either account level (e.g. Wittwer, 2006) or at structural level (e.g. Decaluwe, 1999). Comparative analysis will be done modifying the inputs or the functional forms. The *dynamic* models can be classified in: truly dynamic ("inter-temporal") or sequential dynamic ("recursive") models. The *first* type of models stems from optimal growth theory: agents' behaviour is characterized by perfectly foresight; they know all about the future, thus they consequently react to future change in prices. However, those models are still little used for the problems of LIC (Briand, 2007). The *sequential dynamic* models are solved as a series of static models linked between periods and solved sequentially over time. Within this setting, the agents have myopic behaviour. These "recursive" models represent an extension of the static ones. The change consists of adding

[21] From the policy maker's perspective, CGE modelling provides a simulation laboratory within which he needs to be comfortable. From a different perspective the analyst's should be able to explain the causal chain determining the results by standard as simplest as possible economics.

a time subscript to prices, demand and supply functions of the static model. The introduction of an exogenous growth rate and the projection of the equilibrium in future scenarios allow to make a comparative static analysis, where each scenarios is characterized by different assumption on the structural change (Wittwer, 2006).

(ii) The domain of a CGE model that can vary from global trade models, international, national (Decaluwé *et al.,* 1999), regional, county (Seung *et al.,* 1998, 2000) and village level is made in order to differentiate among global models, multi-country, single country. Depending on the objectives and the problems they want to address one category will be more suited than another. For instance, single country CGE models with a regional differentiation are well suited in assessing country specific policy issues and local redistribution problems (Briand, 2007; Müller, 2006).

(iii) Finally, a further possible classification of CGE models relates to *policy analysis approaches*. This categorization seems to be well suited for classifying LIC as empirical multi-sectoral models dealing with LIC have been driven by policy concerns. Moreover, it is worth to explicitly recall that CGE models have been used to study both industrialized and less industrialized economies.

However, the use analysts make of this analytical tool modifies in order to meet different needs in different context of development. For instance, it may be hard to introduce a price scheme in a context of deep poverty. Additionally, availability of data may be in certain context a constraint more than in others. Furthermore, the different potential of technological innovation needs to be taken into account, as for instance, in a LIC, a small productivity improvement in the agricultural sector may translate in a huge increase in yields. Moreover, in such a context there may be a lack of markets (for certain produced goods) and a lack of infrastructure such that any increase in productivity might not be beneficial for farmers.

Alternative polices have been associated to exogenous counterfactual scenarios. Shocks that have been modelled include: trade shocks – e.g. sudden changes in international terms of trade or abrupt falls in exports for a given country or region; droughts (Berck *et al,* 1991); technological changes (Bellú, 2009) and; financial crises. Example of policy changes include: the impact of trade liberalization (Berrittella *et al,* 2007a) and tariff harmonization on efficiency, the structure of production and employment; the impact of structural adjustment and harmonization policies (e.g. agriculture, education, and health) on output, food security and the distribution of benefits received; the effects of public investment (e.g. large scale physical infrastructure projects) on output and income distributions (Kojima, 2006); the consequences of environmental policies on the structure of production, on income and wealth; the impact of multilateral trade negotiations and agreements (e.g. Doa Round) on the world trade pattern; the impact of various taxation schemes on income distribution (Letsoalo *et al*, 2005); the interregional consequences of alternative public investment, taxation and subsidies scenarios (Berrittella *et al.,* 2006).

1.3. The Introduction of Water

Another option for classifying CGE studies is the way they deal with water.

Water can be modelled in different ways depending on the scope of the analysis. In general water may be seen as production factor, as intermediate input and final output. Regarding the first point, water can be modelled either implicitly or explicitly.

On one hand, some models (e.g. Seung *et al.,* 1998, 2000) treat the natural resource implicitly and in fixed proportion with land. Therefore, simulations are run considering land and indications on water uses are drawn indirectly.

On the other hand, there are many studies considering water as an explicit production factor and can be substituted with the others (typically capital, labour and land) either in a regional (e.g. Berck et al., 1991), national (e.g. Mukherjee, 1996; and Sahlén, 2007) or multi-countries setting (e.g. Berrittella *et al*, 2007a, 2007b, 2008). In particular this latter group of models typically deal with the concept of *virtual water*.

In addition, water has been also modelled as an intermediate input - as modellers just wanted to focus on the impacts of economic activities on the use of natural resources (Boccanfuso *et al*., 2005; Wattanakuljarus, 2005). In this case, the raw water used to produce the intermediate good (i.e. the processed water) is not taken into account.

Furthermore, water has been also modelled as production factor, intermediate input and final output (e.g. Decaluwé *et al*., 1999; Tirado *et al.,* 2004). This comes with the introduction of a water sector that using raw water (water factor) produces for either final consumers (households) or for economic activities (industry, agriculture and service sectors). This sector may produce water extracting it from the ground (Decaluwé *et al*., 1999) or through a desalinization process (Tirado *et al.,* 2004). A further complication may be added introducing a differentiation between production and distribution of water (Briand, 2004)[22].
Moreover, water can be introduced at structural and at reduced level. The second mechanism for introducing this resource into a CGE model is considerably easier and allows for more complication. Wittwer (2006) describes the inclusion of water accounts in a dynamic multiregional CGE model for Australia. In his work the author details water accounts for users (industries plus households) in each state.

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[22] Besides, water may be considered a secondary output. For example textile and clothing manufactories along with their primary products they sell on the market typically produce waste water. From a different perspective, waste water may be used by farmers - especially in LICs and in urban and peri-urban areas - as an intermediate input.

2. CGE MODELS STUDYING WATER ISSUES

The aim of this section is to draw a classification for CGE studies on water issues in order to underline the evolution of water CGE models, critical points and further development possibilities. This has been done with the practical aim of providing a CGE modeller - approaching the issue of introducing the water component in a CGE framework – with a comphensive picture of metodoligical possibilities and different approaches. Many criteria could have been used. Among the others:

- the consideration for water – as a production factor (i.e. a natural resource), an activity or a commodity (see paragraph 1.3 and chapter 4);

- the context to be studied – climate change, agricultural production and pollution/waste management issues;

- water production technologies – systems for pumping ground water, desalinization plants, rain water harvesting systems.

While these interesting issues will be treated along with the discussion, the criterium choosen for the classification is based on policy criteria. In particular, which policy questions modellers tried to answer? Which are the related simulations they implemented?

Based on these questions I singled out 4 branches of models dealing with water issues:

1. Competition between different sectors

This group deals with the simulation of those policies aimed towards making more efficient use of water among sectors through shocks on quantities. In this first group, the modellers have been interested in assessing the impacts of quantitative restrictions to water supply, in a given socio-economic context with different levels of hydrological complexity. Water has been modelled both directly - as a production factor or as intermediate inputs - and indirectly – in fixed proportion with land.

2. Water pricing policies and tariffs

The second group considers those models that study the transmission mechanisms of the micro-to-macro links – namely, water allocation reforms at micro level - i.e. perimeter, district, and region: changing water assignment rules, changing water pricing methods (e.g. from per area, per output produced to volumetric pricing), or introducing institutions and mechanisms for trading water and water rights among individual farmers (Roe *et al.*, 2005). Given the fact that often water has no market, I grouped those models focusing on water pricing issues (i.e. water shadow price) and on cost recovery strategies in the second set of water CGE models. Thus the second group more directly deals with economic efficiency and also with equity issues and redistribution policies related to impacts of water scarcity and climate change.

3. Water and trade issues

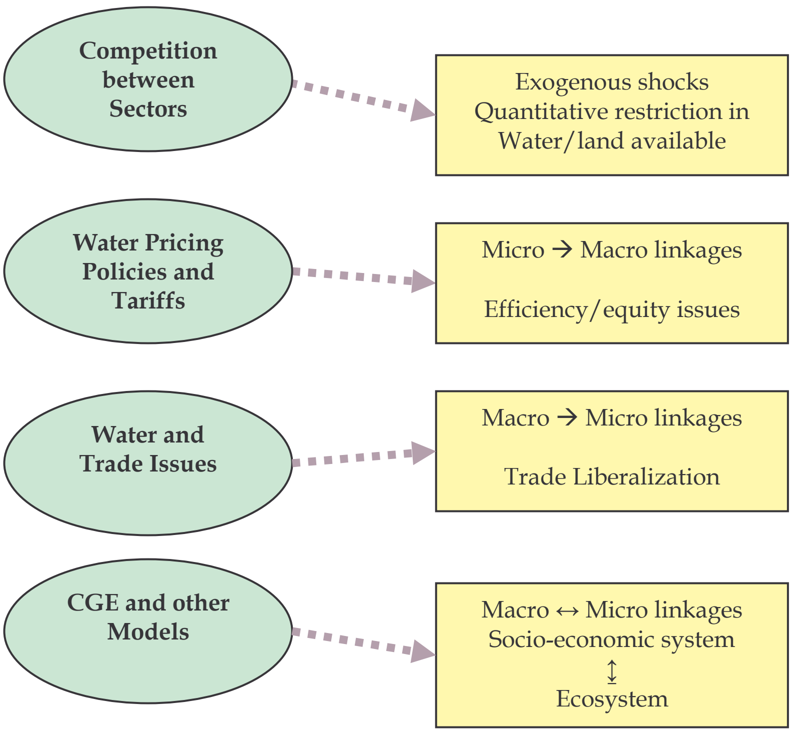
The third groups is composed by those studies focusing on the modeling of macro-to-micro links – namely policies on trade liberalization, import substitution, government policies, public infrastructure (e.g. construction of a dam). The models of the third group point out interactions and correlations between trade related issues and water allocation – both at country, multi-country and global level. From this sub-set of water CGE models it also emerge the international specialization trend for the agricultural commodities production based on water intensity. A general result is that trade policies and international trend have a stronger impact on national economies than water policies. These studies are intrinsically neoclassical. Trade liberalization has a positive value by definition which is not always the case (Taylor and von Armin, 2006).

4. CGE and other models

The final group is mainly comprised of studies combining CGE models with other models, namely farm models and bio-economic models. The former models study local water policies with trade policies: they may be seen as a synthesis of the second and third groups of models. The latter models investigate more specificly, at wateshed level, the interactions between the socio-economic system and the ecosystem.

The scheme proposed, per se, is arbitrary as a study may fit in more than one category. However, it is worth to stress that what is at the central stage of the classification process is the consideration for water[23] and the applied features/experiments of the water CGE models.

Figure 2: Water CGE ModelsThe main features of Water CGE Models groups



[23] Therefore, for instance, Robinson and Gehlhar (1995) is defined by the same authors as part of the "trade" focused CGE models branch. However for the scope of the present survey what is at the stake is the consideration of water. Thus we will put the study within the "water pricing policies" branch as it introduces interesting assumption on the way of interpreting the shadow price of water. A further example is given by Seung *et al* (2000). The authors use a CGE model and a recreational demand model so the work might be seen as fitting in the "CGE and other models" branch. Again here it is more relevant to stress the policy aim of the study; therefore we include it in the branch "Competition between different sectors".

2.1. Competition between Sectors

2.1.1. A Drought Study

One of the earlier CGE model is largely recognized as the first seminal contribution in evaluating water redistribution policies at the regional level and is the fundamental work of Berck *et al.* (1991). It represents an exercise of reduction of the available water in the southern portion of the San Joaquin Valley. The study analyzes the effects of reducing water input to agriculture on aggregate Valley gross domestic product and on sectoral output, employment and land use.

Considering the "small" region, the authors appropriately assume the sectoral exports facing a perfectly elastic world demand at a given price. They are considering "non comparable" imports which means that these latter are consumed or used as intermediate goods[24] and not produced by domestic producers. This is clearly a simplification assumption in order to reduce cross effects once simulations are run.

The model consists of 14 sectors, 6 of them are agricultural sectors (dairy, grazing/livestock, cotton, grains, fruits/vegetables, nuts and other agriculture), 2 processing sectors, (1 for dairy and one for all other agricultural sectors), 2 manufacturing sector and 4 service sectors (trade, freight, banking and other services).

The factors of production taken into account number to five: capital, labor, land, water (primary) and intermediate inputs. Capital is assumed to be fixed and immobile. Labor is considered as a fixed input as well. Then, the model will solve for the market-clearing wage and the sectoral allocation of labor. The exchange rate is conveniently fixed equal to one. The reason is simple: the need to avoid the introduction of clearing foreign market conditions. The capital account always adjusts considering any possible import-export equilibrium

[24] The respective demands are given by fixed coefficients.

combination. Furthermore, land and water are considered to be inputs solely for agricultural sectors: this represents a difference with respect to some other literature on this topic. Land is supplied in three types, at fixed quantity according to a land quality order: the good one can be devoted to a lower use although the inverse is not possible. The supply of water is fixed and the simulations are characterized by a reduction of available water. Water's coefficients are assumed to be fixed by crop. However, the resource is freely mobile across (agricultural) sectors: switch from a use to another (according to the previous criterion) and is accompanied by a variation of the water needed. The sectoral production is expressed in terms of nested multilevel function with two variants specifications: high and low elasticity of substitution. In the first case, the specification of the functional form of agricultural value added is a Cobb-Douglas function which mixes land, capital and labor. The two former are assumed to vary in fixed proportion in the low elasticity case. However, in both cases the substitution possibilities in sectoral production are limited, being domestic and imported inputs demanded according to fixed input-output coefficient (i.e. there is no direct substitution between land and intermediate inputs such as pesticide and fertilizers) and being the land a mix of water and acreage (with water-land ratio given by a fixed coefficient). In the high elasticity case, there are some possibilities for substituting land with labor, when the quantity of available water reduces, in order to modify yields.

The authors run two sets[25] of five simulations reducing water to 10% increments from the benchmark case. In general, the changes in the high elasticity case, where factors are relatively more substitutable, are much more gradual with smoother change in cropping mix than the low elasticity case. Moreover, the removal of water does not reduce the production of high value agriculture (i.e. fruits and vegetables). There is an increasing livestock output as irrigated crop land is re-oriented to dry pasture land. While in the experiments

[25] The two sets are different with respect to high and low elasticities of substitution amongst factors of production in the four agricultural sectors which have been discussed before.

farmers are not compensated by reduction in available water, a transfer of 67$[26] per acre-foot of water removed per year would compensate their income keeping it at the same level of the benchmark.

The main result of the decreasing water supply is a reduction in GDP, in employment and in agricultural income.

The strong restriction on substitution among the different inputs is a limit of this study. There is no consideration for water consumption out of agricultural sectors and there is no production of water. While the study of Berck *et al.* (1991) is fairly aggregated and highly stylized, it is an useful illustration of the methodology which has been used by a considerable number of further studies.

2.1.2. Water and Land Reform

Mukherjee (1996) presents a static “Watershed CGE Model” for the Olifants river Catchment in the Transvaal – which represents a 4% of South Africa’s area. The aim is to explore possible policy alternatives for achieving more efficient water and land use. In fact, the water distribution system was in favour of commercial, agriculture and industry sectors penalizing domestic use. This is one of the first studies to explicitly mention a trade off between efficiency and equity in water allocation and to consider other sectors beside agriculture.

The study considers ten activities: four agricultural (field crop, horticulture, livestock, “homeland”) and six non-agricultural (mining, manufacturing, transport, electricity & water, construction, services).

There are three broad categories of factors: capital, labor (with thirteen sub categories) and a land/water aggregate. The author does not model water explicitly: the resource (water) is considered in fixed proportion with land.

[26] In the case of low elasticity of substitution among factors of production.

Eleven household's types distinguished by race and level of income are considered. The government, the enterprise and the rest of the world (both in the rest of South Africa and the rest of the world) are the other institutional actors.

Concerning macro closures, the authors choose to hold the exchange rate fixed, letting the balance of trade adjust. Saving rate is exogenously fixed therefore aggregate investments are subsequently determined. Government tax rates are held fixed with government saving/deficit determined residually.

With respect to simulations, Mukherjee (1996) first replicates the effect of a reduction in available water. The value of the land/water aggregate - which comprises both the value of raw water and the water right associated with land ownership - increase from the benchmark. The model simulations offer the possibility to separate the rent for the two "sub-factors" as there are no separate market for raw land and water in the benchmark. In a second group of simulations, land and water reforms are implemented – through a progressive reduction of both uses till reaching a decrease of 25% - and increase of productivity in the "homeland" agriculture – by exogenously modifying the input-output coefficient value in the production function.

Regarding the results, the study shows that land becomes - from an economic point of view - virtually useless after a certain threshold of water availability. At that point, the value of land within the mix water/land tends to be zero; meanwhile, what matters is the value of water associated to that land. The work concludes that top priority must be given to those measures that promise to raise long term productivity growth in all economic sectors especially *vis-à-vis* water. The model shows how fighting against inequality toward "homeland" farming system may be possible through a relatively small investment.

2.1.3. From Agriculture to Recreational Use

A study further related to water reallocation issues is presented by Seung *et al* (1998). They apply a dynamic regional (county-level) CGE model to evaluate welfare gains of reallocating water from irrigated agriculture to recreational use in Stillwater Wildlife Refuge in Churchill County, Nevada. According to the model, transferring water from agriculture to Stillwater Wildlife Refuge will diminish agricultural production within the region and increase water related recreational activities and expenditures both within and outside the study area.
The model describes an economy based on eight production sectors. Three of them are agricultural sectors: livestock, other crops and pasture. The other five are: mining, construction, manufacturing, transportation, communication and public utilities, trade, finance, insurance, real estate and services.

Agricultural sectors use, as primary production inputs, labor, capital and land; whereas in the non-agricultural sectors are used as primary production inputs just the two formers. Here water is used in fixed proportion with land and is not modelled explicitly. Following, supply of labor comes from inside and outside the region. Moreover, it is assumed that labor is freely mobile across sectors such that the sectoral distribution ratios of wage rates are constant; and on the other hand, that it is partial and freely mobile across regions. Profit maximization for each production sector yields its factor demand for each production factor.

The model considers four different variants depending on possibility of factor substitution in agricultural production. Each scenario is described from a starting point in which water withdrawing from agriculture determines a reduction of land use by about 51.2%: labor and capital diminishes proportionally with a reduction of land use: no factor substitution is allowed; capital is reduced proportionally with a reduction of land use: labor can substitute land and capital; capital is fixed at its base year level: labor is the only substitute for land; both labor and capital are substitutes for a reduction in land.

Here, the level of complexity in terms of water reallocation possibility is increased compared to the framework proposed by Berck *et al.* (1991). However, as in this latter study, there is no possibility for substituting water which is used in a fixed quantity with a unit of land in agriculture. In other words, a reduction in available water implies a proportional decrease in land use. Nevertheless, while Berck *et al* (1991) model water explicitly, Seung *et al* (1998) do it implicitly. Welfare effects are considered by comparing four variants which are different depending on how the others inputs (capital and labor) vary with a decrease in land supply. In general, for each model variant, the higher is the degree of substitutability, the smaller the impact on agricultural output.

Another similarity among the two studies regards production technology. On one hand, the production technology is for each sector represented by a Cobb-Douglas value added function and on the other hand, a linear technology is assumed for each production sector. Intermediate inputs are used in fixed proportions. Again, differently from Berck *et al*. (1991), crop substitution is assumed not to occur when water is withdrawn from agriculture[27]: water is not freely mobile across sectors. Moreover water is also consumed by non-agricultural branches.

Concerning consumption, households are divided into three groups with respect to income: low, medium and high. Their preferences are represented by a constant return elasticity (CES) utility function. The utility maximization for each group subject to his budget constraint yields his demand function for each good.

A transfer paid to the farmers and based on their water rights accompanies the removal of water. The farmers may use this compensation in order to move away from the region considered or to modify their expenditures. Additional information is required to assess how the policy's impact affects the net change

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[27] This is justified by the authors considering the characteristics of Nevada's territory which inhibits switching crops.

in expenditure levels. Thus, in order to avoid this assessment problem, it is assumed that there is no change in farmer expenditures[28].

Concentrating on model's results, the simulations have been run with an availability of water inflow by the Stillwater National Wildlife Refuge wetland of 125,027 acre feet. An econometric analysis made by the authors has found a positive correlation between increase in water acreage in the National park and the numbers of visitors in hunting, general recreation and angling. The increase in available water will be met through an acquisition of water rights (101,000 acre feet) from agriculture. The increase in visitors' trip expenditures is negligible. It just represents the 0,0006% of the base-year value of aggregated production. This corresponds to US$ 3,615. Thus, the effects on non-agricultural sectors are negligible. However, the authors do not take into account the effects of water reallocation on extra-regional economic impacts. It is not introduced in the study information about expenditure/migration behaviour due to compensation for their water rights (after withdrawing water). Finally, while the discussion paper focus on economic impacts of a water reallocation policy, there is no consideration for the change in consumers' welfare deriving from an increase in recreational activities. In order to include this in the analysis *the authors* should have incorporated a framework to introduce welfare change deriving from more recreational activities.

An extension of Seung et al (1998) is Seung et al (2000) which combines the county level dynamic CGE model with a recreational demand model.

A further study analyzing the effects on withdrawals of water from Australian economy is Horridge *et al.* (2003). The model developed uses the TERM (The Enormous Region Model)[29] which is a bottom-up CGE model of Australia that

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[28] i.e. without taking into account the change in expenditures provoked by both an exit from agricultural sector of farmers due to the reduction in water inputs and an increase in expenditures by farmers which are receiving public funding proportioned on the property rights owned

[29] TERM usng Input-Output tables and regional data showing agricultural output and employment for each 144 sectors and 57 Australian regions (statistical division).

treats each single region as a separate economy. Horridge *et al.* (2003) uses a 38-regions 45-sectors specification of the model simulating the short run effects of the 2002-2003 droughts, the mot widespread for 20 years.

Some results for specific regions are even extreme. Furthermore even if agriculture concurs for a relatively more share of the Australian GDP, this latter is reduced by 1.6 per cent by the shocks (i.e. reduction in the sectoral output).

Another recent Water CGE model focusing on reallocation from rural to urban activities in South East Australia is Dwyer *et al.* (2005). This 12-regions static CGE model is an application of the TERM and is aimed at assess the effect of an expansion of the water interregional trade given a reduction of its supply. Water is considered as a production factor.

The two simulations run consist in: a reduction of water endowment for urban regions and for both urban and rural regions. These simulations are run in four different scenarios with respect to water trade: no trade, rural trade, limited urban-rural trade, full urban rural trade.

The main conclusion is that trade is beneficialfor both water buyers and sellers. Moreover, If water endowments of urban regions are reduced, increasing opportunities for trade significantly reduce the estimated losses in gross regional product from a decrease in water availability.

2.1.4. The Impacts of Changes in Tourism on Land, Forest and Water

Wattanakuljarus (2005) studies both the positive and negative economic-wide effects of tourism in Thailand on the economy and the environment and proposes the application of a CGE model to investigate these impacts. More specifically, the goal of the research is to study the impacts of changes in: tourism towards other industries, income distribution and labour market;

tourism on land, forest and water; the environment on tourism and social welfare.

Concerning the role of water, the resource is not a factor but an intermediate input whose simplest form is represented by the so called “natural water” – namely the water stored in dams or reservoirs. It has five main uses in the Thai economy: irrigated agriculture; household consumption; industry and tourism; electricity production and ecological purposes.

With respect to the *theoretical framework*, the CGE model explicitly specifies the behaviour of producers, households, tourists, exporters, importers, investors and the government. Moreover, it explicitly considers market clearing conditions and various macroeconomic variables and price indices. Producers are profit maximizers or costs minimizers depending on the CES technology which aggregates primary factors (labor, capital and land-forest aggregation) and intermediate inputs (several composite goods including water) in order to realize the output. Households spend what they earn in composite goods (which include tourism goods and services) composed of two parts: subsistence and luxury. Only the latter part enters the household’s Klein-Rubin utility function through which households can modify their consumption mix as their incomes change, being the Klein-Rubin a non homothetic utility function[30]. Tourists are assumed to have restriction in the substitution among consumption goods within the composite good “tourism”. For instance they are not allowed to substitute transportation for food, hotels or other services. Thus, tourism can be as a bunch of goods and services combined together in fixed proportion. While the outbound tourism is a function of the income, the inbound one depends on tourism prices and exchange rate. Exports are assumed to be related to the local production through a CET function. Imports are directly used just by local producers. A CES production function combines those

[30] For a non homothetic utility function a change in income provokes a change in the budget share even if price share are fixed, differently from the case of CES and Cobb-Douglas, homothetic utility functions.

imports and their own output produced into composite goods which can be used as intermediate inputs and as final goods for consumption. However, the two production factors are not perfect substitutes: this is consistent with the Armington assumption. The rest of the models describe: market clearing conditions for composite goods and factors, transfers between institutions, savings of RoW, macroeconomic variables (e.g., absorptions, trade balances and current account deficits), distributions of net factor incomes and savings of non-government institutions.

Regarding *macroeconomic closure rules,* they are connected to the specification of exogenous and endogenous variables which depends on how one wants to describe the world.

Three *simulations* have been run in the research: *base* (10% tourism consumption expansion), *drought* (5% technical regress in primary factors of agricultural piped water sector)[31] and *price* (10% tourism price reduction).

Simulations' *results* are three folds. The findings underline that tourism expansion in Thailand can stimulate GDP and enhance the current account deficit, inducing an additional growth rate in services and domestic-oriented industries rather than agriculture, manufacturing and export oriented industries. Thus, the increasing water demand is due to non-agricultural uses. The higher cost of production, distribution and waste-water management might be financed by part of the gains experimented by some industries (i.e. transportation, restaurant, hotel, clothing and textile, food manufacturing, beverage and communication) as a result of tourism expansion. However, among the results presented the net uses of irrigated water and piped water are higher than they otherwise would have been – because of the net expansion of water intensive agriculture, water non-intensive agriculture, water and wastewater intensive non-agriculture sectors is positive. The simulation results indicate that primary production factors move to tourism related industries.

[31] Reduction in productivity of agriculture and piped water sector due to water crisis or drought

Primary factors are combined according to a Leontief technology with the intermediate inputs. Thus, if primary factors increase irrigated and piped water will increase. The simulation results also indicate an increase in both natural[32] (0.10%) and piped water (0.29%) uses. Moreover the 10% of growth in tourism simulated provokes an increase in the use of all primary energy products.

To conclude, the demand of water increases by both agriculture and non agriculture uses because of tourism growth. This causes an increase in wastewater management costs, because of more treatment needed - in particular to avoid contamination. Thus, *ceteris paribus,* tourism expansion increases the level of air pollution because of an increase in transportation, manufacturing production and primary energy uses with an overall increase of environmental costs[33].

2.1.5. Water Reservoirs and Water Transfers

Goodman (2000) represents a further study I include in the branch of "Competition between different sectors" related issues. The author uses a dynamic CGE model of the South-eastern Colorado economy to show that the net benefits of an enlargement in storage capacity are similar to the impact of allowing a relatively small increase in water transfers. This is the first study to have introduced a comparison between allowing for water transfers and

[32] Natural water is the one extracted from dams or reservoirs.

[33] An other study investigating tourism sector is Berrittella *et al.* (2008). It focuses on the economic implication of climate change induced variation in tourism demand, using a global CGE model. The authors fixed a hypothetical benchmark equilibrium in a future year, which is then shocked simulating the effects of climate change through two sets of shocks simultaneously replicated: first, change in consumption preferences for domestically produced goods; second, reallocating income across world regions – simulating changes in tourism's expenditure. At a global scale, the main result of the climate change is the unevenly spread welfare losses.

increased water capacity. The context of study refers to policy makers scoping water policies to face an increased municipal and agricultural water demand.

Regarding the model, it is set up using four productive factors: land, labor, capital and water. The economy is disaggregated into four productive sectors: irrigated and non irrigated agriculture, commerce and industry. Labor grows at the same rate of the population and so does the capital stock - given the period net investment (determined typically by capital growth and depreciation). While labor is mobile among sectors, capital is sector specific. Stocks of Land and water are fixed in supply and those factors are use specific. There are two representative agents: rural and urban households. Both utility and production are nested CES aggregates. Regarding factors two different elasticities of substitution are in use: one for water and the other for a mix of land, labor and capital along with the intermediate inputs. Concerning Water, it can be either used immediately or stored for future use.

With regard to simulations, “Business-as-usual” benchmark is compared with the alternatives of increase in storage or transfers.

The main finding is that the benefits from increased transfers are as high as or higher than those from increased storage. Additionally, temporary water transfers have the potential to be accomplished at little or no additional cost. This is especially true if water authorities can reduce the legal barriers to these transfers.

Another work related to the assessment the impact of varying the storage capacity is Strzepek et al. (2008) which uses a comparative static CGE model in order to evaluate the economy-wide impacts of the Answan dam in the Nile river basin. Even if the dam seems to have a very little impact on the Egyptian economy, the CGE model has been deemed to be useful as the construction of the dam has had cross-cutting impacts on multiple sectors each competing for the same resource: agriculture, commercial shipping, power generation and tourism. Water is modelled in a nested CES production function as a fixed land-water technology production factor. The authors take into account the hydrological cycle and the variability of water supply by considering seasonal water stocks and flows. Simulations are run considering a scenario where the dam would not have been built. The shocks simulated referred to the reduction of water supply in the summer - this has been done by using historical data on summer water flows.

Diao *et al*. (2007), inspired by Decaluwé *et al.* (1999), explicitly takes into account both surface and ground water uses in Morocco. The CGE-water model is an extension of Diao *et al.* (2005). The authors consider: (i) a prolonged extraction beyond natural recharge of ground water that lowers the aquifer's water table; (i) a transfer of surface water from rural to domestic uses, and (iii) a reduction of (surface) water available due to drought. In particular, drought scenario is replicated through a decrease in surface water, which determines an increase in shadow price of water and in the use of ground water.

These effects in turn push resources out of irrigated crop's productions. This decrease in production determines lower factor price in agriculture and a decrease in farm income. Furthermore, simulating an increase in groundwater costs causes a decrease in groundwater supply which determines an increase in surface irrigation water shadow price in turn responsible for a reduction in irrigation water demand. Imposing an increase of 20% in ground water costs in just one (out of seven) region has an economy wide implication. The shadow price of surface water increases even if not in proportion to the increase in cost: the higher the water intensity of crops the larger the increase in the shadow price of surface water. However, the three set of shocks have similar impact on state variables. For example, the increase in cost of extraction and the drought scenario have similar economy wide impacts – and regions with a better access to groundwater facing a smoothed negative effect. Urban areas directly benefit from water transfers from rural to urban areas.

2.1.6. The Water Transfer Projects

Berrittella *et al.* (2006) realizes a multi-sectoral, multi-country model using a GTAP-W model[34] (see Appendix 1) to estimate the impact of the South to North Water Transfer project (SNWT) of the economy of China and the rest of the world. As for Berrittella *et al.* (2007a, 2007b, 2008), the production function is composed by a nested structure: water is combined with a value added (natural resource, land, labour and energy + capital) and intermediate inputs.

Regarding simulations, they are grouped into two sets: one considering a "no-water transfer" situation and the other allowing for water transfers. Three scenarios are simulated, all referring to the increase in water supply. In the first, increase in supply is reached through augmented productivity (called "base") but without considering the capital investment. In the second (called "investment"), additional investment are exogenously provided for China only for financing the SNWT project, with the savings allowed to adjust in order for the relative market to clear. The third presents the first and the second simulations together ("base + investment").

Looking at the main results, an increase in water supply in China leads to an increase in productivity of their water-intensive goods and services (non-market solution) this would result in a huge positive welfare effect because of the increased production and export. Considering the market solution, the effect on China's welfare would still be positive, but the world as a whole would lose because of the worsened terms-of-trade. However, authors underline how well functioning water markets in China are unlikely to exist.

Furthermore, Peterson et al. (2004) assess - by mean of a CGE model - water transfers among regions in the southern Murray-Darling Basin (MDB) - Australia. The model called TERM provides preliminary analysis of the long

[34] For a detailed description of the model (for example the production factors used, nested production functions, the use of Argminton assumption, utility function etc.) see Berrittella *et al.* (2007a, 2006a 2007b) repectively sections: 3.3.2., 3.3.3., 3.3.4. With respect to water data see section 3.3.2.

run regional and industry impacts of reductions of 10, 20 and 30 per cent in water availability in the base year, under conditions of no trade, intra-regional trade only, and both intra- and interregional trade.

The model estimates that moving from no trade to intra- and interregional trade together strongly reduces the impact of the reductions in water on the gross regional product (GRP) of the southern MDB.

A 20 per cent reduction in water availability has more than double the effect on GRP of a 10 per cent cut, while a 30 per cent cut has an almost fourfold effect. The relative effects of expanding trade in all cases is similar. The 10 per cent reduction in irrigation water leads to an output decline in most industries. However, in most industries, declines in output are lower when intra- and interregional trades are allowed.

This analysis does not take into account the impact of changes in water trade on environmental conditions such as salinity and soil fertility.

Similarly Wittwer (2006) estimates reallocation of water resource in a dynamic setting through simulations of increasing population in Australia.

2.1.7. Impact of Enhanced Irrigation Efficiency

Calzadilla *et al* (2008) uses the new version of a multi-region world CGE model, called GTAP-W model (see annex 1) in order to study the world economy-wide impacts of enhanced irrigation efficiency[35]. The aim is to analyze if improvements in irrigation management would be economically beneficial for the world as a whole as well as for individual countries. Additionally, the study investigates whether and to what extent water savings could be achieved. The

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[35] This study is considered as part of the first group consiring that the increase in efficiency may be seen as an expedient to increase the volume of water available for certain sectors.

GTAP-W model is based on the GTAP[36] *version 6 database* which represents the global economy in 2001. The model presents 16 regions and 22 sectors of which 7 are agricultural (rice, wheat, other cultures, cereals, sugarcane, vegetal fruits, oil seeds).

Regarding production function, value added and intermediate inputs are mixed in fixed proportion. The value added consists of the aggregation of four factors: land (pasture, rain-fed, irrigated land), labor, natural resources, and capital-energy composite. Irrigated land emerges from an association of land and irrigation – which comprehends both irrigation infrastructure and water resource. Its value is estimated using the ratio of irrigated yield to rain-fed yield. Capital and labor are perfectly mobile domestically, but immobile internationally. The different types of land and the natural resources are imperfectly mobile. The production functions are specified through a series of nested CES. The national income is allocated between an aggregate household consumption, government consumption and savings. Regarding the simulations, the first two scenarios present an increase - to a level of 73% - in irrigation efficiency[37] either for LICs (first) or independently of the level of development (second). In the third scenario, irrigation efficiency is improved up to 73% for all the 16 regions.

In general, Carzadilla *et al* (2008) shows that higher level of irrigation efficiency, depending on the scenario and the region, a noteworthy effect on crop production, water use and welfare. At global level, water savings are achieved and the magnitude increases when more regions have higher levels of irrigation efficiency. Increased irrigation efficiency contributes to ameliorate water conservation in regions where no change in efficiency occurred. Moreover,

[36] The GTAP model is a standard CGE static model distributed with the GTAP database of the world economy (www.gtap.org). For detailed information see Hertel (1997) and the technical references and papers available on the GTAP website.

[37] Faurés *et al.* (2001) defines irrigation efficiency as "The ratio between the estimated irrigation water requirements and the actual irrigation water withdrawal" is usually referred to as "irrigation efficiency".

welfare is positively correlated to additional irrigation water used in irrigated agriculture. However, there are also losses in terms of welfare coming from the less competitive rain-fed agriculture sectors. Nevertheless, such losses are more than offset by the gains from increased irrigated production and lower food prices. Finally, there are three main limitations related to the study. First, availability of water is given by countries' average. Second, irrigation efficiency does not affect water prices: higher levels of efficiency are possible with the same technology at zero cost. Thus, positive effects of increase in irrigation efficiency are probably overestimated. Third, water productivity is a proxy of irrigation efficiency.

2.1.8. The Increase of International Prices and the Water Resource

Another recent contribution in the water CGE modelling literature is Sahlén (2008). The author studies the impact of the recent increase in international food and oil prices on Namibia's economy with a focus on the role played by water resource. The increases in cereals, oil seeds and meat international prices are simulated. Moreover, as Namibia is a net oil import country, another simulation refers to an exogenous increase in oil price.

The model used is a static CGE model whose basic version has been developed by IFPRI (Löfgren *et al.*, 2002) and presents standard features, i.e. Stone-Geary utility function, CES Armington and a nested production function composed by a Value Added nest and a Intermediate Inputs nest - respectively aggregated through a CES and a Leontief aggregation – with a top level Leontief aggregation.

The value added consists of land, capita, skilled/unskilled labour and raw water.

While the first two are assumed to be fixed given the short time horizon, skilled labour is free to move as it is the unskilled one whose wage is fixed (in this market there may be unemployment). Concerning water, different closures are simulated: (i) a perfectly elastic water supply (i.e. water unemployed), fixed supply with water that can be either (ii) mobile or (iii) sector specific. The study uses the SAM of Namibia (2002) and the Water Accounts to calibrate the model. The SAM has been modified in order to model water as a factor - allowing for substitutability with the other factors. Therefore, Sahlén (2008) differentiates between two types of agents using raw water: water self providers (farmers) and water authority (serving all the other agents using processed water in the economy). The raw water used by water authority can be deduced from the payments made for capital. Moreover, the raw water used by self providers is a "hidden" factor of production, as it is represented by a fraction of the mixed factor used in the agricultural production sectors. From additional data - on the quantity of water/per sector (m^3) as well as the value of water/m^3. Therefore, water is modelled as a production factor - used by self providers and water authorities; as intermediate inputs – used by processing activities; and as a final good – consumed by households.

Given this, the simulations run are as follows: +50% in the prices of petroleum products, +30% in the prices of cereals and grains, +20% price increase for other oil seeds and +10% for meat products and dairies. These exogenous shocks are combined with the three different assumptions about total supply of water as described above.

The results show that the overall impacts on national production of increased world market prices of food and oil-products are negative, with the GDP decreasing by around 1.1-1.3%. This is mainly due to the impossibility for the increased exports of primarily agricultural products to offset the overall increase in production costs given the exogenous increase in import prices of petroleum and agricultural products. The agricultural sector that is benefiting the most is the commercial (non-cereal) crop production sector. Overall, there is a redistribution of production from non-exporting sectors (for example, textiles, manufacturing and the service sectors) into exporting sectors (commercial agriculture, fishing and mining).

Agricultural growth will largely depend on the availability of additional water. If water supply is assumed to be perfectly elastic, water use will increase by almost 20% following the agricultural expansion. However, as the current water availability poses the water depletion's issues Sahlén (2008) also focuses on the effects of a limited availability of water supply. With water fixed supply, there is less ability to adapt for the economy, the agricultural sector being more constrained by the water limited availability, thus there is a greater decrease in total GDP than the previous scenario. Moreover given the distortive allocation policies (based on subsidies) in the agricultural water use, the water immobility between sectors, imposed in one of the scenarios, might lead to slightly less negative impacts than when water is mobile between sectors.

Reid *et al.* (2007) uses the same data set and model in a dynamic framework. The aim is analyzing the climate change impacts on Namibia's natural resources and the implications for the Namibian economy in a dynamic setting.

2.2. Water Pricing Policies

2.2.1. Water tariffs

Velasquez *et al.* (2007), differently from Diao et al. (2007), does not refer to a specific water source but focuses on charging the distribution of water in order to recover operational and maintenance costs. The author analyzes the effects of an increase in the agricultural water tariff on the efficiency of the water consumption in agriculture in Andalusia. Moreover, the standard static CGE model in use studies the possible reallocation of water to the other sectors. The production function is a nested Cobb-Douglas, under Armington assumption. There is just one representative household whose utility function is a Cobb-Douglas. Regarding water, an indicator of direct water consumption was created assuming a linear relation between production and consumption. This indicator is a technical parameter and measures the direct water consumption for every euro of output produced in any sector using water. The parameter accounts for the different intensities across sectors. The SAM of Andalusia is the main data base used for the model. It includes 16 productive sectors and two production factors (labour and capital) a savings/investment account, a government account, direct and indirect taxes, a foreign sector and a representative consumer. Additionally, water consumption levels are obtained by the emissions input output table of Andalusia. The Data refer to year 1990.

The simulation part refers to five scenarios progressively increasing the water tariff on agricultural sector (starting from the actual price of 0.006€/m^3 to 0.12€/m^3). Even if relevant water savings are not achieved, the reallocation of the resource seems to generate a more efficient and rational behaviour from the production point of view.

Van Heerden et al. (2008) applied a standard CGE model (UPGEM) to the South African economy - where chronicle water problems are in place. The aim of the study is to model water demand in two of the most water intensive sectors in South Africa: irrigated agriculture and forestry. As some previous models, water is implicitly modelled in fixed proportion with land.

The study analyzes the impact of government investment and water tariff on GDP, employment and water consumption in three scenarios. In particular, the Government Accelerated and Shared Growth Initiative (AsgiSA) has been analyzed. In the first scenario, the government invests R1 billion into each of the nine sectors linked to the areas of AsgisSA investment: dry-field agriculture, irrigation horticulture, livestock, timber, other mining, the water sector, communication, construction and other non metal minerals. In the second, the water tariffs are increased by 1c/m^3 including water that has not been taxed before. In the third scenario, the revenue collected through taxation are redistributed – by exogenously decreasing real government revenue and tax rate per industry - with a positive effect on GDP and on the employment of unskilled labor.

Analyzing the first scenario, the slight increase of the GDP is mostly due to the expansion of livestock and timber plantation sectors. There is also an increase in unskilled labor. Regarding water, its demand would exceed the available water supply meaning that these resources should be averted from some other activities. In general, the benefit from those activities is disproportionately less than the negative impact on water resource. With the implementation of the tax scheme, (scenario 2) the burden of the tax (0.011% of the GDP) would be much less than the decrease in water demand (around 3%)

2.2.2. Agricultural Policy Reforms and Water Market

Robinson and Gehlhar (1995) developed a static economy-wide CGE model that disaggregate agricultural sector and provide special treatment of land and water. This land and water (or LW) - CGE model is in the tradition of the trade focused CGE models that have been used to study structural adjustments in a number of developing countries[38].

The aim of the study is three fold. First, the authors want to provide partial-equilibrium measures of the responsiveness of single sectors to removal of taxes and subsidies. This has been done by removing taxes and subsidies sector by

[38] See Robinson (1989) for a survey of CGE models in developing countries. Devarajan and Robinson (1990) describe the structure and properties of these trade-focused CGE models.

sector. Second, the study explores the general equilibrium impact of eliminating distortions due to tax, subsidy and tariff – both in agricultural and non agricultural systems. The focus is on the welfare and structural implications of major pervasive, reform of Egyptian industrial and agricultural policy. Finally, the LW-CGE model estimates the demand curve for water by agriculture. This is done through a progressive reduction of water endowment aimed at tracing out the change in water price and in the structure of agriculture and in the water use. Considering this point the model constitutes the first experiment of a static shadow price approach to water issues.

Regarding the production function, it consists of a linear combination of primary factors and intermediate inputs. There are six agricultural sectors (cotton, fruits and vegetables, rice, sugar, grains and other) each using land, water, capital, labour, and intermediate inputs. The non agricultural sectors are five (oil, industry, services, electricity and construction) each one using capital, labour and intermediate inputs.

The model describes a single land type which can be freely allocated across different crops. Similarly, capital and rural and urban labour are assumed to be freely to move across agricultural activities and there is no consideration for livestock. The real value added is a CES combination of labour, capital and a linear mix of water and land. The aggregation of intermediate inputs is demanded via fixed input/output coefficient. The model ignores non-agricultural uses of water and also assumes that there are no distribution costs. Water is a necessary, costless input to agriculture. No other water uses are considered. No leakages of water are considered. Thus, consumptive use is considered rather than supply.

In the model, at the benchmark, the rental rate for land/water aggregate does not reflect a market valuation. The authors assume that when a farmer uses land to grow a certain crop, he is entitled to the needed water. The market return to his land reflects that entitlement. The model separately prices land

and water and so decomposes the rental value of land and the value of the water entitlement. Therefore, this latter represents the virtual market price of water if such a market would be implemented.

The model consider a variant with migration in which labour forces move between the rural/urban labour markets to maintain a fixed relative wage between agricultural and non agricultural labour. Labour is fully employed. Egypt is assumed to be a small country: changes in exports' quantity do not affect the world prices. Regarding macro closures, the model solves endogenously for the real exchange rate. Aggregate savings finance the balance of trade in domestic currency. Government revenues are determined endogenously while government taxes are fixed. Following savings rate adjusts to achieve savings investment balance.

Focusing on general equilibrium results, the complete elimination of distorting policies increase the aggregate welfare by 4.8 – 5.9% (constrained and unconstrained water) in the no immigrant variant and by 3.6-3.7% considering migration. Furthermore, when all the distortions are removed, there is an appreciation of the equilibrium real exchange rate by 20-23%. This figure reflects the empirical importance of export taxes in agriculture compared to protection in the non-agricultural sectors.

The elimination of agricultural policy distortions leads to a decrease in the return to water/land aggregate – coming from a change in the intensity of the factors demand. It becomes more convenient for farmers to use either labour or capital intensive technology rather than water/land intensive. Furthermore, considering the "raw factors"- water and land - in the base scenario, the market price for water is zero and that of land is quite high. Again in the base scenario, the shadow price of water is significantly positive, with the shadow price of land much lower than its market price. This means that the actual policy framework is biased in favour of less water intensive agricultural sectors. Following, with the introduction of policy liberalization the price of water steeply rises whereas its shadow price increases just slightly. Therefore social value of water does not change much with the reform implementation.

With policy reform, any water distribution system that relies on quantitative allocations at zero cost to the recipients will engender enormous incentives for cheating and corruption.

A more recent contribution – with respect to Mukherjee (1996) - dealing with water and land use reform is the work of Müller (2006) applied to Uzbekistan economy. The high level of dependency of Uzbek agriculture from irrigation and the attempt to develop market oriented non agricultural sector are important issues on the agenda of Uzbekistan's policy makers. In particular, cotton production is managed through production targets and administrative prices on the farmers. The model shows how agricultural producers do not necessarily benefit from a liberalization of the cotton market. The author uses an estimation model to infer regional allocation of water by which the total water usage in each region equals the per hectare values times the allocated areas.

2.2.3. Alternative Water Pricing Schemes

The CGE model calibrated by Decaluwé *et al*. (1999) enlarges the scope for water substitutability, introduces different price water options and considers specific water production technologies and consumers' heterogeneity in terms of income. Moreover, it allows for water substitution with other intermediate agricultural inputs and for possibility of simulating exogenous rainfall variation (i.e. explicitly considering the percentage of rainfall that allows for increase in water level of reservoirs).

The objective is to build a comparative analysis of different price water options – namely marginal cost pricing (MCP), Boiteux-Ramsey pricing (BRP) and an arbitrary increase in agricultural water pricing - in order to reach three governments' objectives: to reach the most optimal resource allocation; to control the level of deficit of water management authorities; to reduce water consumption. The study is based on Moroccan economy which is suffering from an increased pressure on the water resources due to persistent population growth, increasing urbanization and market inequalities. Concerning those latter, the point is that price for irrigation water is far less than the price charged on other users. This is due to three reasons. First, high subsidy for water tariffs prevents the increase in tariffs because of consolidated consumption trend. Second, it would play against agricultural self sufficiency policy. Finally, higher irrigation water price would be negative for the agricultural sector and rural households that are increasing its migration flows towards overpopulated urban regions. Therefore, current Moroccan price scheme is highly inefficient leading to large deficits and over consumption of water which has three branches: residential, industrial and agricultural.

Concerning the MCP approach, the marginal cost of reducing water equals marginal benefit of consumption for each demand. Regarding BRP, quasi-optimal prices are settled for each market such that they deviate from the marginal cost inversely proportionate to the demand price elasticity in the given market: inelastic demand will support higher prices.

About the production of water, while Seung *et al* (1998) focuses on surface water, there is another source considered: the ground water. The first font tends to be fully exploited in the drought periods. At an initial stage facing those periods, the water management authorities use more efficient surface water collection methods. Then, it will increasingly use the second source. The authors therefore distinguishes two types of production technology. The first type represents surface water produced by dams. This technology produces water with a constant unit cost only using input physical capital invested in dams. The second type represents the combination of withdrawing surface water more efficiently and pumping ground water. A composite input – formed by capital and labor – is used to produce water. In this second case, depending on the dominance of surface water on ground water withdrawn or vice-versa, marginal cost will be respectively decreasing or increasing. The two production techniques are related by an additive function, with the first linked via a fixed relation to its capital stock and the second characterized as a Weibull technology (with a composite factor as an input[39]). In particular, concerning the second type, using dam or pumping technology depends on the relative scarcity and on the difficulty to capture surface water. This is called "two interval water production function".

The model incorporates four agents' types: household, firm, government and the rest of the world. The household utility function is specified as a Cobb-Douglas linear expenditure system: this allows for the introduction of a minimum level of consumption in the household's basket. Given the marked difference between north and south regions in terms of hydrological conditions, the model differentiates water production among the two different regions which produce similar commodities linked by a CES function. In this context, having a production technology which allow for substitutability between primary factors permit to capture the impact of water policies on production behavior.

It is worth mentioning that the authors, differently from the previous discussion papers, consider a level of substitutability among water and fertilizers. Although this is considered by the author "a crucial feature within an agricultural production function", it is worth to note that from an agronomic practice, the water and fertilizers are definitely complementary goods and not substitutes. All the different level are aggregated through a CES function but the last one which uses Leontief specification (combining a composite good

[39] The composite factor is defined by a Leontief fixed coefficient between capital and labour.

with the other intermediate consumption good) and gives the final production for agricultural branches.

Starting from the base year, seven simulations have been run: three using BRP, three MCP and the last one imposing an arbitrary 10% increase in irrigation water price and no redistribution. Results show that BRP - along with the reduction in distorted production taxes - is the most efficient scheme in reducing water consumption with a positive impact on welfare and it eliminates WMA subsidies. Following, MCP scheme has a more positive impact on welfare while it provides just a slight reduction in water consumption and in subsidies to WMA. In the case of arbitrary increase of water price, the effects are negative in terms of EV, while only small reductions in water consumption and WMA subsidies are achieved.

Another attempt to induce a more efficient use of water resources has been made in the study conducted by He and Chen (2004) applied to China, They use a dynamic shadow price approach based on multi-periods Input-Output optimizing model. The trend of water shadow prices over around hundred years is considered (1949-2050). The lesson learned from the study is that in China – a water scarce country - a more efficient pricing method for water is highly needed and this could be based on shadow pricing as it considers the economic, socio-cultural, and environmental value.

A further application of comparative pricing schemes analysis is proposed by Kojima (2005). The author applies a single country dynamic CGE model to Morocco aimed at simulating water policy towards sustainable development. The model is a neoclassical one, it nevertheless considers two types of risk: a risk due to climate change in rain-fed agriculture[40], and an health related risk

[40] Here it is considered a multiplicative risk factor with stochastic distribution associated with the rain-fed production function

due to the lack of safe water[41] in the rural areas. Furthermore, government controls the water price and level of public investment. While the study, as Decaluwé *et la.* (1999), compares different pricing schemes (MCP vs. RBP) – it also examines public investment in different sources of water (raw, processed and irrigation). The study also simulates the impact of international aid flow in strengthening the public capital stock (+20%) for water management projects and a liberalization process (reduction of import tax rate -20%). The main outcome of the simulations is the need for: the safety improvements in the access to water for maintaining an appropriate level of investment in irrigation scheme (this policy stems from the level of unemployment determined by reducing the public intervention in irrigated agriculture); a positive trade liberalization (because of reduced consumers' prices). The international aid flow greatly mitigates negative welfare impacts of sustainable development.

2.2.4. Water Markets and Welfare Gains

Tirado *et al* (2004) shows that the problem of local scarcity can be better tackled using water more efficiently than trying to increase its supply. The present paper focuses on the potential welfare gains related to the development of a water market in the Balearic Islands. While Decaluwé *et al* (1999) shows that higher agricultural water prices reduce agricultural production, the present study goes further illustrating that "water market" would have a positive impact on the agricultural income.

A static theoretical model is used to describe both economic framework and hydrological characteristics of the Balearic Islands. The economy is described through ten sectors: two agricultural sectors (rain-fed and irrigated agriculture); livestock, mining, fishing and the residual primary activities (a unique sector);

[41] Welfare impacts of lack of safe water access are represented by 'penalty' on household members who lack safe water access In the applied model the "penalty" is specified as a reduction in total working time that results in a reduction in wage income.

energy; manufacture; construction; tourism; services; and two sectors producing drinking water (the traditional one and the other producing through desalinization). While those latter generate the same product though with different cost structures, any other sector produce a particular good. Then, considering the condition of the islands, the two agricultural sectors are considered producing imperfect substitutes with the overall agricultural product described by an Armington function. As in Decaluwé *et al* (1999), four agents are considered: *consumers* – which are assumed to be all identical; *firms* - there exists a representative firm for any sector; *government* – which collects taxes and distributes them as lump sum transfers to consumers; *the rest of the world*.

Five production factors are considered: *land* – which is only used in agriculture and is mobile across irrigated and non irrigated sectors; *capital* – which is sector specific except for agriculture where is freely mobile among irrigated and non irrigated branches; *labour* – which is mobile; *water* and *seawater*. Concerning water supply, it is considered to be fixed and the related water rights - distributed among agriculture and water distribution sector – are not tradable.

Regarding agricultural technology, the availability of a substitute for raw water is crucial in considering the potential advantages of water transfers. Instead of substituting factors, the economy could react to shortage or to increasing price, shifting to non-irrigated crops[42]. These adjustments are included in the model considering both irrigated and non irrigated crop production technologies, as nested multilevel CES. The only difference is that rain-fed agriculture does not use raw water. As in Decaluwé *et al* (1999), it is assumed that capital and land are also CES aggregated.

While in Berck *et al* (1991) and in Seung *et al* (1998) water and land enter in the production function with fixed Leontief coefficients, here the first level of

[42] In this context, it is fundamental the contribution of Berrittella et al (2007a, 2007b) which introduced the concept of “virtual water” in a CGE model framework. The paper will be discussed later on.

aggregate inputs (capita – land and underground water - energy) makes the model more flexible. The overall agricultural production is a CES aggregate of irrigated and non irrigated output which must be equal to internal and external demand. Concerning the non agricultural production technology, the traditional water production and distribution sector extracts underground water and transforms it into drinkable water through the use of capital, labor and intermediate inputs in fixed proportions. In the case of desalinization - which will be activated when the underground water available is below a certain threshold, being this production technology very costly - the same inputs are used through a Leontief production function. The overall drinking water production is the sum of this two production technologies.

This production structure ensures a higher level of flexibility with respect to the previous studies. The explanation given by the authors is that "water demand is rather flexible and can be substantially reduced during drought periods (e.g. by water savings campaigns or the installation of water saving devices in households and firms)". Demand for water in drought periods is in general higher considering the demand for water strictly related to seasoning[43]. The "not tradable water rights" situation is the benchmark: the "no water market situation". In this context, there is an external trade surplus that has been considered by the authors as a constant because the model does not allow accounting for external capital flows. In order for balancing the external sector, the real exchange rate will adjust.

The counterfactual scenario is obtained assuming that raw water is not a specific input anymore and that water endowment can be freely move until its marginal productivity in agriculture and in drinkable water production sector are equal.

[43] In this context, it could be interesting to introduce a *peak water pricing*. This form of pricing consists in applying different prices depending on different elasticity of demand related to seasoning.

Following, the authors run eleven simulations sequentially reducing – as in the precursory work of Berck *et al* (1991) - the water endowment by 5%. It has been taken as base year the 1997. Regarding the main results of the simulations, it is worth to mention that water markets determine a better allocation of water between irrigated agriculture and drinking water production. Additionally, the water markets prospected by the simulations would diminish the negative effects of drought over drinking water consumption. Besides, in a market scheme, drinkable water consumers benefit from a higher supply at a lower price with respect to the "no water market situation". In this latter scenario, the supply of raw water through the traditional production method must be reduced in order to keep the price high enough for the desalinization process to be introduced. Subsequently, while the effect of drought on the irrigated crop production is negative, this very effect is even stronger within a water market scenario.

On the other hand, if water transfers are allowed the rural income always increases with drought (whereas in the counterfactual scenario not). Moreover, the higher drinking water supply and the lower price can also explain a moderately higher level of activities in other sectors of the economy (for instance, the demand for energy increases when the desalinization production is activated). Concerning the effect of drought over tourism – the main economic activity of the island - it is positive if there are water transfers.

Finally, the presence of a water market affects the opportunity for building up new regulation infrastructure (i.e. dams, desalinization plants, and water transfer facilities), achieving savings by avoiding these investment decisions.

A further study is represented by Tirado *et al.* (2006). It introduces the Water Framework Directive in the model presented in Tirado *et al.* (2004). Moreover, it further explores the effects of drought over tourism in Balearic Islands. The aim of this study is to explore the impact of enhancing technical efficiency of water use in the tourism sector being this very sector the principal cause of the water resource depletion in the Balearic Islands. The study shows how increase in water use efficiency does not necessarily determine a reduction of water withdrawals and an improvement of the relevant parameters measuring the pressure of economic system on the ecosystem.

Diao *et al*. (2005) presents an evolution of Diao *et al.* (2002) and investigates the micro-to-macro links of a water allocation policy. It studies the potential gains to the irrigation sector and to the economy as a whole from allocating water to its most productive uses in an economy with considerable spatial heterogeneity in water availability and productivity - include a detailed accounting of the agricultural sector in Morocco. Their model includes seven water districts that span the entire irrigation economy in Morocco. The spatial heterogeneity encourages a more decentralized mechanism for allocating water while also requiring that policy makers consider indirect effects of districts' policies on other districts and other factors (i.e. hired labour, capital, etc.). The model uses two basic data sources: the SAM of Morocco and the Input-Output data on crop production and water use at the perimeter level. The Moroccan economy is disaggregated in 88 production activities (82 of which agriculture related) producing 49 commodities and employing 8 production factors. Moreover, to capture spatial heterogeneity, 66 crop production activities are further differentiated by location – namely within (32 – of which 21 irrigated and 11 rain fed) or outside (34) the 7 water districts. These latter are public districts managed by authority districts (the focus is not on private irrigated lands) and are further sub-divided in 20 perimeters. In each perimeter there is a representative farm which maximizes its profit and uses 4 primary inputs (capital, labour, land, water). Labour is of two types: rural and urban. Rural (urban) workers are free to be hired but not in an urban (rural) labour market. Therefore, the analysis does not take into account any change in the level of unemployment nor in the level of wage. Water is mobile within a given perimeter but not among perimeters. Land and capital are mobile among agricultural sectors, however they are perimeter specific. The water is supposed to be charged by volumetric pricing. However given that the price is lower than the marginal willingness to pay for water, the natural resources needs to be administered. When the quota assigned is lower than the demand the shadow price for water is positive. The benchmark is set with the pre-reform water quota assigned to them by the water authority. Allowing for trading in water rights', water is reallocated from crops yielding relatively low return (low shadow price) to those crops whose shadow price of water is relatively high. The higher the standard deviation of water shadow price the higher the percentage of water reallocated. Water reallocation determines changes in other inputs' price. Considering patterns within regions, a general trend has emerged with the reform: for producers of grain, sugar and other industrial crops (low water shadow price) – it is more profitable to rent out the water to producers of fruits and vegetables (high water shadow price). This does not affect the income given the extra revenue associated with selling out part of their water endowment. Another effect the authors look at refers to the implication of the water sector's reform for the rain-fed areas. In those areas, there is just a slight reduction in the production of grain, sugar and other industrial crops - mainly due to increasing cost of intermediate inputs. Considering the price of the other factors of production, while rural wages slightly reduce, the rental rates of capital and land are region specific - because of their mobility across crops within a perimeter. The sign of the changes is driven by the different in factor intensity across crops. Water reform - even though just regards a sector producing the 10% of GDP - determines economy wide effects: increase in GDP, in welfare gain with the urban income increasing more (this being due to the slight reduction in rural wages). Also the trade pattern is influenced by the water reform. Given the comparative advantages of Morocco in producing vegetables and fruits for the European market and the reallocation of water towards those sectors, total trade will increase. Besides, there is a rise in imports of wheat sugar and other industrial crops, given that their domestic productions will be reduced.

2.2.4. Water Pricing and Distributional Sectors

Briand (2004) developed a static CGE model considering different water pricing policies in Senegal. In particular, the author introduced a differentiation among water providing systems: formal and informal. The objective of the study is to estimate the impact of those water policies on the formal and informal distribution strands in terms of production and employment.

The model is based on Decaluwé *et al.* (1999) EXTER, on typical neoclassical assumptions (i.e. perfect information and competition, economic rationality) and distinguishes five economic sectors: drinking water production, drinking water distribution (formal/informal), agricultural production (irrigated/rain-fed), industry and services. Furthermore, it considers four agents: firms, government, the rest of the world and households. Those latter are grouped in income quintile according to geographic area (Dakar/other, urban/rural).

The model uses four factors of production: water, capital, labour (formal/informal) and land (irrigated/non-irrigated). Concerning the way water is modelled, the resource is considered a primary production factor in the drinking water production sector and in the agricultural sector. The processed water commodity is then either directly used by agriculture or sold by the production activity to the distribution systems (formal/informal) which delivers/make available the resource to households. The difference in the production functions of formal and informal distribution systems is that the former capital in addition to energy and labour – which are also used by the informal one.

This theoretical study is followed by an empirical application in Briand (2007) where marginal and average cost pricing (respectively MCP and ACP) are compared in the presence of climatic shocks in Senegal. Briand (2007) presents a dynamic model and considers different levels of water availability.

In the *short run*, resource availability increases. In the *long run* there are three phases which have been taken into account: firstly, considering the supply policies of the Senegalese government, an increase in the resource availability; secondly, stability phase; finally, given the increasing demand (due to demographic evolution), a reduction in water available. Two scenarios are compared: the first considering ACP and the second MCP with a subsidy to the drinking water production authority. The *results* illustrate that in the short term MCP has to be preferred to ACP in terms of households' welfare, agricultural production, total investment and reduction of unemployment rate. MCP is even better compared to ACP in the long term as it allows a better management of resource scarcity and a reduction of food insecurity – through an increase in agricultural productivity. The simulation regarding the subsidy to the water companies shows how it might not be a good idea to impose in the long run a budgetary equilibrium to them. Moreover the study questions the average cost pricing on the base of which the increasing block water tariff is based in Senegal.

Furthermore, Boccanfuso *et al* (2005) use multi-households[44] integrated CGE model to study the impact of privatization of water utilities in Senegal on poverty and inequality. The approach is top-down, namely connecting macro reforms with income distribution and poverty and inequality changes. This model - even more than Briand (2004) - is based on Decaluwé *et al.* (1999) EXTER.

[44] According to the Boccafuso *et al* (2005) there exist three main approaches to link macro reforms to change in income distribution (top down linkages): the representative household approach: the multi-households approach: the top-down or micro simulation sequential approach.

In particular, on the households' side, the model used here includes all 3,278 households of the Senegalese households Survey (ESAM-I, 94-95) to capture intra group changes in the distribution of income. Households are aggregated into sub-groups with two decomposition criteria: the first is based on regional and educational criteria; the second is based on the source of water used. Factor initial allocation is exogenous and factor payments are endogenous. Capital being fixed by sector, there are 18 payments for capital and 2 wages (qualified and unqualified). There is no unemployment and the labour markets are perfectly separated. Moreover workers are free to move within their own market (either qualified or unqualified). Regarding macro-closures, exchange rate is flexible and savings driven closure is considered.

Simulations relate to two sets of scenarios replicating an increase in tariffs by the water utility company in order to: recover operating cost (first scenario); and operating costs and capital costs (second scenario). Next simulation is a transfer to selected households in order to offset the negative consequences of the price increase. Four modes of fund transfers are investigated: increase in the households' income tax level, increase in private firms' income tax, increase in import tariffs and transfer funded by an external donor. In order to show the effects of privatization of water utility on poverty Boccanfuso *et al.* (2005) uses two indices: the Foster, Greer and Thorbecke (F-G-T, 1984) and the Gini.

Results show that the main winner is the private sector firms. The situation for the government presents gains in some cases and slightly losses in others. All the households' groups are negatively affected when there is no compensation provided. Transfers are positive for all subgroups receiving them.

2.2.7. Triple Dividend of Water Consumption Charge

Letsoalo *et al* (2005) investigates the proposal of South Africa to reduce water consumption by levying a "water resource management charge". The authors analyze the triple dividend of a water consumption charge in South Africa. The first dividend is represented by less water scarcity; the second being a faster economic growth – stimulated by allocation of extra revenue from the water charges; and the third consisting in reaching more equity in welfare distribution.

The model is the so called UPGEM[45] and is static. It presents three production factors - labour (in different types), capital and land – which are tied by a CES aggregation. Regarding the assumptions on factors, capital stock is fixed, with the rate of return of capital endogenously determined. Labour supply is perfectly elastic with fixed real wages. Supply of land is inelastic. The production function - at its top level - is characterized by a complementarity's relation (Leontief aggregation) between value added and intermediate inputs. Households demand is defined by Linear Expenditure System (LES) differentiating among necessities and luxury goods. With respect to closure rules, exchange rate is fixed (and represents the numeraire) and foreign savings are flexible; direct tax rates are fixed and government savings are flexible; fixed investment and variable savings.

The main data set is the 1998 SAM of South Africa which divides the households in 12 income and 4 ethnic groups and distinguishes 27 sectors – those are further spilt in 39 for a better disaggregation of energy and water intensive sectors. Besides, data on water come from Water National Accounts which have been used to create a vector of "taxable water" (i.e. water extracted from the underground or rivers and water received from the formal water sector) for each industry in the SAM, as well as a vector of "extra water charges" that may be charged on volumes of water used.

Regarding simulations, different scenarios were tested through the model: increase in charge by 10c per cubic meter of water used by forestry; by irrigated

[45] University of Pretoria CGE model of South Africa.

agriculture; and by mining industries. On the other side, a decrease in overall level of: direct tax on capital and labour; sales tax on households' consumption; and a decrease in the sales tax rate on food to households.

Concerning results, a tax o
n irrigated agriculture gives a double dividend in all three reduction taxes simulated (direct, indirect and food taxes) and provides a triple dividend in the case of reduction of the food tax. A direct water tax on mining sector is also particularly effective in terms of dividends (i.e. less water consumption, positive impact on poverty reduction). In general a reduction of a tax on food is more effective than a decrease in direct taxation.

2.3. Water and Trade Issues

2.3.1 Water and Trade Policies

Diao and Roe (2003) uses an inter-temporal applied general equilibrium model focusing on the linkages between water and trade policies in Morocco. The idea is that changing water policy without a trade reform – correcting trade policy distortions - leads to an even more inefficient allocation of water. However, performing a trade policy reform alone can make protected pre-reform farmers even more worse off. This is shown through a simple trade model with water as an input. The small model is further developed to empirically describe the actual Moroccan economy in a dynamic setting. This latter is described through 20 productive sectors. There are 12 agricultural sectors - 6 of which are irrigated and other 6 rain fed – producing 6 commodities. Besides agriculture, there are 4 agricultural related and four non-agricultural sectors. Each of those is producing a single commodity. Except for public administration and rural services, each product can be exported abroad or consumed domestically. The model employs four production factors (labor, capital, land and water) as a

Cobb-Douglas aggregate combined with intermediate inputs. Capital and labor are relatively freely mobile across agricultural or non agricultural sectors. Land is either irrigated or non-irrigated. The water resource – controlled and distributed by the water authority collecting water charges from farmers using it - is assumed to be used just in irrigated agriculture. Households behave as extended immortal families and are aggregated into urban and rural. The government policies regard import tariffs, indirect taxes on producers, households taxes/subsidies, producers support price subsidies and non tariff barriers. All those policy's instruments are exogenous. The main data set is the 1997 SAM of Morocco developed by Doukkali. Among the other distortions, the actual tariff rates implemented are of about 50% on the imports of wheat and industrial crop (which are strongly protected) and of an average of 7% for vegetable and fruit. However, the protected markets are those using more water intensively. Technical data on water related to irrigated areas and water consumption by crop is obtained by the Department of Rural Engineering.

Moreover, the share of water charges to the gross value of output was calculated from data of the ministry of Agriculture. Water charge rate just cover on average the operational and maintenance costs and is less than what marginal users are willing to pay. If the water's assignment is lower than what is demanded by single farmer, given the water charge, then there is an implicitly positive shadow price for water. This latter will be varying depending on the single crop water productivity – although the volumetric price charged by the government is unique. The difference between shadow price and charge applied is the net benefit for the farmers which depends on the water sectoral productivity. Regarding simulations, the first scenario refers to the trade reform - namely removal of trade distortions and production subsidies.

The results show – from an economy-wide point of view - efficiency gains from the allocation of all resources (but water) to more profitable activities and growth in capital accumulation due to the more profitable investment options which increases wealth and rental rates of land and labor. From a sectoral point of view those producers of the protected crops are in the post reform framework worse off: first because of a reduced output price, second, because of a lower water shadow price - due to the decline in the return of their water quota. While trade reform determines a strong reduction of those sectors' production (i.e. irrigated wheat and industrial crops; in contrast, it realizes comparative advantage in the production of vegetables and fruits and increases their willingness to pay for water.

Hence, in the second scenario, farmers are allowed to rent in or out their water user rights – they are entitled to their pre-reform water quota. Water user rights market determines: the reallocation of some water from a production yielding relatively low return (i.e. low shadow price). Water consumption increases in those sectors with a higher marginal water productivity (other cereals, vegetables and fruits). However a water user rights market is difficult to implement because of transaction costs and institutional difficulties (i.e. water authorities to accept more responsibilities without any additional compensation). Nevertheless, it would be useful to implement such a market in order for the returns to water to be separated from that of the land and to fully realize the economy's comparative advantages.

2.3.2. The Impact of Restricted Water Supply on International Trade

In Tirado *et al* (2004) an alternative in facing water scarcity is to replace agriculture water intensive activities with less water intensive activities. In this context of studies the contribution of Berrittella *et al.* (2007a) is important. While the authors do not directly investigate the reallocation of water, interestingly, they consider the reallocation of water-intensive products. Instead of studying a more efficient allocation of water, the idea is that when water becomes a scarce good, an economy could increase the imports of products that require a lot of water in their production. In this sense, it is useful to introduce the concept of *virtual water*: the "water (directly) used in production, rather than the water contained in the product".

The authors analyze the impact of a restricted water supply for "water-short regions" through the use of a *global,* static multi-regional, multi-sectoral trade CGE model - with *virtual water* flows - containing water as a production factor (as provided by GTAP-W, see appendix 1). Inevitably a decreasing water supply implies that the relative price of water intensive goods would increase and the relative competitiveness would change along with the terms of trade of all regions likely in favour of the regions rich of water.

Looking at the *model framework*, it is based on GTAP-W which considers – in its version 1 here in use - 17 sectors (among which 6 are agricultural sectors) and 16 regions, with water resources modelled as a non market good. For each industry, it exists a representative firm, which is a profit maximizer in perfect competitive markets, producing through a nested CES technology. As domestic and imported inputs are not perfect substitutes is worth considering the "Armington assumption". Four primary factors are considered: land (imperfectly mobile); natural resources (industry specific); capital & labour (locally perfectly mobile but immobile at global level). Capital and labour are perfectly mobile domestically but immobile internationally. Land, imperfectly mobile, and natural resources are industry specific. A representative consumer gets his income defined as *"the service value of a national primary factors"*. The national income – which is described at the higher level through a Cobb Douglas function - is distributed between aggregate households' consumption, public consumption and savings. The aggregation for those inferior levels is defined by a Constant difference in elasticity (CDE): here are taken into account homothetic function in order to consider difference in income elasticities for the various consumption goods. It is worth to mention the only two non regional industries: international transportation – providing services associated with the movements of goods among regions – and a hypothetical World Bank - collecting savings and allocating investments.

Concerning water - as a factor for producing tradable goods and services – it is combined with intermediate inputs and value-added - which also comprehends energy nest – in fixed proportion. In the *benchmark* case, water supply is supposed to be unconstrained. Furthermore, water is provided to the sectors of the economy through a distribution service sector. Thus, distributed water can have a price although primary water resources are in excess supply (and the price for "raw" water is zero). Moreover, water is mobile between the different agricultural sectors but immobile among agriculture and the distribution service. Water treatment and water distribution are very different among agriculture and other uses. The key parameter determining the level of regional water use is the *water intensity coefficient*, defined as "the amount of water necessary for a sector to produce one unit of commodity". With respect to water data which are provided by AQUASTAT database, they are mainly water used by commodity and by country and are used to estimate water intensity coefficients.

Regarding simulations, the benchmark is modified coping with the economic effects of water supply restrictions. In general there is a reduction of available water in four areas: North Africa (Naf), South Asia (Sas), United States (Usa) and China (Chi). The first four simulations[46] deal with a water market mechanism: owners can profit from exchanging water. On the other hand, the fifth one provides a non market scenario,[47] where supply restrictions imply productivity losses.

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[46] First scenario: reduction in water supply; second: what would have happen without the implementation of water efficient use policies; third: same first scenario's setting with water immobile even within agricultural sectors; four: same first scenario's setting with water insensitive to change in water price.

[47] The authors propose a non market scenario because of the unrealistic assumption behind the existence of a market for water: definition and enforcement of property rights on water resources. If this might be possible for irrigation water, it can be excluded for rainwater.

In the *first scenario* (benchmark) the water reduction in Naf, Chi, Usa and Sas determines different water rent between agricultural sector and water distribution sector. This is because of the higher elasticity of demand to water price of water distribution with respect to the one of agricultural sector. Another remarkable simulations' result is that regions facing the same water supply constraint experiment different rate of use and different price. While according to the authors, this cannot be explained through a different responsiveness to price changes, there are two way to reduce the size of water demand: inducing a decrease in water demanded by industries and provoking a reduction in the demand for goods produced with water. However, due to a relatively more expensive production of water intensive goods, a reduction in available water leads to an increase in virtual water import in the constrained regions. This is not necessarily translated in a worsen trade balance. However, global welfare decreases with a constrained production. Moreover agricultural prices increase more than industrial ones, this resulting positive in particular for industrial sectors and more generally for countries[48].

In the *second scenario,* where the water constraint for Naf reaches the 44%, there is not just an increase in the rental price for the region *de quo* but also in other constrained regions. Those regions which are rich of water experiment a higher water demand due to increasing water intensive product exports towards constrained regions. Naf results being worse off, compared to the former scenario; and this substantially decreases global welfare. This intuitively says that in reaching sustainability, water supply should be reduced gradually.

In the *third scenario,* water is immobile among agricultural sectors and being nested at the upper level in the production function of the water intensive goods and services, it cannot be substituted with other inputs. What is

[48] For instance, even if USA are net importers of virtual water, they register improvements in their trade balance. This is because the loss in agricultural export is more than compensated by its gains in industrial exports. This is partly due to distortionary subsidization of agricultural production in the USA.

interesting here is that global welfare increases whereas in the first scenario decreases. This is due to the high distortions in agricultural economy: its decrease in production is welfare improving. The global loss in terms of welfare is higher than in the base case.

In the *fourth scenario,* water intensity does not respond to change in water prices. As this scenario worsens the global welfare with respect to the benchmark there is a call for water efficiency.

The *fifth scenario* is based on non-market mechanism. In this setting, water users cannot benefit from higher resource rents. Thus productivity is decreased to cope with water supply increased constraints (the same of the benchmark case). The innovative contribution of the paper consists in the introduction of water as an explicit production factor in a global general equilibrium setting. This study focuses on the international dimension which is pivotal as water - implicitly traded at global scale – mainly exchanges through agricultural products. Concerning the limitation of this study, the authors simplify considerably assuming the water service sector supplying indifferently for both industrial and domestic uses, with the same price for all industries (but for agriculture): there is no quality difference of water supplied. Moreover, in considering regional water supply, the perfectly competitive water market seems to be an unrealistic assumption. Besides, intraregional transportation of water is assumed to be costless. Furthermore, waste of water is not considered and the substitution of water with other inputs in the production process is not possible. Regarding agricultural water, there is no differentiation among the use of irrigation and rain water. Finally, the use of a single data set for water uses and water resources does not take into account uncertainties in the data.

2.3.3. The Impact of a Water Tax

We have just seen how on international markets water is just implicitly traded, in particular through food and textile products. Thus, it is fundamental in studying the impact of a hypothetical water tax to investigate the international trade related effects. Therefore, Berrittella *et al*. (2008) studies - within the same framework (GTAP-W, version 1) of Berrittella *et al*. (2007a the implication of the introduction of alternative water taxes.

Four alternative simulations have been run, the first three taxing production use and the fourth one the consumption. In all the simulations water tax revenue is redistributed by lump sum transfer to the representative household. The *first scenario* provides a water tax of \$10 mln per 10^9m^3 of water, with an increase in water price of 1 cent/m^3. The idea is to check for achievable water savings. Here, the water tax leads to a net increase in virtual water imports for those regions relatively water intensive (i.e. North Africa) which are also the water short regions and need to import water intensive products. In this setting, global welfare decreases being water use restricted owing to higher resource price. In the *second scenario*, the price has been lowered to 0.5 cent/m^3. However, water price differs both among countries and sectors. For instance agricultural water price is generally lower: owing to the availability of other (undifferentiated in the model) sources of water for this activity (namely rainfall, soil and irrigation water) which has to pay just for irrigated water. In this scenario, water demand decreases less than in the former case with water demand slightly less than linear in water tax. Welfare falls (increases) in the more water intensive (efficient) countries but less than in the first scenario. At a global level welfare falls less than in the former simulation. In the *third scenario,* water taxes are introduced just in the water short regions (Naf, Sas, Usa and Chi). An increase in water taxes just for the water short regions determines a reduction in water demand: the less water efficient region, the bigger the drop in water demand. The trade in virtual water changes consequently with an increase of water intensive products imports for those regions. The global welfare decreases in the third scenario but less than in the first. In particular, North Africa gains from increasing the imports with respect to the first scenario, because the trade is relatively cheaper. Taxing water-scarce regions only would lead to a shift in agricultural trade and would increase water demand in the exporters of water intensive goods. In the *fourth scenario* final consumption is taxed of 10 mln per $10^9 m^3$ of water. In the *last* scenario, taxing consumption of water intensive commodities and services leads to a global more uniform decrease in demand with lower changes in *virtual water* trade. In this setting the global welfare increases. In particular, the more a region imports water intensive goods, the more that region gains with respect to the benchmark case. Taxing the final water consumption would be less effective in reducing water use although would be less costly.

The study points out that local water policies - implemented through a water tax - have implications for international trade. Thus, as regional water policies are linked they should be set considering the other countries' policies. Moreover, what emerge clearly is a trade off between water savings and welfare changes.

Furthermore, Roe and Diao (1994) studies the setting of a water tax in a region with a shared water aquifer. The authors focus on changes in GNP due to water taxes in Israel and Jordan. If a tax on water is imposed in just one of them, this will reduce the country's GNP while increasing the GNP of the other. The imposition of a tax by both countries in a cooperative way will raise the GNP in both countries[49].

2.3.4. The Impact of Trade Liberalization on Water Use

[49] Along this line Kohn (2003) applies the Heckscher-Ohlin-Samuelson model, incorporating costs of transport in order to illustrate the advantages of international trade in freshwater in Middle East.

Berrittella *et al.* (2007b), using the GTAP-W model, focuses on the impacts of agricultural trade liberalization on water use – where markets and property rights exist in only a few countries. The trade liberalization scenarios are based on Doha Development Agenda. The water demand is supposed to react to trade liberalization in the following way: the lower the import tax on water intensive agricultural products, the lower the demand for water for that specific region - with an increase in the water demands for water abundant countries (and vice-versa).

Any analysis investigating trade liberalization scenarios based on Doha negotiation has to consider different, often diverging interests. Agricultural exporters stand up for trade liberalization and distortions' reduction. On their side, industrial exporters from emerging economies want to remain protected. Countries specialized on service are in favour of reducing the protection on service sectors. While this study considers liberalization in service and non agricultural sectors[50], it just modifies the level of liberalization in agricultural sectors, being focused on trade liberalization in agriculture.

Four simulations are run assuming no export subsidies and a reduction by 50% in domestic farm support. In the *first* scenario, there is a uniform reduction of tariffs for all agricultural sectors by 25%. In the *second* and *third* scenarios the tariffs are respectively reduced by 50% and 75%. The *fourth* scenario proposes two different tariff reductions for developed and developing countries, respectively 75% and 50%.

As expected, trade liberalization would imply an increase in water use in relatively abundant water countries (Canada, Australia, New Zealand and Eastern Europe) and a decrease in relatively water stressed countries (Western Europe, Japan, South Korea and Russia). The USA will reduce water use for a partial liberalization; with a more complete liberalization, the USA will increase

[50] The cut of tariffs in the service sector is 25% while for the non agricultural sector the reduction implemented is 36%.

water use. This trend can be better understood looking at the production per crop. For instance, larger liberalization means for US rice producers regain in competitiveness with respect to Japanese and Western European producers while US rise production decreases for lighter tariff reductions (with a consequent reduction in sectoral water demand). However, changes in water use due to trade liberalization are less then 10%. In general, trade liberalization would have a small and largely beneficial effect on the use of water.

One of the most recent contribution to the Water CGE modeling literature is the study done by Cirpici (2009) applied on Turkish Economy. The aim of the study is the assessment of the agricultural tariff reduction. The model used borrows from Mukherjee (1996) and water is considered explicitely as a production factor. The results suggest that with trade liberalization Turkish farmers would be worse off but the producers of fruits and vegetables, while the Turkish households would be better off. The water consumption reduces in particular for cereal productions whereas it remains stable for fruit productions.

2.4. Combining Modelling Techniques: CGE & Other Models

2.4.1. Trade Reform vs. Water Reform

The close linkages between macroeconomic policies and agriculture it is not a recentissue. However, more recently macroeconomic policies have been receiving more attention in their linkages to water resources and water policies (Tsur *et al.* 2004). For instance, as we have seen above (section 2.3.) an import substitution trade policy tends to induce the allocation of water to the production of the protected crops. Therefore, after a trade reform, the marginal value of water allocated to protected crops would decrease.

While in the previous section I have considered the top-down approach (typically trade reform approach), in this section, I look at some more recent CGE models focusing on micro-macro linkages related to water issues. They use both bottom-up - water trading and/or changes in farms water assignment – and top-down – typically trade reform – approaches. A general conclusion from these studies is that trade reform has a stronger effect than water reform.

For instance, Roe *et al.* (2005) applies a CGE framework - simulating both a water reform and a trade reform - to Morocco. They find that water productivity is strongly influenced by these policies. The trade reform has had a stronger absolute impact than the water reform one. The model is based on Diao et al. (2005) (see 2.2.3.) for what concern the micro-to-macro linkages, the spatial identification of irrigation districts, in turn divided into perimeters, and the identification of EU as a major Morocco's commercial partner - which has been separated from the rest of the world. In Roe *et al.* (2005) has been added the link between the farm model and the macro model within the irrigation districts. Since each perimeter is aggregated from the farm level data, the data for the farm "micro" model are from the same data source of the "macro" model which is in turn micro-based.

Two sets of scenarios refer to: (i) the trade policies chosen to illustrate macro policies and (ii) the micro-to-macro linkages. Regarding the results of (i), the liberalization process turns out to be positive: the GDP and the exports – given the depreciation of the real exchange rate – increase, and the resources are allocated in a more efficient way – with the import competing sectors producing less and the export oriented ones more. The trade reform tends to lower the shadow price of water for the protected crop. However, given the decrease in the price of inputs, the total effects on water shadow price is reversed. Furthermore, considering that farmers just pay a nominal water charge, increases in the water shadow price positively influence the farm profit. Anyhow, the effects of trade reform, at farm level, are better captured by the farm model which separates them into direct, indirect and total effects of the output price changes (given changes in crop output). Regarding (ii) the water reform is analyzed considering direct, indirect and total effects. To simulate the removal of the water assignment's constraint, in the farm model, the authors allow farmers to equate the marginal cost of water across crops with the objective of profit maximization. In this way, farmers allocate water in a more efficient way. The results are in line with the outcomes of Diao *et al.* (2005)[51].

However, what has been stressed by Roe *et al*. (2005) is that a water reform *tout court* could lead to a Pareto inferior outcome – i.e. water from an export oriented to a protected sector. To investigate total effects of water reform the CGE model is used. The water assignments - based on historical trends - become tradable among farmers within the same perimeter.

Finally, the two sets of scenarios are considered together. For the representative farmer – highly dependent on sugarcane and wheat productions – the trade reform produces a fall in the output revenues and in farm profits. Nevertheless, the water reform is positive for the farmer since it partially off-sets the negative effects of the trade reform. In Diao and Roe (2003) the same study confirmed the previous results in a dynamic setting.

Cakmak *et al.* (2008) proposes a CGE analysis of Turkey focusing on irrigation. The studies present many similarities with Roe *et al.* (2005): the micro-macro linkages approach to water management, the consideration of the spatial heterogeneity – through a regionalized SAM, exogenous shocks related to climate change, and the use of the farm model in order to derive shadow prices.

The authors use the farm model to estimate the shadow value of water in agricultural production which has been compared with the actual water price paid by farmers – with the first being twice the second.

Three sets of simulations have been presented: (i) changes in world agricultural prices – with average increases of about 30%; (ii) impact of drought – with

[51] Diao *et al.* (2005) has been presented in section 2.2.3,

transfers (and related variation of the supply) of water from the rural to the urban areas; (iii) impact of climate change on agriculture – with falls in the yields of both rain-fed (30%) and irrigated (10%) agriculture. In all the simulated scenarios reductions in GDP are registered, whereas agricultural value added increases. This is due to increase in production in irrigated sectors – for climate change scenario; and in rain-fed activities – for the urbanization scenario and in the world price increase scenario. Irrigation is considered the most indicated adaptation measure to cope with climate change effects on agricultural sector. In climate change dynamics also global warming may play an important role on water availability. However, this has not been considered in this study.

2.4.2. CGE and Bio-economic models

Smajgl *et al.* (2005) combines a CGE model with an agent based model (ABM) in order to investigate the interactions between the socioeconomc system and the Great Barrier Reef (GBR) ecosystem. In the context of the Reef Water Quality Protection Plan which defines objectives and mechanisms for the protection of the GBR – Smajgl *et al.* (2005) provides the framework for a Decision Support System (DSS) aimed at analyzing the *ex-ante* impact of policy options. These latter affect activities which are putting under pressure water quality, quantity and land use determining a number of environmental, economic and social consequences. The authors put in place an approach developed for the GBR region, which integrates a CGE model with an agent based model (ABM) for integrated policy impact assessment given that environmental, economic and social goals have to be contextually considered.

This approach is called Integrated Assessment and Modelling (IAM). The CGE – called Policy Impact Assessment (PIA) - studies the interactions among

economic and environmental systems - within the catchment area. Water is integrated as an input to production sectors in a similar way to labour and capital through a CES nested aggregation. On one hand, PIA defines a series of response functions for ecosystem services and species. As economic activities - such as tourism – partially depend on ecosystem services, some element feed back into the market driven system. Nutrients are considered as an indicator water quality which is affected by the use of fertilizers in agriculture. Therefore, the model is able to capture the non-market impacts of some economic activities (e.g. agriculture) on reduction in water quality which in turn influences other economic activities and the environment. On the other hand, the agent-based model SEPIA (Single Entity Policy Impact Assessment) describes the efficient use of land and water in the GBR region; this latter represents the agro-ecological system where the interactions are analyzed in a spatial distribution.
Finoff and Caplan (2005) also studies the interlinkages between the socio-economic system and the ecosystem of the Great Salt Lake (GSL). The authors present a CGE model of the interface between the watershed containing the GSL and the regional economy that impacts the GSL ecosystem.

Regarding the ecosystem, the model treats the various representative species as net-energy maximizers and the period-by-period population dynamics depend on the sizes of surplus net energy. Energy markets determine equilibrium energy prices. With respect to the regional economy, five production sectors (at the aggregate industry level) are modeled - brine cyst harvesters, the mineral-extraction industry, agriculture, recreation, and a composite-good industry - as well as the household sector.

By performing dynamic simulations of the joint ecosystem-regional economy model, the effects of period-by-period stochastic changes in salinity levels are studied.

As a result, the authors demonstrate how the model can be used to estimate the economic benefits of managing an ecosystem within its watershed.

To conclude, concerning the opportunities for further studies many directions can be taken. In order to take into account externalities and waste water management, the depletiation of the natural resource a dynamic CGE model could be considered to show what the advantages of water markets are for an extended period of time. One temptative in order to study waste water issues has been made by Brouwer *et al.* (2008) where economic activities are linked to water pollution flow (emissions) in Netherlands[52].

[52] In particular the study focuses on how national economy wide impacts of different emission reduction scenarios simulated through a CGE can be disaggregated to the level of river basins (Brouwer and Hofkes, 2008).

3. KENYA'S BACKGROUND

In this chapter, as previously been said, I introduce Kenya's economy on which the water CGE model (chapter 4) is applied. A fundamental condition for targeting the policies to be implemented is a detailed understanding of the situation of Kenya's economy with particular focus on agricultural sectors and the availability of water and by the legal-administrative water framework and water marketing.

3.1 Geographic and Hydrologic and Demographic Outline

The Republic of Kenya (figure 3) is located on the East African coast on the equator. It has a boundary with Ethiopia and Sudan to the north, the Indian Ocean and Somalia to the east, the United Republic of Tanzania to the south, and Uganda and Lake Victoria to the west. The total area of the country is 580'370 km^2.
For administrative reasons the country is subdivided into 8 provinces (figure 2) and 70 districts. Kenya has six major agro-ecological zones: Upper highland (UH), Lower highland (LH), Upper midland (UM), Lower midland (LM), Lowland (L) and Coastal Lowlands (CL). These zones are associated with corresponding temperature variations ranging from freezing to 40°C.

The altitude varies from sea level to the peak of Mt. Kenya - situated north of the capital Nairobi - which is 5'199 metres above sea level. The soil types in the country vary from place to place; in particular in the ASAL the soil is characterized by low fertility and vulnerability to erosion. The average annual rainfall is 630 mm with a variation from less than 200 mm in northern Kenya to over 1800 mm on the slopes of Mt. Kenya. The rainfall distribution pattern is bimodal with long rains falling from March to June and short rains from October to November for most parts of the country. About 80 percent of the

country is arid and semiarid, while 17 percent is deemed to be high potential agricultural land, sustaining 75 percent of the population. The forest cover is about 3 percent of the total land area (FAO-A
QUASTAT, 2005). Total population is 38.6 million (2008), of which 59 percent lives in rural areas.

Figure 3: The Republic of Kenya

Source: FAO – AQUASTAT, 2005

3.2. Overall Economic Performance

Since the early 1980s, the growth rate of the Kenyan economy has been quite low - at an average rate under the 3 percent/year -. This rate has been below the population growth rate in the 1990s[53]. The economic liberalization process

[53] The average growth rate since 1990 has been even lower at about 2.5%.

(1986-1994) had limited impact on the economy and did not positively impact on the economic growth rate which has been volatile till 2003. Several factors undermined the poor performance of Kenya's economy. Among others the most relevant were: politically induced economic uncertainty, corruption and high interest rates as the government borrowed heavily in domestic markets (FAO 2008). The 2002 witnessed the change in the political scene when the candidate of the National Rainbow Coalition (NARC) Mwai Kibaki ended President Moi's rule, who led the Kenyan African National Union's since 1978. This political change seems to have substantially contributed to a steep growth averaging 4.9 percent/year. The Kenya Vision 2030 set to an ambitious 10 percent the national growth rate.

Regarding sectoral evolution, Agriculture slowed during the 1980s and early 1990s while rose considerably since 1993 even with periodic fluctuations and then declined after 2000. On the other hand, the industrial and the services sectors even though stagnated during 1990s rose back after 2002 (FAO, 2008). The primary sector seemed to have been more positively affected by the end of the liberalization process than by the economic expansion after 2002 elections. By contrast, Secondary and Tertiary sectors positively benefited from the new Government's 2002 Economic Recovery Strategy. Even if macro-stabilization policies reduced inflation and interest rates, they did not stabilize them. Nevertheless they succeeded in stabilizing the exchange rate. The real appreciation in recent years favoured imported capital goods and reduced the competitiveness of agricultural exports (Thurlow *et al.*, 2007).

Low economic growth matched higher population growth during the last two decades. Therefore per capita income stagnated and the poverty rate increased. According to Thurlow *et al.* (2007), poverty rose more in urban settings since rapid urbanization has been accompanied by slow industrial growth. On the other hand, rural poverty increased moderately because of the strongest agricultural performance associated to slower rural population growth.

Anyhow, the poverty level in Kenya remains high with nearly 10 million people living in the ASAL areas with permanent threat of drought and famine. 36 out of its 74 districts are within the ASAL zones where more than 60% of households live below the poverty line (subsist on 1US$ or less per day). The high poverty incidence is accentuated by climatic shocks, environmental degradation, insecurity and diseases which affect human welfare and animal heath.

3.3. The Agricultural Sector

Agriculture contributes about 24% to the nation's GDP[54]. Moreover, it generates about 60% of the country's foreign exchange – mostly with exports of coffee, tea and horticultural products - and employs around 75% of its total population, 80% of which are smallholders (KIPPRA, 2009). Even if it represents the main sector using water, Agriculture is for the most part rain-fed and is concentrated in the narrow central part (the 33%) of Kenya, which is regarded as to medium/high potential for agricultural purposes. The remaining 67% of the country, is ASAL, and is categorized as having low potential for agricultural purposes (FAO, 2008). The ASAL zone which is most vulnerable to drought runs along the borders with Somalia, Ethiopia and Uganda. Therefore, drought related social economic problems have a cross border dimension as these areas are mainly inhabited by pastoralist communities that practice traditional livestock, supporting the 74 percent of the country's total livestock production. The importance for economic activities in ASAL is also given by considering that they have over 90% of the wildlife in the country which supports the tourism sector (KIPPRA, 2009). These areas, however, have the lowest development indicators and the highest incidence of poverty. Households' food

[54] The share of agriculture declined slightly from a 33% of the early 80s. Also the share of industry has also declined and reached about 21%. Primary and secondary sectors both ceded to the services sector – now about 55% of the economy (Thurlow *et al.*, 2007).

insecurity – exacerbated by droughts - is a common feature in these areas (UN-WWAP, 2006).

Within rural activities, the shares of crops, livestock, forestry and fisheries have remained almost constant over the past decade, with crops dominating at 69% of the agricultural Value Added (VA). Livestock[55] is the second largest element at 24% with the rest of rural activities relatively smaller[56]. Considering the National Accounts data for 2003 (the year for which the SAM of Kenya is available), the main industrial crops (including the main exports) – tea, coffee, sugar, and cut flowers – account for around 25% of total agricultural VA (figure 4) – corresponding to 6.4% of national GDP. Following, I am further focusing on maize and livestock producing activities as they are particularly important for Kenya's economy and are also strongly affected by droughts[57].

Looking at food production, maize dominates accounting for 13% of agricultural VA. However, this figure does not provide a full appreciation of the socio-economic, and hence political, importance of this staple crop. Looking at the share of maize in total value of crop production, this figure is indeed large (20%) but not as dominant as it appears looking at the maize cultivated area (46% of the total crop area) with 98% of small scale farmers cultivating it. The same discrepancy between value and area holds for beans - with 6.8% share in value but 26% share in area (figure 5 and 6).

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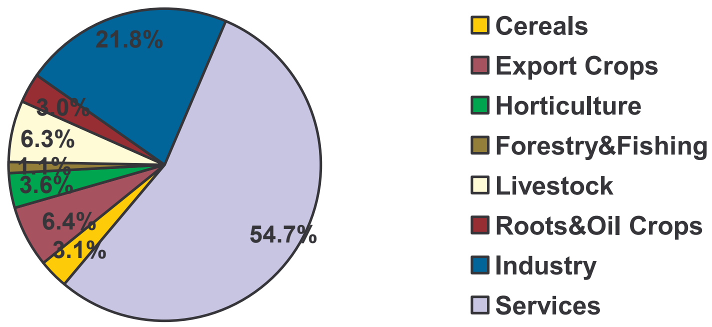
[55] The sector is composed by red meat sub-sector (cattle, sheep, goats, and camels), the white meat sub-sector (pigs and poultry) and by products (milk, hides/skin). (FAO, 2008).

[56] However according to Ayieko *et al.* (2005) the relative weight of livestock sector is even stronger reaching the 38% of agriculture GDP

[57] Drought is a recurrent phenomenon affecting large areas and numbers of people in the country. The cumulative effects of these droughts include the erosion of assets, impoverishment of rural communities. The effects of droughts have become more pronounced in recent decades: in the 1990s there were three major droughts. The 1991/92 drought in the ASALs affected the livestock production with losses of up to 70% of herds, and unprecedented high rates of child malnutrition of up to 50%. During this very drought, 1.5 million people in seventeen arid and semi-arid districts of four provinces received relief food assistance. Another drought hit again at the end of 1995 up to 1996 affecting an estimated 1.41 million people. The worst drought emergency in recent years affected Central, Eastern, Rift Valley, Coast and North Eastern Provinces, with 4.4 million people requiring food assistance in the year 2000. This year in Kenya recent droughts are - along with post election conflicts and economic global crises – undermining national food security (FAO, 2009).

Figure 4: The structure of the Kenyan Economy with a focus on agricultural VA



Source: Thurlow *et al.* (2007)

A first element emerging from the overall performance of Kenya's agricultural sector is that - in spite of the strong production growth in dairy, tea, fresh fruits and vegetables - it has been negatively affected by slow productivity growth in maize. Given the wide spread cultivation of maize, a further reduction in the production of this staple crop - due to drought during the crop season - is likely to undermine poor agricultural growth in Kenya[58].

In the following, I focus on the livestock sector, as it is the second most important rural activity. Moreover, it is concentrated in those areas which are suffering the most from droughts. In the ASAL, pastoralists' activities are largely dominant. Nevertheless, the characteristics of livestock ownership and movement vary significantly across different ethnic groups and food economy zones[59]. However, the FAO (2008) analysis underlines a common pattern[60]

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[58] However, according to the FAO (2008), maize productivity growth is likely to reduce the overall area devoted to it and promote diversification toward crops that provide higher returns to land and labour in particular settings. Nevertheless, even if the sector would succeed in moving toward higher-return cropping patterns, maize will remain a crucial part in reaching food security as a staple food of an enriched more diversified rural economy. Furthermore, on the production side, as a cash crop in areas where it is agro-ecologically suited to provide high returns.

[59] Pastoral lifestyles range quite a lot within the territories where they are developed: from fully nomadic patterns in the arid parts of Marsabit and Turkana, to nomadic patterns which are closely linked through family ties and movement patterns to settlements as in Wajir, and to semi-sedentarized pastoralists around the Ewaso Nyiro River, Lake Turkana, and the Moyale

emerging from those different pastoralist communities: the poorest are those who lose their livestock during drought periods and that consequently move in and around urban centres. Thus, an immediate intervention for mitigating droughts' negative effects would be not just beneficial in the short and medium term for pastoralist communities of ASAL but also positive in order to avoid migrations and reduce demographic pressure to urban slums where living conditions may be worse than in the rural setting.

If we consider the structure of Kenya's agriculture, the predominance of crops sectors – mainly rain-fed - in the contribution to agricultural GDP this translates to relatively high volatility in terms of agricultural growth. The fluctuation in crop output is due to the weather component. According to FAO (2008), considering that only one-fifth of the total irrigable land has been currently exploited, there is room for gains from irrigation expansion.

Figure 5: Share of Major Crops by Value (% of total crop area)

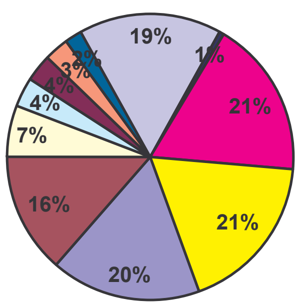
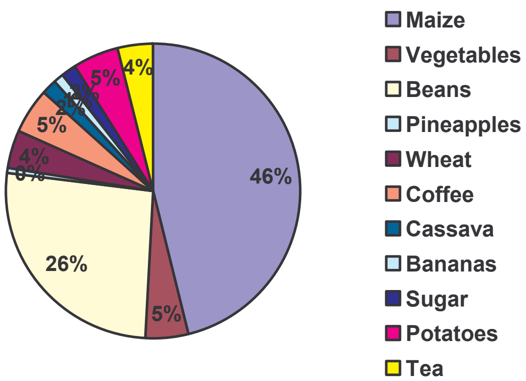


Figure 6: Share of Major Crops by Area (% of total gross crop value)



Source: FAO database[61]

Hills. There are also bunches of settled communities relying predominantly on crops, for instance in the vicinity of Marsabit mountain and the high potential areas of Isiolo (FAO, 2008).

[60] Key Characteristics of any Pastoral Production System: animals represent more than economic assets; they provide social identity and security; large herds are reared mainly for subsistence, with occasional trading; herds are composed mainly of indigenous breeds; practised on extensive basis with animals depending on natural pastures for feed; mobility in response to variations in climate Odhiambo (2006).

[61] Shares are averages of 2001 – 2003.

3.4. Water Resources

Policy makers in Kenya (and in Eastern Africa more in general) are increasingly facing a number of challenges related to water sector management. Among the most relevant problems there are growing population, increasing climatic variability, water (local) scarcity, uneven water availability, increasing water demand, water pollution, storage and infrastructure investment, water allocation, resource assessment, water legislation. The country is considered water-scarce with only 647 m^3 of renewable fresh water per capita[62] and faces serious challenges with regard to water and sanitation services. The water distribution in the drainage basins is both skewed and uneven, with for instance 282'600m^3/km^2 in the Lake Victoria and 21'300m^3/km^2 in the Athi and Coast catchments. The five main irrigated areas are presented in figure 7.

The total renewable surface water resources[63] are estimated at 20.2km^3/yr, while about 3.5km^3/yr of groundwater[64] is produced annually. Concerning the use of water, the total water withdrawn is estimated to be over 2.7 km^3/yr. This figure is projected to more than double, reaching the 5.8 km^3/yr, by the 2010 (FAO-AQUASTAT)[65].

The focus of this study will be on the use of water in agriculture and rural activities as the resource's availability represents a constraint on production. Agricultural water plays a central role in agriculture-based rural livelihood, as the irrigation can play a central role in increasing agricultural productivity.

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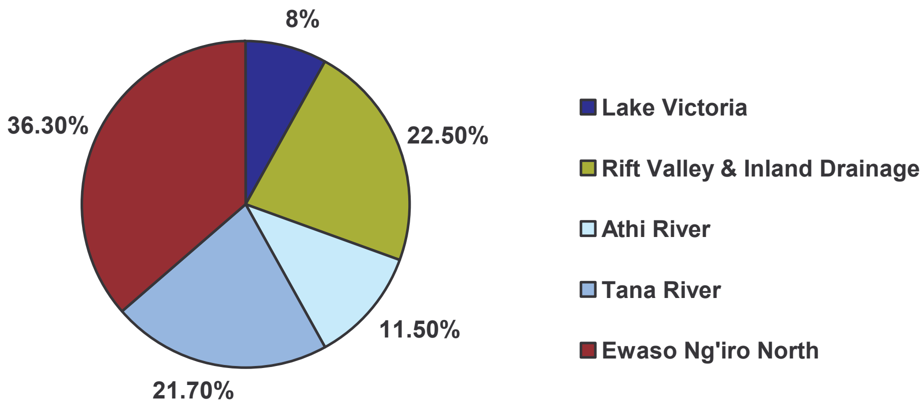
[62] According to World Water Assessment program (UN-WWAP, 2006) a sufficient level corresponds to 1000m^3 per capita per year.

[63] According to AQUASTAT, the total renewable surface water is the sum of the internal renewable surface water resources and the total external actual renewable surface water resources. http://www.fao.org/nr/water/aquastat/data/glossary/search.html

[64] Long-term annual average groundwater recharge, generated from precipitation within the boundaries of the country. Renewable groundwater resources of the country are computed either by estimating annual infiltration rate (in arid countries) or by computing river base flow (in humid countries). http://www.fao.org/nr/water/aquastat/data/glossary/search.html

[65] The difference among water withdrawals and estimated presence of water resource is mainly due to the mentioned skewed distribution and to the fact that not all the water that exists is then available to be used.

Figure 7: Main Kenyan Irrigated Areas (% ha)



Source: AQUASTAT database.

Moreover, it is also worth introducing the tri-partition of the Kenyan irrigation system. There are public, smallholders and private schemes. The formers are managed by the National Irrigation Board (NIB)[66], designed mainly for rice production (just residually to vegetable and fruit), and account for about 12% of Kenya's irrigated land. The Smallholder schemes, mainly designed for subsistence agriculture cover roughly 46% over the total area under irrigation in Kenya. The production within these schemes meets mainly the subsistence production and, only residually, the domestic and export markets. The private schemes, mainly designed for large farms, are mostly related to commercial flowers and vegetable farms and represent 42% of the irrigated land in Kenya (Neubert *et al.*, 2007). The problem of scattered availability of water.

Nevertheless, even though irrigated agriculture is the major activity using water in Kenya – accounting for 76% of the resources used (UN-WWAP, 2006) – its potential, according to AQUASTAT, is underdeveloped.

This mainly depends on lack of infrastructure and skewed availability of the resource. According to Onjala (2001), major constraints to the implementation of irrigation projects are: (a) low water availability at local level – given the

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[66] Since 1966 the NIB – semiautonomous governmental institution of the Ministry of Water and Irrigation (MWI) - manages the national large-scale irrigation schemes in Kenya (Onjala, 2001; UN-WWAP, 20056).

scattered availability of the resource - and the rising costs of supplying water through irrigation schemes; (b) relatively low economic performances and lack of efficient technologies in the existing irrigation schemes; (c) large fund requirements for project implementation overheads. Furthermore, poor management, weather changes and unpredictability complicate irrigation planning; uncontrolled exploitation of groundwater leads to a drop in the water table and an increase in extraction costs. In addition, low producers' participation contributes to undermine efficiency of the irrigation system.

Moreover, according to the Gulyani *et al.* (2005). the price charged covers only about the 35% (55% according to WWAP) of the average operational and maintenance cost of supply (with charges in many systems being much lower). Therefore, despite considerable irrigation potential, the Government of Kenya (GoK) is unable to realize a sizable irrigation focused development, and for sometime, the government's irrigation programme has almost been suspended. Given this, the GoK modified its direct involvement undertaki

ng the implementation of the water policy towards a stronger participation of communities, private sector and other sectors' stakeholders[67]. Participation and involvement of stakeholders, decentralized management and self sustainability of the system are the main drivers of the Water Act (2002)[68] which has been

[67] On this issue, according to studies of the World Bank, in Nepal, within farmer-owned and managed irrigation systems, producers contribute large amounts of cash and labour to pay the annual O&M maintenance costs. Although many of these farmers are very poor, they are willing to pay for good-quality, reliable irrigation water services that raise and stabilize their income (World Bank, 2002). On the other hand, the fee payment system applied to small-scale water users in Tanzania failed to achieve the expected goal of self-financing management; whereas the large scale private system derived considerable benefits from service improvement due to fee payment (van Koppel *et al.*, 2004).

[68] The following principles drove the Water Act (2002):

a) Decentralization- the decision making and operations have been decentralized from the national level to the catchment's level to increase efficiency and effectiveness.

b) Devolution of responsibilities for water resources management to the Water Resources Management Authority, Catchment's Boards, communities and other actors.

c) The inclusion of stakeholders and users in advisory and decision-making capacities wherever possible.

d) "No responsibility without authority"- all actors now have clearly defined roles and will have delegated authority when performing their defined roles.

adopted in order to: define clear roles for the different actors involved in the local institutions; and to separate policy formulation (centralized level) from regulation and service provision (decentralized level). The reform of the water sector puts a primary attention to domestic water provision and health issues, secondly on irrigated agriculture. This approach is strictly related to the strategies towards achieving the Millennium Development Goals (MDGs) regarding the reduction of poverty, hunger, child/maternal mortality and major diseases as well as environmental sustainability. The present study will not focus on households' water consumption[69], scoping the study more on rural water and irrigated agriculture – which, according to Neubert *et al.* (2007), could dramatically improve the life quality of the people concerned in smallholder farms, government schemes and private commercial oriented farms.

As we will see, the drivers of the new settings in the water management policies – private actors' involvement, efficiency and supply increase – will be modelled within a CGE analytical framework.

3.5. Droughts related Problems

Droughts impact on various aspects of Kenyan society and economy. Those impacts are becoming more dramatic as the drought cycle has increased in frequency (from 5-7 to 2-3 years) and the number of households affected is

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e) Avoiding conflict of interest - institutions and authorities should not at the same time be both "referee and player" - Separation of policy from implementation functions within the water resources management sector.
f) Clarity of mandate – Avoiding duplication of functions and confusion of competencies.
g) Human resource redeployment and development leading to more effective institutions. Redeployment of existing staff to the proposed institutions will be supported by performance based incentive schemes, promotional policies and competitive salaries and benefits. This is aimed at ensuring the availability of sufficient numbers of qualified staff of all disciplines required by the sector. (UN-WWAP, 2006).

[69] For an interesting study on water households' consumption and equity issues in Kenya see Gulyani *et al.* (2005).

increasing[70]. Moreover, a number of factors contribute to the severity of droughts in Kenya:

- Inadequate capacity for storing rain water for use during periods of shortage.

- Lack of local guidelines for water catchment and storage at household level and inadequate capacity for community's water resource management.

- Lack of communities' capacity for limiting/solving resource based conflicts, with the resultant insecurity restricting livestock movement in search of pasture and water.

- Over-utilization and degradation of pasture and water resources in pastoral safe havens and buffer zones.

- Lack of infrastructure constraining the marketing of livestock during periods immediately prior to the onset of drought.

- Widespread poverty affecting the communities' capacity (for self-reliance) in coping with droughts.

Droughts imposed heavy burdens on Kenya National Budget diverting financial resources from planned programmes to emergency food aid assistance. It has been estimated that: during the drought of 1996/7 the GoK spent approximately USD 94'000 (7 million Kenyan Shillings) on relief food distribution; and the financial cost of the 1999/2001 drought was USD 340 Million (22.5 Billion Shillings), which included emergency relief, livestock losses, and the cost of operating the Early Warning System (EWS) by the ALRMP.

For example, during the 1999-2001, drought over 2.3 million sheep / goats, 900,000 cattle and 14,000 camels valued at about USD 77.3 million were lost. An assessment carried out by Oxfam - following the 2005 drought in northern

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[70] According to the Republic of Kenya (2008), population affected range from the 150'000 of the drought in the Garissa district (1975) to the over 4.5 Million in the case of the recent widespread drought of 2004-6.

Kenya - revealed that over 70% of the livestock had been lost. Another direct effect of droughts is soil erosion which subtracts available land to diversified uses. For instance, pasture for grazing domestic animals and for pastoralists' activities is hardly affected.

More in general, wildlife and biodiversity - fundamental components for the tourism sector - are tremendously hit by this sort of natural disasters. There are also important health concerns related to drought problems. Farming communities have experienced more frequent crop failure, reduced yields and low calorie intake resulting in declining level of nutrition in the community.

Drought impacts are often compounded by widespread poverty and disruption of traditional coping mechanisms. After a severe drought, heavy rains tend to follow with intensity leading to flooding, spread of malaria and other water borne diseases. Poverty and food insecurity after droughts affected even stronger rural communities not just in economic but also in social terms: for instance, disrupting the local relationships and damaging the social safety networks that are built around lending and borrowing of livestock thus promoting equitable ownership of the only means of livelihood. Moreover, effects of natural disasters tend to force pastoralists out of their production system. Expectations on better life conditions make them move to urban centres where they hope to improve their life conditions.

Given all this, a coherent plan for natural disaster management - providing pre-emptive mitigation measures rather than merely actions on response – is highly needed.

4. ANALYTICAL FRAMEWORK

4.1. The SAM of Kenya

The CGE model developed is based on the 2003 Social Accounting Matrix (SAM) of Kenya (Kiringai *et al.,* 2006). A macro-SAM represents the description of the monetary flows within a national economy on a highly aggregated bases. The flows are structured according to a number of accounts each of which compares as a row (revenues) and a column (expenditures) of the matrix.

The transactions appearing in a SAM relatively to the different agents and productive sectors are reported in the flow diagram in figure 1. The 2003 SAM of Kenya represents the principal source of data. On its basis the model is calibrated. The SAM-based calibration ensures that the values in the original SAM are reproduced by the model in absence of perturbation. In a SAM a number of sectors - or activities - are described. Each of them may produce more than one commodity[71]. However, in the SAM of Kenya there is a one to one correspondence between the fifty commodities and the fifty activities.

Regarding in particular the water sector, there exists in the SAM a water activity. This latter provides purification and distribution service process to: almost all manufacture activities - but fishing, forestry and grain milling; all the service activities; some agricultural productions – mostly rice, residually fruits and vegetables – and some domestic institutions - households and government.

About 65% of Kenyan population is rural, and of these almost 60% live in poverty (Thurlow *et al.*, 2007), relying directly or indirectly on agriculture for their livelihoods. Their wellbeing and overall economic growth are significantly affected by the performance of agriculture.

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[71] The dairy sector, for instance, may produce different commodities: cheese; drinking milk products; other dairy products; yoghurt and sour milk drinks. Another example that we will discuss later on is represented by the water activity producing more than one commodity.

Households are divided into two groups: rural and urban. Each of them – with the first one more numerous than the second - is further divided into deciles of expenditure. The welfare distribution is extremely skewed in the urban context. The two richest deciles of urban households consume about 81% of the total consumption in the urban setting (and 48% of the entire households' consumption). In the rural context, the two wealthiest deciles of rural dwellers consume 37% of total rural consumption (and 15% of the households' consumption).

In the original SAM the factors of production are capital, skilled, semi-skilled and unskilled labour and land.

4.2. The Adjustment of the SAM

First of all, it is worth defining the concept of "Primary water" which is raw water, a non man-made input[72]. "Primary water" is allocated in Kenya through permits. The responsibility for permits allocation is vested with the Water Apportionment Board (WAB) based on advices of District Water Boards, Water Catchment Boards and technical advice from the Directorate for Water Development (Mogaka *et al.*, 2005).

I assume that the actors providing raw water are: *(i)* the Water Activity, and *(ii)* the Self-Providers.

(i) The Water Activity uses "Primary water" to produce[73] *three* water commodities:

- irrigation water (produced by NIB – part of Water Activity - which distributes it through public schemes),
- industrial water, and

[72] "Primary water" is simply the water factor which will be introduced in the recalibrated SAM (see section 4). From now on raw water and water factor have to be considered as synonyms.
[73] The production process consists of purification and distribution services (Kiringai *et al*, 2006).

- drinking water.

Those are consumed respectively by *three* groups:

- some agricultural activities (i.e. mostly rice (Ruigu, 1988), vegetables and fruits),
- manufacturers, and
- services and domestic users.

Furthermore, other activities are using irrigation water schemes - i.e. the Coffee sector (UN-WWAP[74], 2006) – and no payments are registered in the SAM.

(ii) Therefore, I introduce the Self Water Providers which fetch the "Primary water" they need with their own means. In other words, they don't access the market to buy any water commodity. They are:

- providing water through private (e.g. cut flowers producers) and smallholders' schemes (e.g. maize producers), or
- rain-fed and the value of the land they use crucially depends on the rainfall water[75].

The assumption regarding Water Activity and Self-Providers is coherent with what has been done in previous works (e.g. Sahlén, 2007 and Carzadilla *et al.*, 2008), with the SAM of Kenya and with the Kenyan irrigation structure.
Summarizing, water is modelled as:

- a *primary factor,* i.e. "Primary Water";
- an *output* of the Water Activity;

[74] The World Water Assessment Programme (WWAP), founded in 2000, is the flagship programme of UN-Water. Housed in UNESCO, WWAP monitors freshwater issues in order to provide recommendations, develop case studies, enhance assessment capacity at a national level and inform the decision-making process. Its primary product, the World Water Development Report (WWDR), is a periodic, comprehensive review providing an authoritative picture of the state of the world's freshwater resources.

[75] In both these interpretations, we will consider the value of water used by Self Providers implicitly embedded in the land account. This assumption is pivotal for the adjustment process of the SAM.

- an *intermediate input* for industrial activities (industrial water), selected agricultural activities (irrigation water - served by the NIB) and service (drinking water) sectors; and
- as a *final consumption good* (drinking water) for domestic users.

Prior to discussing the model and the simulations, I introduce two modifications in the SAM of Kenya to account for:

(*i*) the explicit consideration of water as a factor; and
(ii) the distinction among different water commodities produced by the *water activity* in order to better target sectoral water policies.

(i) Regarding the first modification it is worth to recall how other authors deal with considering the value of water. Some authors (i.e. Decaluwé, 1999; Tirado et al., 2003; Briand, 2004) consider a benchmark with zero price for water, assuming that the resource is not scarce – simulating then different pricing schemes (i.e. Boiteux-Ramsey[76], marginal cost pricing) and a water constraint.

The water constraint should be based on the actual available water. In order to find out the quantity of water used by each sector, one can infer - focusing on the theoretical efficiency level of water used per unit of output- the water productivity[77]. However, this theoretical figure will be different from the water effectively used. I am not considering the actual use of water by each single activity nor considering the theoretical water productivity based on the Kenya's topography. Instead, I am undertaking a more straightforward approach.

I consider the use of **"Primary Water"** in a fixed proportion with capital and land (following Berck *et al*, 1991 and Seung, 1999) depending on water coefficients assumed to be fixed. Therefore, I explicitly consider "Primary

[76] The Ramsey-Boiteux pricing consists of maximizing the total welfare under the condition of non-negative profit, that is, zero profit. In the Ramsey-Boiteux pricing, the mark-up of each commodity is also inversely proportional to the elasticities of demand but it is smaller as the inverse elasticity of demand is multiplied by a constant lower than 1 (ref.).
[77] AquaCrop is the FAO crop-model to simulate yield response to water of several herbaceous crops (http://www.fao.org/nr/water/aquacrop.html).

Water" by assuming payments for water as embedded in payments to other factors, typically capital and land.

- Regarding the payments that the **Self-Providers** make to get the raw water, they are assumed to be embedded in the rental value of land. This assumption is in line with the System of National Accounts (2008)[78] as the "Land" account embeds also raw water - if there is no other specification through water accounts. Therefore, I can extract payments for water from those for land (Sahlén, 2008). In order to explicit the rental value of water, the differential in the rental value of arid and umid land paid by different agricultural activities has been considered. In particular, I compared the rental value of one hacre of land used by the coffee activity (highly irrigated) and the rental value of one hacre of land cultivated by roots and tubers producers[79], as follow:

$$\frac{R_{l1}}{Q_{l1}} = r_{l1} \qquad (1) \qquad\qquad \frac{R_{l2}}{Q_{l2}} = r_{l2} \qquad (2)$$

$$r_{l1} - r_{l2} = w \qquad (3)$$

Where R_{l1} and R_{l2} are respectively the rental value of land paid by the activities producing "coffee" and "roots and tubers" (2003 SAM of Kenya)[80]; Q_{l1} and Q_{l2} are respectively the cultivated land by "coffee" and "roots and tubers" producers; r_{l1} and r_{l2} the rental value of land per hectar for the cultivated land by "coffee" and "roots and tubers" producers; w represents the differential

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[78] "*Land consists of the ground, including the soil coveringand any associated surface waters, over which ownership rights are enforced and from which economic benefits can be derived by their owners by holding or using them*" System of National Accounts (2008)

[79] Alternatively I have tried to use data on Value Added by single activities. Unfortunately the main data available were to aggregated (http://data.un.org/)

[80] Those activities have been considered because the first one is largely irrigated and the second is entirely rain fed and water resistant (FAO, 2005).

value of the land and it is assumed to depend just on land umidity. The differential value of land resulted to be around 20%.

Furthermore, we assume that each crop uses the optimal quantity of water at the benchmark (replicated by the SAM). Therefore, I specify three different levels of water use by agricultural activities[81]. A *"zero level"* refers for example to the production of sorghum and millet[82]. An *"intermediate level"* concerns for instance the production of seed oils. Finally, a *"high level"* of water regards for example the production of cereals and sugarcane[83].

- For the **Water Activity**, following Sahlén (2008), payments for raw water are derived from payments made for the factor "Capital" - as the SAM reports no payments from the Water Activity to the "Land" account. However, Sahlen (2008) considers as a proxy for the value of water as capital factor the average cost substained by households assuming that they were entirely paying for the water factor. Given this, payments for water made by water activity are assumed to be 20% of the payments for capital.

In this adjustment process, I take into account the value shares of water used by sectors: agricultural self providers use around 80% of "Primary Water" whilst the water activity – serving the other sectors – consumes the remaining 20%.

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[81] Here we implicitly define efficiency as productive efficiency. Therefore the more water intensive an activity is, the less efficient in the use of water.

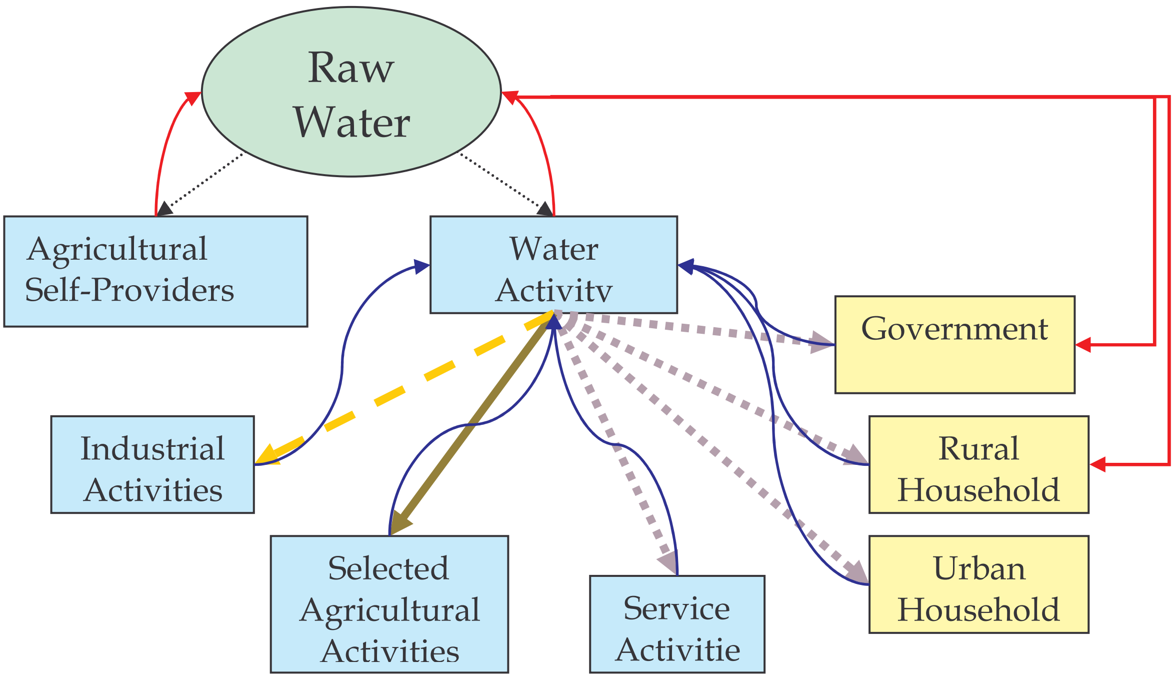
[82] In the SAM of Kenya grouped as "roots".

[83] Self providers using water more intensively are productions of: maize, wheat, barley, sugar, cotton coffee, tea and cut flowers. Those activities using less intensively water are productions of: oil seeds and roots. The agricultural production not using irrigation at all is the one of other cereals and roots. For the activities using water more intensively I assume a 20 percent of land payments corresponding to payments for water, in the second case the percentage is 7.5 whereas in the last is zero. I considered as a price benchmark the price of irrigation water for rice. I also made a sensitivity analysis giving less weight to the implicit value of water namely reducing the implicit payments for water. For the activities using water more intensively I assume a 10 percent of land payments corresponding to payments for water, in the second case the percentage is 5 whereas in the last is zero. I also conducted a sensitivity analysis with payments for water made by the Water Authority at 10% which is may be seen more appropriate level given the average cost of domestic water per person 260 Ksh/m^3 of the payments for capital.

The information on water intensity have been made available by Natural Resource Water and Land (NRWL) Division of UN-FAO.

Figure 9 shows the incidence of water expenditure – which depend on both sectoral payment for land and sectoral water intensity - on overall expenditure for those sectors using "Primary water". In the next section, I will see how the model allows for the substitutability of water with other inputs depending on the CES production function and on the closure rule for water.

Figure 8 - The Physical and Monetary Flows of Water



Flows of Water

Physical quantity: - Raw water
- Drinking water
- Agricultural water
- Industrial water

Payments for: - Primary water
- Water commodities

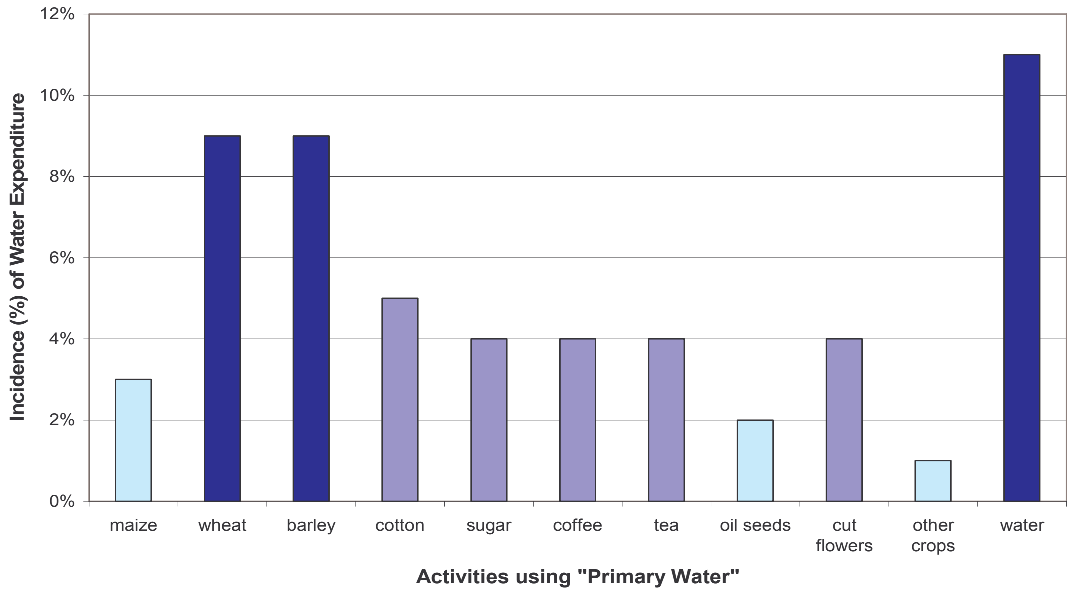
Source: own elaboration.

(ii) Regarding the adjustment referred to the creation of more water commodities (irrigation, industrial and drinkable water) - although some more complicated models have been used in order to distinguish between water production technologies (Decaluwé, 1999; Tirado, 2003, Briand, 2004 and 2007) – here, I just want to look at markets' segmentation for water. Therefore, I consider just one production process (and the same production function) providing three different types of water. The goal of this process is narrowing the scope of policy simulations. The payments from the agricultural activities using the public scheme; the industrial activities; and services, households and the government are registered as outflows for the use of water going to respectively: irrigation, industrial and domestic water. The three commodities in turn will remunerate the water activity.

Considering the remuneration side of the water value chain, water has a shadow value for households, mainly rural, and for GoK (figure 8). This shadow value is registered in the SAM as transaction values from "Primary water" account to households and GoK account. These adjusted transactions represent payments that the water owners would fetch if their water resources were to be sold[84]. Under the above assumption the incidence of shadow water revenues for the various categories of households was calculated as reported in figure 9.

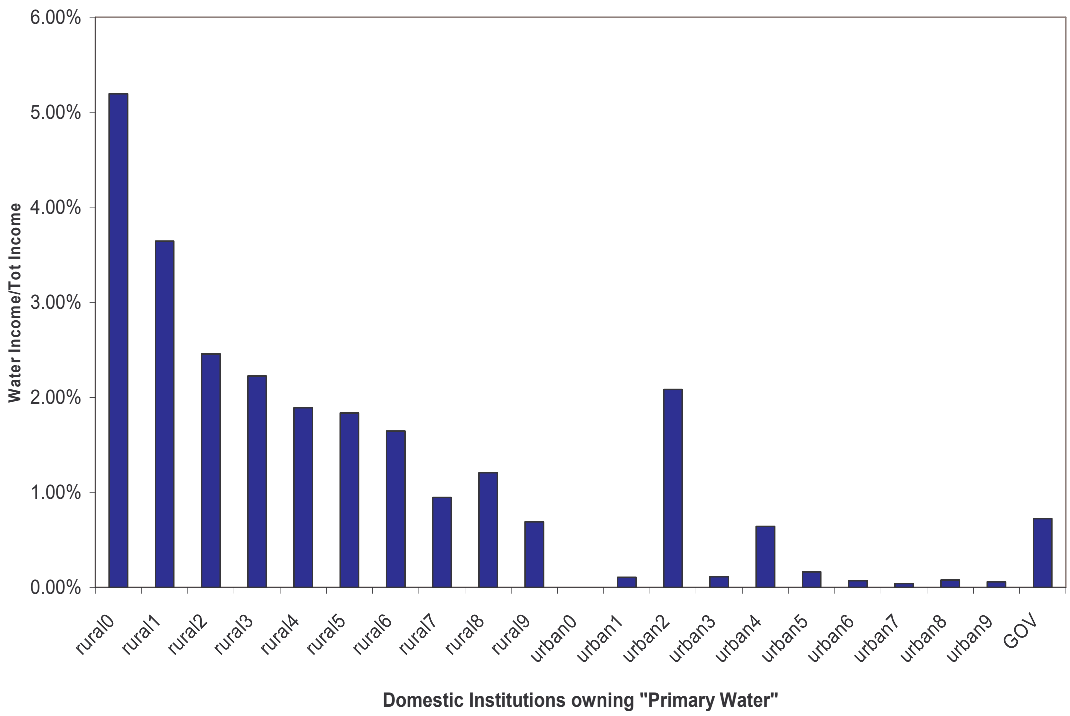
[84] This information on the way to interpret transactions from "Primary water" to institutions accounts is derived from the way the 2005/06 Kenyan Integrated Household Budget Survey (KIHBS) has been conducted with respect to the cost of land (Kenya National Bureau of Statistics, 2007)

Figure 9: Incidence of water expenditure on overall Self-Providers' sectoral expenditures



Source: 2003 SAM of Kenya

Figure 10: Incidence of Water Revenues on the Income of households and Government of Kenya (GoK)



Source: Own calculation on the 2003 SAM of Kenya.

4.3. The Model

I want to simulate the reaction of the Kenyan economy to a variation in the water endowment (sections 5.3) and to a drought scenario (section 5.4). The CGE model adopted for this study has been largely used for policy evaluation and macroeconomic analysis in a number of less industrialized countries[85].

The model is a set of simultaneous equations and is based on the standard neoclassical assumption on agents' optimizing behaviour and perfect markets. However, the model allows for a more realistic representation of an actual economy allowing for some market imperfections as for instance factor immobility and/or fixed wages[86]. The model is static and allows us to carry out comparative simulations: an exogenous shock on a given parameter determines the relative quantity to change and the economy to adjust to a new equilibrium. The model considers a nested production technology (Figure 11) based on substitutability among primary factors. Therefore, in order to capture both the economic implications of water policy simulations and the effects of exogenous shocks on water uses, there is the need to explicitly model water as a factor.

It is worth mentioning the crucial importance of the elasticity of substitution between factors. In the base model standard elasticities used by Loefgren (2001) for Malawi have been adopted. Specificly for Kenya, I used the elasticity of demand for domestic water - 0.16 for rural households and urban poor and 0.10 for urban non poor – estimated by Gulyani *et al.* (2005).

Furthermore, I will discuss the most important behavioural assumptions of the model[87]. In the sequel, I introduce some important ideas related to the system constraints with respect to factors, in particular to water.

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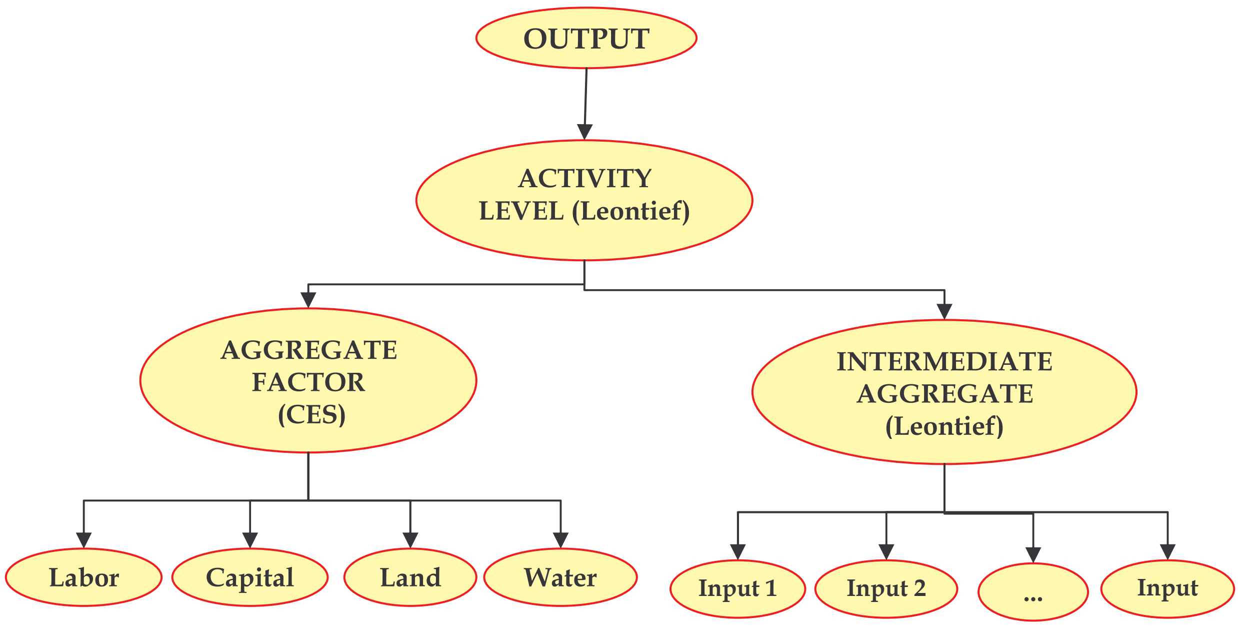
[85] For example in Malawi (Löfgren *et al.*, 2001), Namibia (Sahlén, 2007), Kenya (Marelli, 2008) and Burkina Faso (Bellú, 2009).
[86] See for example Van Heerden *et al.*, (2008) where a similar CGE model is used and the high level of low skilled workers unemployment is taken into account.
[87] For a full description of the model see Löfgren *et al.*, (2002).

Figure 11: Nested Production Technology



Source: own rielaboration on Löfgren *et al.* (2002).

4.3.1. Households

Households receive income from production factors and transfers from other institutions. Their consumption is equal to the net income after direct tax payments, savings and transfers to other institutions. Households maximize a Stone-Geary utility function subject to their disposable income:

$$U = \prod_c (q_c - y_c)^{\beta c} \qquad \text{st: } q_c * p_c \leq Y \qquad (4)$$

Where q_c is the total consumption of the commodity *c*, p_c *the price*, γ_c is the subsistence consumption and β_c is the relative weight of utility that consumer derives from spending on commodity *c*. *Y* is the consumer's income.

The use of this peculiar utility function implies that for each household a minimum level of each commodity must be consumed independently of its price.

Moreover, a CES Armington function also describes the imperfect substitutability between imports and domestic output sold domestically. In the (4), households arbitrate between domestic (QD_c) and imported products (QM_c) which is part of what is supplied (QQ_c) - with the other part being domestic produced exports – and entirely domestically consumed.

$$QQ_c = \alpha^q{}_c \, [\delta^q{}_c * QM_c^{-\rho^q{}_c} + (1-\delta^q{}_c) * QD_c^{-\rho^q{}_c}]^{-1/\rho^q{}_c} \qquad (5)$$

Where $\alpha^q{}_c$ is the Armington shift parameter, $\delta^q{}_c$ is the share parameter and $\rho^q{}_c$ is the CES function exponent. A fundamental assumption is that international supplies are infinitely elastic at given international prices. This aggregation allows for substituting between domestically produced goods and imported ones[88].

4.3.2. Production

Producers maximize their profit in a perfect competitive setting. Therefore they take the prices of output, production factors and other inputs as given; there is no extra profit as the level of production is such that average revenues are equal to average costs. This is implied by the fact that production displays constant return to scale. Domestic producers base their production decisions for either the national market or the international one on suppliers' revenue maximization principle, subject to a CET (constant elasticity transformation

[88] This specification has been criticized for being not flexible in terms of price and income responses, for giving strong terms of trade effects and finally for not allowing zero trade flows (Löfgren *et al*, 2002).

between domestic and export goods) function. Therefore, supply of exports depends on the relative price of exports with respect to domestic goods, which are imperfectly transformable:

$$QX_c = \alpha^t{}_c [\delta^t{}_c * QE_c^{-\rho^t{}_c} + (1-\delta^t{}_c) * QD_c^{-\rho^t{}_c}]^{-1/\rho^t{}_c} \qquad (6)$$

Where QX_c is the total domestic output, QE_c is exports QD_c is domestic sales of domestic output. Then $a^t{}_c$ is the transformation shift parameter, $\delta^t{}_c$ is the share parameter and $\rho^t{}_c$ is the CET function exponent.

In the model I use a Leontief function at the top of the technology nest, therefore I introduce here two equations: the demand for value added (7) and for aggregate intermediate input (8) which are both defined as Leontief functions of the activity level:

$$QVA_a = iv\alpha_a * QA_a \qquad (7)$$

$$QINTA_a = inta_a * QA_a \qquad (8)$$

Where iva_a is the quantity of value added per activity unit and $inta_a$ the quantity of aggregate intermediate input per activity unit.

It is worth mentioning that the different production factors are combined into an aggregate production factor (QVA) thorough a CES production function (figure 9):

$$QVA_a = \alpha^{va}{}_a \left(\sum_{f=1}^{n} \delta^{va}{}_{fa} * QF_{fa}^{-\rho^{va}{}_a}\right)^{1/\rho^{va}{}_a} \qquad (9)$$

Where QVA is the aggregate production factor required by each production sector, a. QF represents the quantity of each production factor used in the production process, a_a is an efficiency parameter, ρ_a is the CES function exponent which is calibrated using the elasticity of substitution[89]. The value added described by (9) is combined with intermediate inputs (see figure 9) using a Leontief specification, implying fixed proportion (7) and (8).

At this stage, I also introduce the Absorption equation (10) which is the total domestic spending on a commodity at domestic demander prices:

$$PQ_c * (1 - tq_c) * QQ_c = PDD_c * QD_c + PM_c * QM_c \qquad (10)$$

Where QQ_c is the quantity of good supplied to the domestic market (composite supply). QD_c represents the quantity of domestic output sold domestically. QM_c is the quantity of imports by commodity Absorption is expressed as the sum of spending on domestic output and imports at the demand prices, PDD_c and PM_c. The prices PDD and PM include the cost of trade inputs but exclude the commodity sales tax.

4.3.3. Other Institutions

Domestic institutions directly earning income from productive factors are: households, enterprises and the government[90]. Equation (11) represents the institutional factor incomes:

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[42] The CES elasticity of substitution is $\sigma = 1/(1+ \rho_c)$. A high (low) elasticity in one sector implies that a change in the ratio of prices between the domestically produced good (competing with the imported one) and the imported good will have a strong (slight) substitution effect. In other words there will be a high (low) responsiveness of trade flows to relative price changes (see Annex 3).

[90] Also the RoW may earn from factors but indirectly (i.e. through transfers from enterprises).

$$YIF_{if} = shif_{if} * [(1 - tf_f) * YF_f - trnsfr_{rowf} * EXR] \tag{11}$$

In equation (11), the income of each factor is divided among domestic institutions (households, enterprises and Government) in fixed shares after payment of direct factor taxes and transfers to the Rest of the World (RoW) (in foreign currency thus multiplied by EXR - the exchange rate – in order to be transformed into domestic currency). Enterprises do not consume and their incomes are allocated to direct taxes, savings and transfers to other institutions – typically households, government and RoW. RoW pays for exported commodities and receives money for those imported. The government levies taxes on commodities, imports, production, factors, households and enterprises. The government saves, consumes market goods and transfers payments to enterprises households and the RoW.

4.3.4. Factor Markets

I finally introduce the factor markets equation (12):

$$\sum_{a \in A} QF_{fa} = \overline{QFS}_f \tag{12}$$

Where $\overline{QFS}_f$ represents the quantity supplied of factor (exogenous variable) and $\sum_{a \in A} QF_{fa}$ is the aggregate demand for factor "*f*". As mentioned I want to introduce water as a factor, such that: $f \in F$ *where F {Land; Capital; skilled, semi-skilled, unskilled Labour; Land; and Water}*.

For a complete description of the Model see Appendix 4.

4.3.5. Macroeconomic Closure Rules

The closure rules define which variables have to be considered as exogenously fixed and which ones have to be treated as endogenous.

Table 1: Alternative Closure Rules for Macro-Economic Constraints

Government	Rest of the World	Savings-Investment
GOV-1: Flexible government savings; fixed direct tax rates.	ROW-1: Fixed foreign savings; flexible real exchange rate	SI-1: Fixed capital formation uniform MPS point change for selected institutions
GOV-2: Fixed government savings; uniform direct tax rate point change for selected institutions	ROW-2: Flexible foreign savings; fixed real exchange rate	SI-2: Fixed capital formation; scaled MPS for selected institutions
GOV-3: Fixed government savings; scaled direct tax rates for selected institutions		SI-3: Flexible capital formation; fixed MPS for all non government institutions
		SI-4: Fixed investment and government consumption absorption shares (flexible quantities); uniform MPS point change for selected institutions
		SI-5: Fixed investment and government consumption absorption shares (flexible quantities); uniform MPS point change for selected institutions

Source: Loefgren *et al.* (2002)

In table 1 are described the alternative closure rules that can be used for CGE models.

With respect to the government closure, I have chosen to keep fixed the level of taxation (GOV-1): government savings (the difference between current government revenues and current government expenditures) is a flexible residual while all tax rates are fixed meaning that redistribution policies will be

founded through debts. Given that, as it had happened in the past, in case of a severe drought the International Community intervenied with cash trasfers this is plausible.
Regarding the exchange rate, I have chosen to keep fixed the current account with the real exchange rate free to fluctuate (ROW-1). This is due to the fact that the actual Kenyan exchange rate policy follows this path. Moreover, the choice of such a closure is more appropriated for a welfare analysis given there is no room for giving a "free lunch". This assumption implying that Kenya cannot increase foreign borrowing but has to generate export earnings in order to pay for imports (Thurlow et al., 2007). In other words there is no "free lunch" opportunity for Kenyan economy.
The last macro-closure will be Investment Driven (SI-2) with fixed savings and scaled Marginal Propension to Save for selected institutions (Lofgren *et al.* 2002).

Regarding the closure for factors of production "skilled" and "semiskilled" labour" are considered fully employed and free to move among different sectors of the economy – while the "unskilled labour" is partially unemployed. "Capital" is considered fully employed and sector specific, while "Land" fully employed and mobile among agricultural sectors.

5. GENERAL EQUILIBRIUM ANALYSIS

5.1. The Simulation Scenarios

I introduce now the simulations which have been implemented and grouped into three sets: (a) exogenous shocks; (b) policy simulations; and (c) combined simulations.

(a) **exogenous shocks** on water endowment

(a.1) In the light of the observed increasing droughts affecting Kenya through the last two decades[91] - **Reductions** in water endowment by 10, 30, and 50 percent ("SCARCE") - (table 2);

(a.1.1) I implement a comparison between two scenarios where two closure rules for water are compared: "SCARCE" with "water transfer" vs. "SCARCE" with "no water transfer" settings. Allowing for water transfers means that water is mobile: activities can vary their share in water consumption with respect to the benchmark[92].

(a.2) **Increases** in water endowment by 10, 30, and 50 percent ("ABUND"), e.g. due to mitigation measures – such as soil and moisture conservation interventions – or to the better exploitation of the irrigation potential, mentioned in section 3.4. (table 2).

(a.3) Reduction of water endowment by 30 percent[93] associated to a reduction in land endowment by 5 percent - in consideration of the land degradation caused by lack of water – and to *two* shocks on

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[91] See note 12. For further readings on drought effects in Sub Saharan Africa (SSA) look at FAO (2006).

[92] Even if there is no trade of water we use the terminology following Berck *et al*, 1991.

[93] According to the experts of UN-FAO's Natural Resource Land and Water Division (NRLW), a reduction of water given by the recent 2009 droughts during the cropping season might be, on average, estimated in a reduction of 200mm/yr on average. Thus we can assume given that the average precipitation are around 600mm/yr a reduction of around 30 percent to be plausible.

productivity: technical coefficients of the production function are calibrated, in order for the cumulative effects of sectoral productivity reductions to decrease of *(i)* about 39% the maize production[94]; *(ii)* around 35% the pastoralists' activities[95] ("DROUGHT") - (table 3).

The exogenous shocks simulated in the "DROUGHT" scenario are even more relevant in the light of the lack of regional specification within the model. For instance, considering exogenous shocks on pastoralists' activities - mainly located in ASAL (areas where communities and their economic activities are suffering the most for droughts) seems to be a quite good proxy of a regional specification when analysing the effects of droughts. Moreover, this kind of exogenous shocks indirectly allows taking into account the skewed water availability.

Table 2: "SCARCE" & "ABUND" Scenarii

Scenarios/ Sets of Change in Water Endowment	1	2	3
"SCARCE" *(a.1)*	-10%	-30%	-50%
"ABUND" *(a.2)*	+10%	+30%	+50%

[94] According to the Agricultural Minister William Ruto, the estimated figures for reduction in maize production range from 24 to 40 percent (http://www.newvision.co.ug/D/9/32/692523). The Regional Agriculture Trade Intelligence Network (RATIN) is even more drastic estimating maize production for 2009 at 2.4 MT (Million Tonnes) 90 percent below the production level of 2008 long rain season (http://www.ratin.net/mainfeature.asp?id=25). According to The World Bank (Mogaka *et al.,* 2005) in 1999, the country realized only the 69% of the expected maize harvest because of the droughts

[95] The reductions in the sectoral output levels are obtained by exogenously modifying the *alphava* – the shift parameter for CES activity production function (see equation (7) in section 5.2.). We fix the reduction in output produced by some relevant ASAL's activity - namely dairy (-48%), beef (-23%), goat (-38%), poultry (-29%), and other livestock (-36.3%) sectors and maize sector (-39%) - on the bases of what has been observed in previous droughts by the Ministry of Agriculture (MoA), the Regional Agriculture Trade Intelligence (RATIN), the World Bank (Mogaka *et al.*, 2005) and Aklilu and Wekesa (2001). Therefore, we consider cumulative shocks on those ASAL activities all together in order to obtain the given output contractions.

Table 3: "DROUGHT" Scenario – The cumulative effects of several shocks[96]

	water	land	maize	beef	dairy	goat	other livestock	poultry
"DROUGHT" *(a.3)*	-30%	-5%	-39%	-23%	-48%	-38%	-36%	-29%

b) In addition to the mentioned exogenous shocks, I analyze three sets of **policy simulations**.

b.1) **fiscal policy** ("POL"). It represents the imposition of a distortionary output and factor income taxes over either the primary water or the different water commodities[97]. The objectives of the different taxes are fostering the cost recovery strategy and improving the efficiency in the use of water. The tax rates are set up, at the benchmark, in order to generate three level of extra revenue: *(i)* 4.2, *(ii)* 7.1 and *(iii)* 42.5 Million of Kenyan Shillings[98] (M Ks), respectively the 0.2, 0.34 and 2 percent of the total current GoK income - by fixing different tax rates for different types of water. These tax rates are then used to simulate the imposition of taxes on Primary Water, on industrial water and on drinking water[99]. The different level of extra revenue have been fixed by considering the World Bank estimation of economic damages provoked by La Niña drought (1998-2000) for: managing the water cross boundaries related conflicts[100] (around 4 M Ksh), the restocking of livestock (around 7 Mil Ksh) and the reconstruction of forests and the reconstitution of aquaculture production (around 40 M Ksh) (Mogaka *et al*, 2005) - (Table 4).

[96] It is worth stressing that the exogenous shocks in *a.3* simulation just refer to water and land resource, the other shocks are the general equilibrium results we were looking for to adjust sectoral productivities on the bases of previous droughts (see note 90).

[97] see equation (8) section 5.2 for the tax on water commodities and equation (9) section 5.3 for the tax on the water factor.

[98] Respectively around 55'851, 94'414 and 565'160 US Dollars – 1$ = 74.9 Kenyan Shillings.

[99] The simulation regarding irrigation water won't be presented. As this kind of water is assumed to serve just rice, vegetables and fruit producing activities it would be too higher to reach the fixed extra revenue considered here – 0.34% of the actual Government expenditure.

[100] Especially between Uganda and Kenya (Aklilu and Wekesa, 2001)

Table 4: Fiscal Policies (Millions of Kenyan Shillings = M Ks)

level of extra revenue/ Taxes	4.2 M Ks	7.1 M Ks	42.5 M Ks
Primary Water	6.6%	11%	65.7%
Industrial Water	7.3%	12%	66.3%
Drinking Water	6.4%	10.5%	43%

b.2.) I mainly focus on welfare effects, narrowing down on the rural households. Therefore the second policy simulation refers to the **redistribution of this extra revenue** to the four poorest rural household groups (PRH)[101] through cash transfers ("REDISTR1") - (Table 5).

b.3.) Additionally, I look at the **cash transfers** the PRH would need to reach their pre-drought level of welfare[102] ("REDISTR2") – (Table 5).

b.4) Finally, I describe the effects of the implementation of the ***"Arid Land Resource Management Project"*** *("ALRMP")* (see section 5.7.).

Table 5: Redistribution of extra revenue (Millions of Kenyan Shillings = M Ks)

Simulations' sets/ Poor Rural HHs	HRUR0	HRUR1	HRUR2	HRUR3	HRUR4
"REDISTR1"	1.42 M Ks	1.42 M Ks	1.42 M Ks	1.42 M Ks	1.42 M Ks
"REDISTR2"	43.6 M Ks	54.5 M Ks	83.1 M Ks	103.8 M Ks	120.3 M Ks

c) **Combined simulations** are also performed: (Table 6)

c.1): "SCARCE" with "POL";

c.2): "SCARCE" with "POL" and "REDISTR1";

c.3): "DROUGHT" with "POL" and "REDISTR2"; and

[101] The subset named 'PRH' is purposely created and comprehends 'hrur0', 'hrur1', 'hrur2', 'hrur3', 'hrur4'.

[102] Here we do not want to assess the issue of financing the transfers but rather compare our results with what has been spent in emergency food aid assistance during previous droughts (see section 2.4).

c.4): "ALRMP" project with "DROUGHT" – ("DR-ALRMP")

I focus on factors' remuneration, output, prices and external current account changes under the simulations' scenarios. Besides, I carry out a sensitivity analysis on water intensity uses (i.e. modifying the elasticity of demand for water commodities, the substitutability between productive factors, and factors' closure rules) and on a reduction of 70% in water endowment.

Table 6: Combined Simulations

	"SCARCE"	"DROUGHT"	"POL"	"REDISTR1"	"REDISTR2"	"ALRMP"
c.1	X		x			
c.2	X		x	x		
c.3		x	x		x	
c.4		x				x

5.2. Simulations' Results

In the analysis of the results, I consider the effects of the simulations described above:

(a) exogenous shocks - "SCARCE", "ABUND" (section 7.1), and "DROUGHT" (7.2), "SCARCE" with "water transfer" vs. "SCARCE" with "no water transfer";

(b) policy simulations - "POL" (7.3), "REDISTR1", "REDISTR2" (7.4) ; and

(c) combined simulations – *c1)* (7.3.1); *c2), c3)* (7.4); and *c4)* (8.2); on:

1) Factors' Remuneration – contextually, for the unskilled labour, instead I will consider its changes in quantity since it has fixed price;

2) Sectoral Output - focus on *agricultural activities* - i.e. tea, coffee, and cut flowers (namely those market/export oriented sectors using water quite intensively); maize (staple food), and "other crops" (e.g. beans); and on *water activity*.

3) Relative Prices of water commodities - the Consumer Price Index (CPI) being the numeraire;
4) Government Deficit; and
5) Welfare Effects - computed in terms of Households' Equivalent Variation (EV)
6) Current Account.

First, are considered results more intuitive, secondly the most sensity distributional outcomes from the welfare analysis.

An important premise is that instead of looking at the magnitude of the single quantitative effect, the analysis will be rather focused on the sign of that effect and on the context in which it is found.

5.3. Scarcity & Abundance Scenarios

1) Within the "SCARCE" scenario *(a.1)*, *water remuneration* increases with the reductions of the water endowment (table 7), which provokes a negligible reduction of other labour wages and land rent. The remunerations of skilled, semi-skilled labour and land - factors fully employed and mobile across sectors - slightly reduce. As the price for unskilled labour is fixed, for this very factor I consider the quantity which slightly reduces[103]. This is due to a generalized contraction of production – especially in the service provision.

Within the "ABUND" scenario *(a.2)*, the reduction of water return is less pronounced in absolute terms than under the "SCARCE" one. An increase of other factors' remuneration (skilled, semi-skilled labour and land*)* is caused by the expansion of the economic activity. The market for unskilled labour - as it has fixed wage - increases since the different activities expanded their demand

[103] For water endowment reduction of 10, 30, 50 percent, the reduction in unskilled labour quantities are respectively of -0.09%, -0.28% and -0.51%.

for it[104]. Anyhow, the negative impacts of water endowment reduction are bigger in absolute terms than the positive effects of higher water availability for the economy.

Table 7: Changes (%) in Factors' Return for the "SCARCE" and "ABUND" Scenarios

	"SCARCE"			"ABUND"		
Changes in Water Endowment	-10%	-30%	-50%	10%	30%	50%
Water Remuneration	7.46	27.6	60.62	-6.30	-16.40	-24.17
Skilled Labour Wage	-0.20	-0.65	-1.20	0.19	0.53	0.84
Semi-Skilled Labour Wage	-0.06	-0.12	-0.37	0.06	0.17	0.28
Land Rent	-0.15	-0.48	-0.88	0.14	0.38	0.60

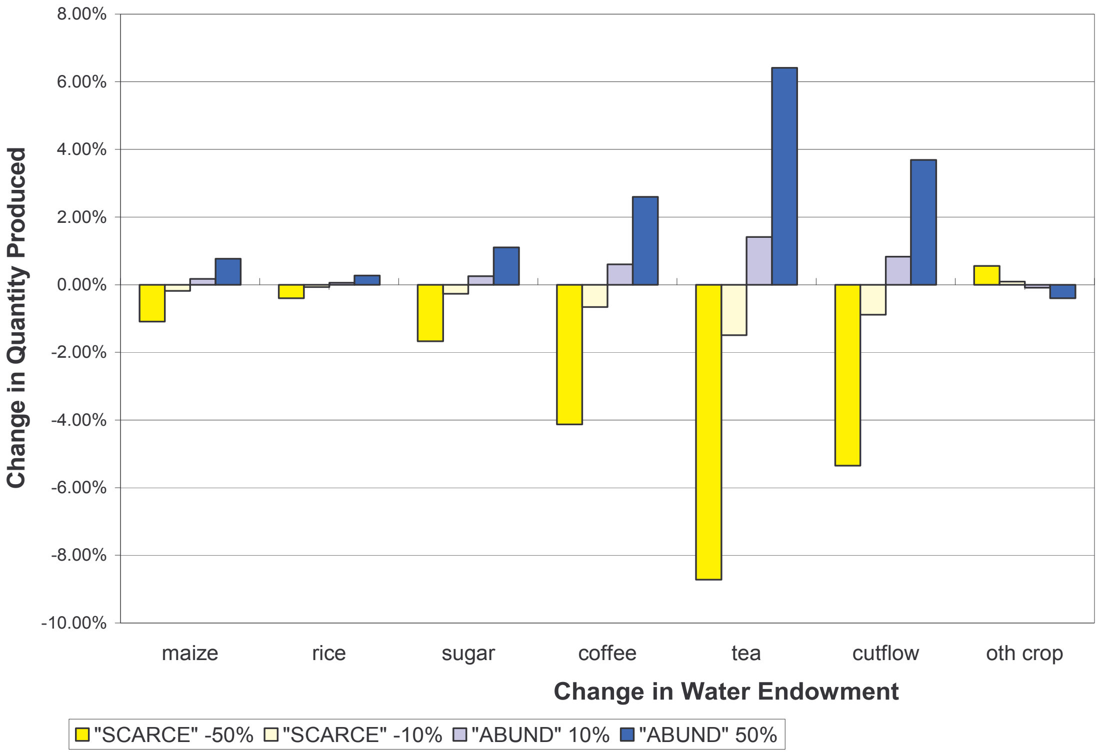
2) Moreover under "SCARCE", the *output* slightly reduces[105] with a decrease of water endowment whereas under "ABUND" it slightly increase. Considering *sectoral output* in "SCARCE", the sectors which reduce their output the most are tea, cut flowers and coffee – but also sugar and maize (figure 12). Moreover, relatively less water intensive activities – as other cereals, other crops and vegetables - are those producing slightly more in the agricultural sector under this very scenario.

This behaviour is exactly reversed in "ABUND". The agricultural production is more affected by the reduction in water endowment than the industrial and the domestic water consumption. This is particularly true for those sectors self providing the water they use (see figure 12).

[104] For water endowment increase of 10, 30, 50 percent, the increase in unskilled labour quantities are respectively of 0.08%, 0.23% and 0.37%.

[105] For a 10% reduction the decrease in output is just of 0.09%; 0.3% for a 30% reduction and 0.55% for a 50% reduction.

Figure 12: Change in Quantity Domestically Produced (%) by Selected Activities



Furthermore, regarding the changes in water output, I compare within "SCARCE" scenario, two different settings allowing for water transfers or not, as described in *(a.1.1)*. Figure 13 describes the change in water quantity demanded by the different sectors – the Self-Providers and the Water-Activity – switching from the "no water transfers" to the "water transfers" setting. Some water intensive sectors (figure 9) - the water activity, maize, barley, cotton and sugar sectors – use increasingly more *quantity of water* with respect to the other sectors when the water endowment reduces.

Figure 13: Changes (%) in Quantity of Primary Water with "Water Transfer"

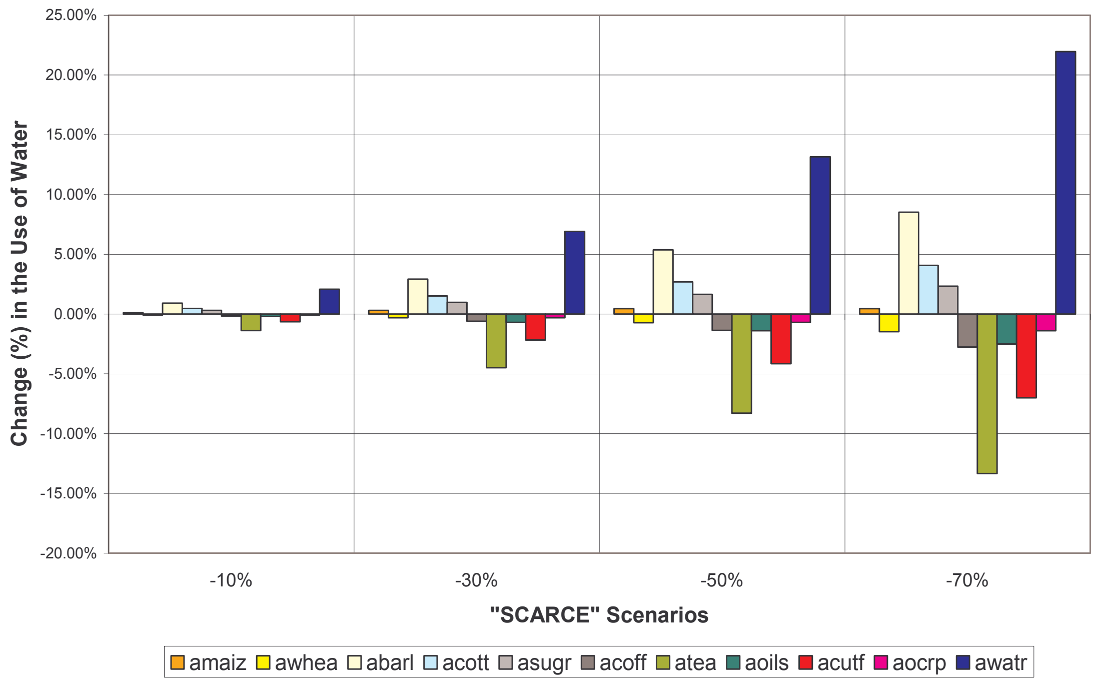
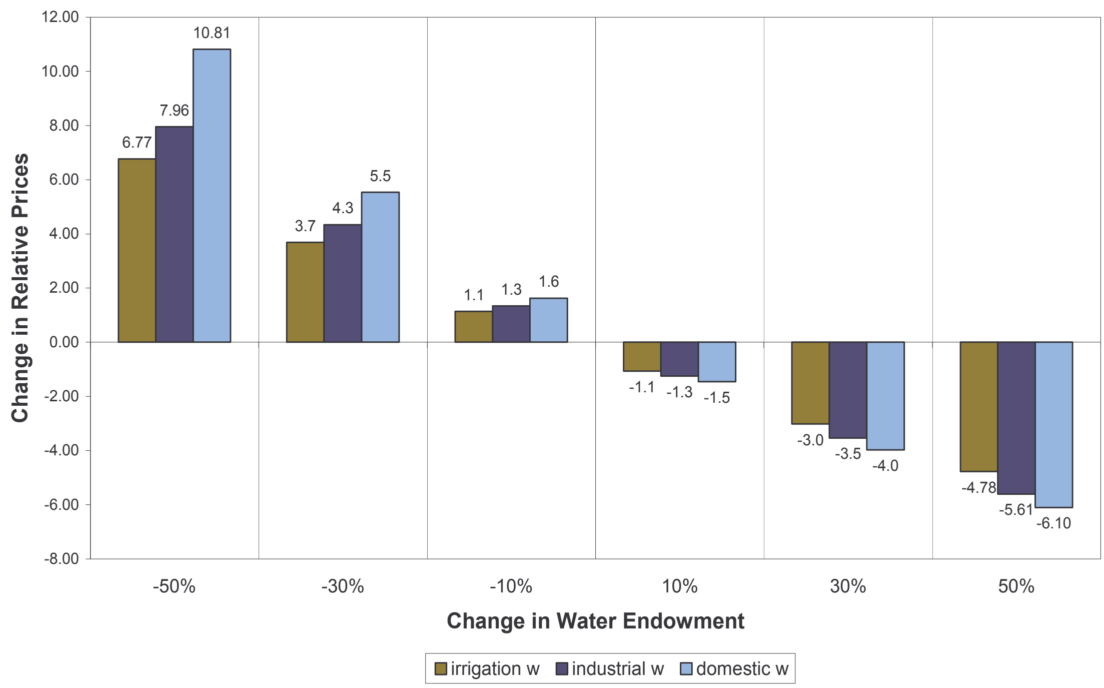


Figure 14: Changes (%) in the Relative Price of the three Water Commodities

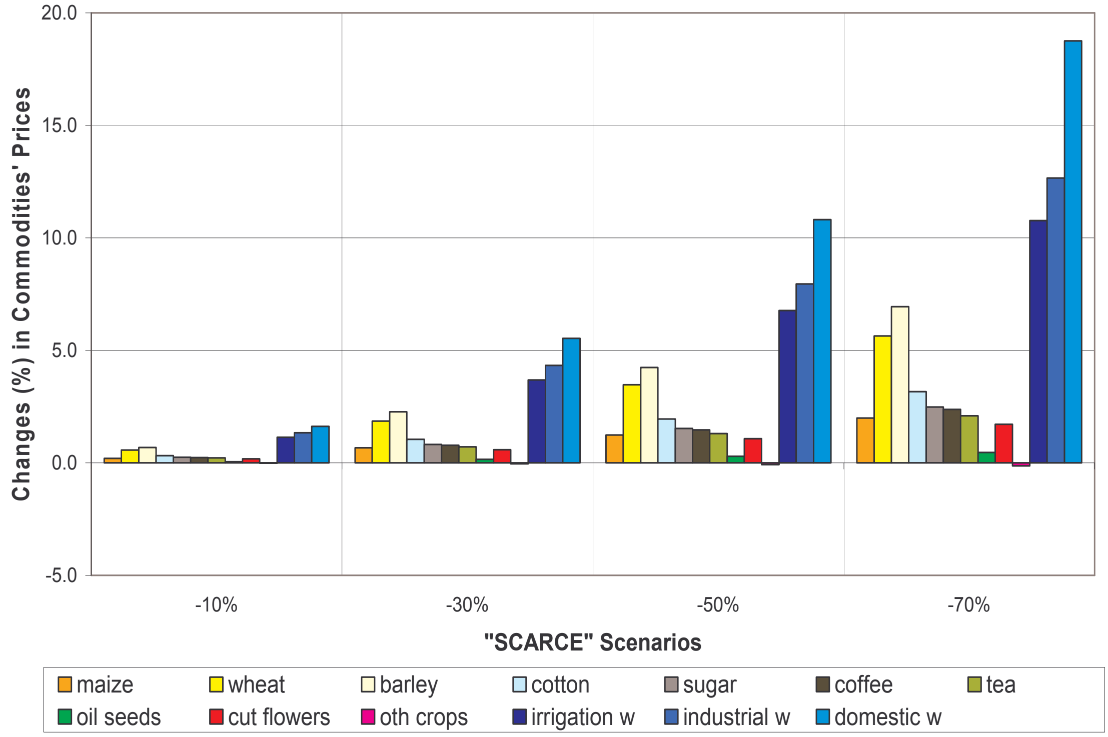


3) Looking at the reaction in terms of *relative prices*, the commodities more affected by the reductions of water endowment *(a1)* in terms of change in

relative prices are domestic, irrigation and industrial water (figure 14). For any reduction of water availability, the price of domestic water is steadily higher than all other prices. Furthermore, the less the water available, the more its price increases in comparison with the ones of industrial and irrigation water. This indicates that when the resource becomes extremely scarce, drinkable water is an even more important resource. The higher variability of the price of domestic water reflects the more rigid demand for this commodity with respect to the others.

In looking at Figure 15, it is worth recalling that the increased price of irrigation water commodity is not directly reflected by the change in relative price of commodities produced by Self-Providers.

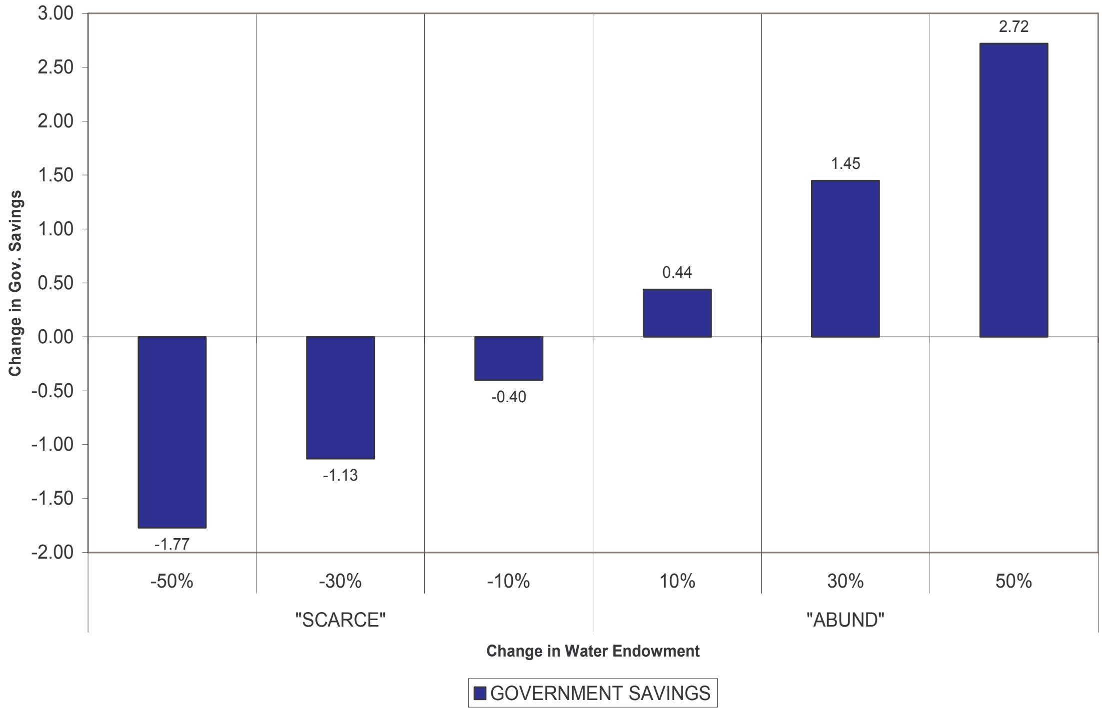
Figure 15: Changes in Relative Prices for those commodities produced by both Self-Providers and Water Activity



Moreover, figure 15 shows how the self Providers do not seem to be very affected by the water endowment reduction. The activities using irrigation water, provided by the NIB (part of the Water-Activity), are even less affected in terms of change in output (figure 19b) notwithstanding that irrigation water price increases widely with water endowment reductions.

4) Regarding *government deficit*, in the case of "SCARCE" it slightly (0.44%) enlarges due to a decline of economic activities. On the contrary, it slightly (0.4%) reduces when the Kenyan economy expands as described in the "ABUND" scenario (figure 16).

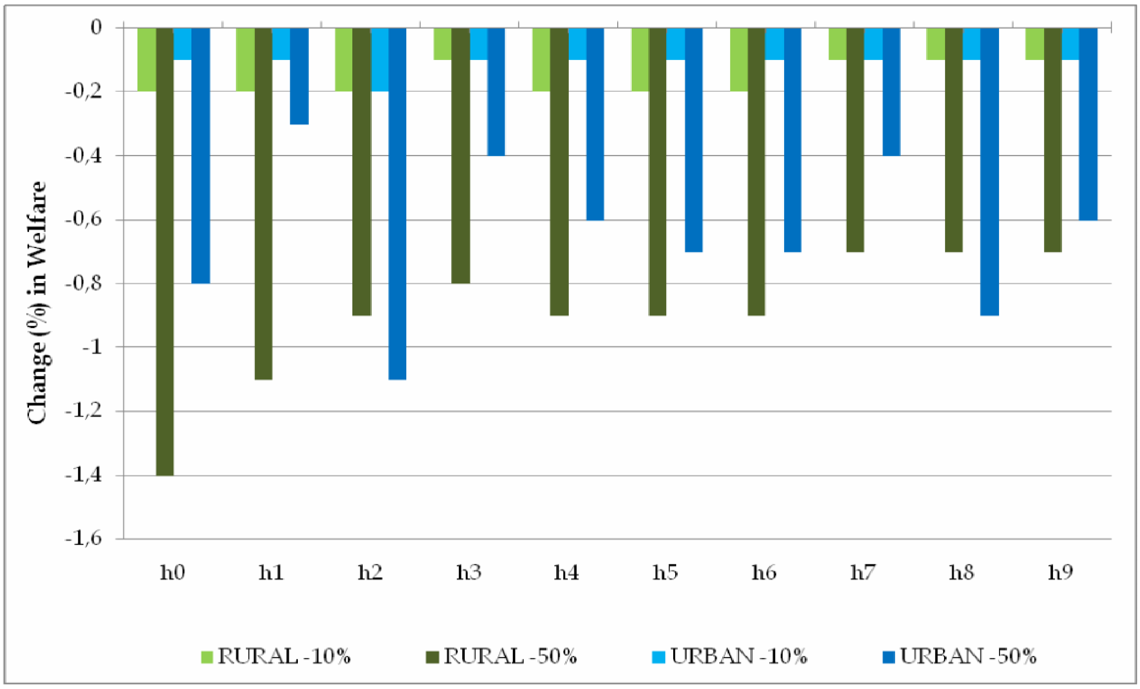
Figure 16: Change in Government Savings



5) Considering *welfare effects*, with decreasing water endowment *(a.1)* rural poor households increasingly suffer more, relatively to the others (see figure 17a). A 10 percent reduction provokes a decrease just slightly more marked for rural households than for urban ones. Instead, with a 30 percent reduction of water availability, rural households loss in terms of welfare are up to four times those of urban ones – as the rural dwellers are getting revenue from "primary water",

through the mechanism transmission described in Figure 8. The behaviour is confirmed by the simulation of 50 percent reduction of water endowment.

Figure 17a: Welfare Changes (EV) due to Water Scarcity

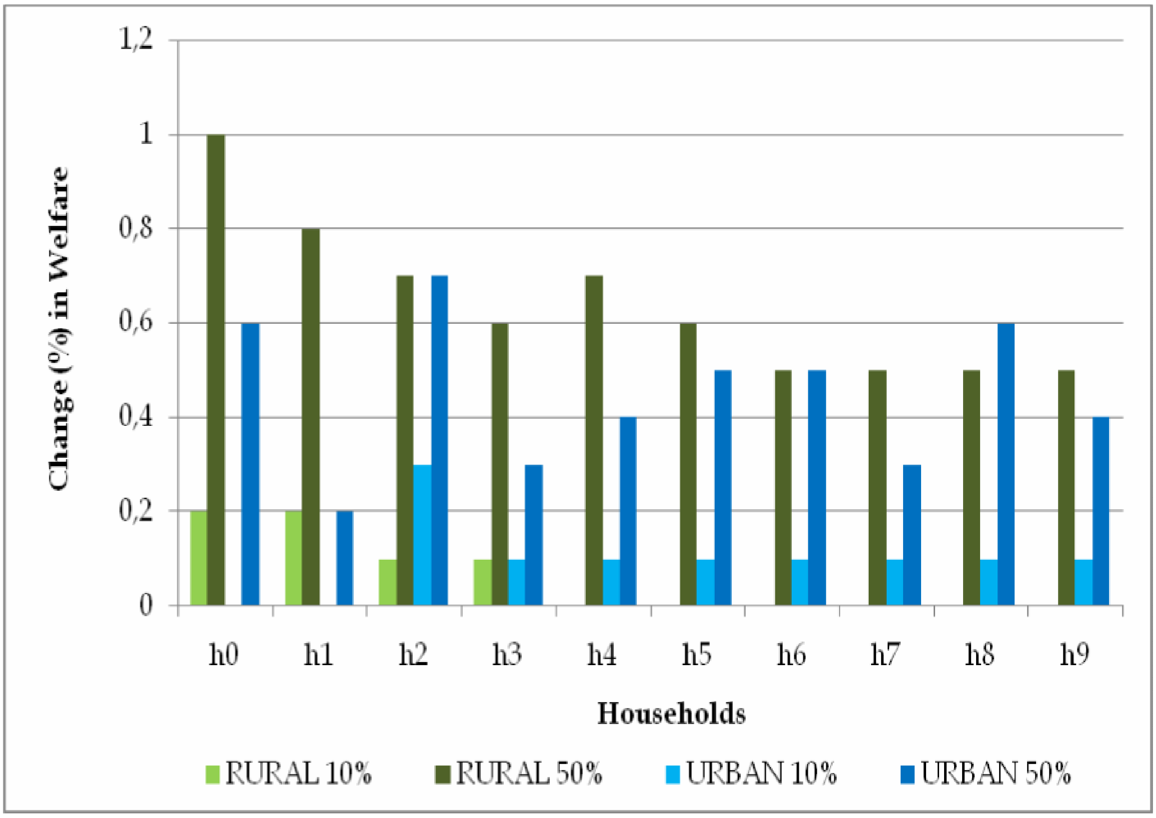


All the households benefit from an increase of water supply *(a.2)* as expected. Moreover, as the quantity of water provided further increases, the benefits for rural households become much higher than those for urban. Increasing water endowment *(a.2)* determines (Figure 17b) a generalized slightly positive effect for both rural and urban households, for a 10% increase, with the poorest rural households ("h0" and "h1") benefiting more. If the increase of water endowment is of 50%, all the rural dwellers are better off with respect to the urban ones (but for the eighth decile).

However, it is worth recalling that urban dwellers are consuming proportionally much more water for domestic purposes (38%) than rural ones

(3%)[106]. Moreover, the incidence of expenditure for agricultural commodities on the total income is higher for rural households (25%) than for urban (7%).

Figure 17b: Welfare Changes (EV) due to Water Abundance



[106] Government (15%) and services (38%) are also using the so called domestic water.

Figure 18a: Reduction (%) in Output for those activities using "Primary Water"

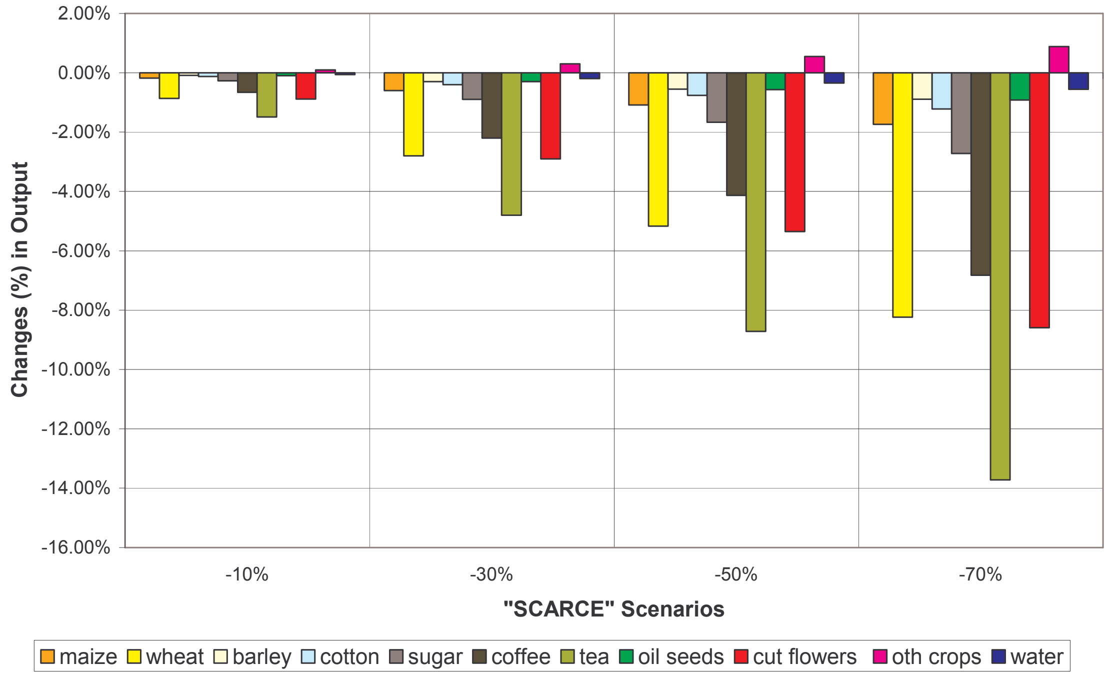
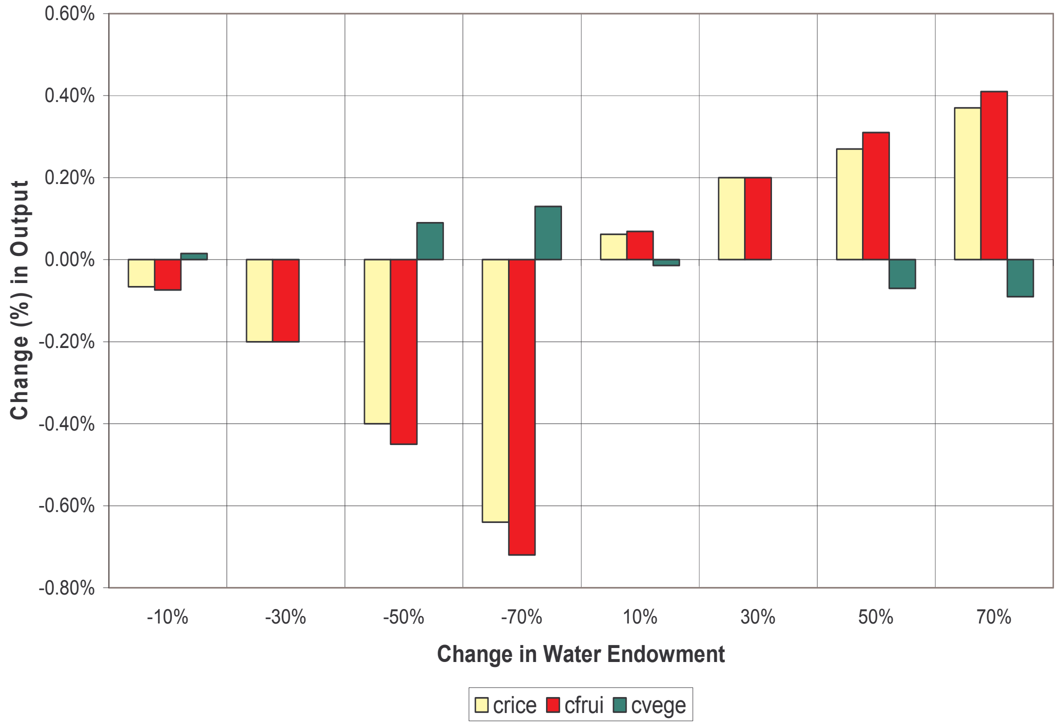


Figure 18b: Changes (%) in Output for those activities using "Irrigation Water"



From the analysis of the "SCARCE" and "ABUND" scenarios - I can summarize as follow.

Firstly, Enhancing availability of water is not just a rural development strategy – as it is more beneficial for rural households – but it also obey to a poverty reduction strategy as the more positively effected are the poorest households.

Secondly, rural poor are increasingly worse off with respect to the urban dwellers in the case of reduced availability of water. The differences are even more skewed if the water provided is further reduced behind a certain threshold (from 30 percent water reduction in the simulations). However, as the distribution of income is more skewed in the urban context, the effects of reduced water availability exacerbate this feature of Kenyan economy.

Thirdly, changes in water availability, with "Primary water" free to move among sectors, widen the distinction among more and less water intensive sectors. The largest part of water reallocated - after simulating a reduction in water endowment - is absorbed by the Water Authority and subtracted to less water demanding sectors. Moreover, reducing further the water endowment (-50 percent), even sectors relatively water intensive and export/market oriented in turn reduce their water use. This is due to the elasticity of demand. The more the demand is rigid, the more those water intensive sectors will increase their consumption in the "water transfer" setting than in the "no water transfer" one. Therefore, the changes of domestic water relative price are steadily stronger than those of industrial and irrigated water.

5.4. The Drought Scenario

A reduction in water endowment *tout court* tends to underestimate the importance of water and the dramatic incidence of droughts for Kenyan economy (see 2.4. and 7.1). Thus, I add another set of exogenous shocks considering a wider range of perturbations caused by persistent droughts: namely "DROUGHT".

1) Regarding *factors' remuneration*, the reduction of water endowment along with side effects[107] *(a.3)* determines an increase in water return of 53.9%. Furthermore, the rental value of land increases too as it becomes a scarcer resource – with respect to the base scenario - because of the droughts. Additionally, wages for skilled and semi-skilled labour reduce as they become relatively more available than other factors.

2) This is due to the strong and generalized contraction in *output* of those activities suffering from decrease in water endowment: they produce less because of the rising cost of water and given the contraction of intermediate and final demand. The GDP sensibly reduces (almost -16%) and this is mainly due to the contraction of rural activities that need fewer inputs. Concerning the production levels, the "DROUGHT" scenario highlights a generalized reduction in agricultural activities with respect to the "SCARCE" scenario. This is due to the strong contraction of maize production. Beside the already mentioned sectors – namely coffee, tea, and maize - also sugar, cotton, livestock and dairy sectors are harshly hit. The sectors less influenced by negative effects of drought are "rice", "other cereals", and "water" activities (figure 19).

3) Furthermore, I look at *relative prices* of some selected commodities (figure 20a) with the Consumer Price Index as the Numeraire. Then I focus on water commodities (figure 20b). In the "SCARCE" scenario (-30% of water endowment) the demand for water commodities is more rigid than those for other commodities, thus the increase in price is higher (figure 20a). In the "DROUGHT" scenario, the GDP sensibly reduces (almost -16%) and this is mainly due to contraction of rural activities production. However - due to the rigidity of demand and the low incidence on the budget of households and

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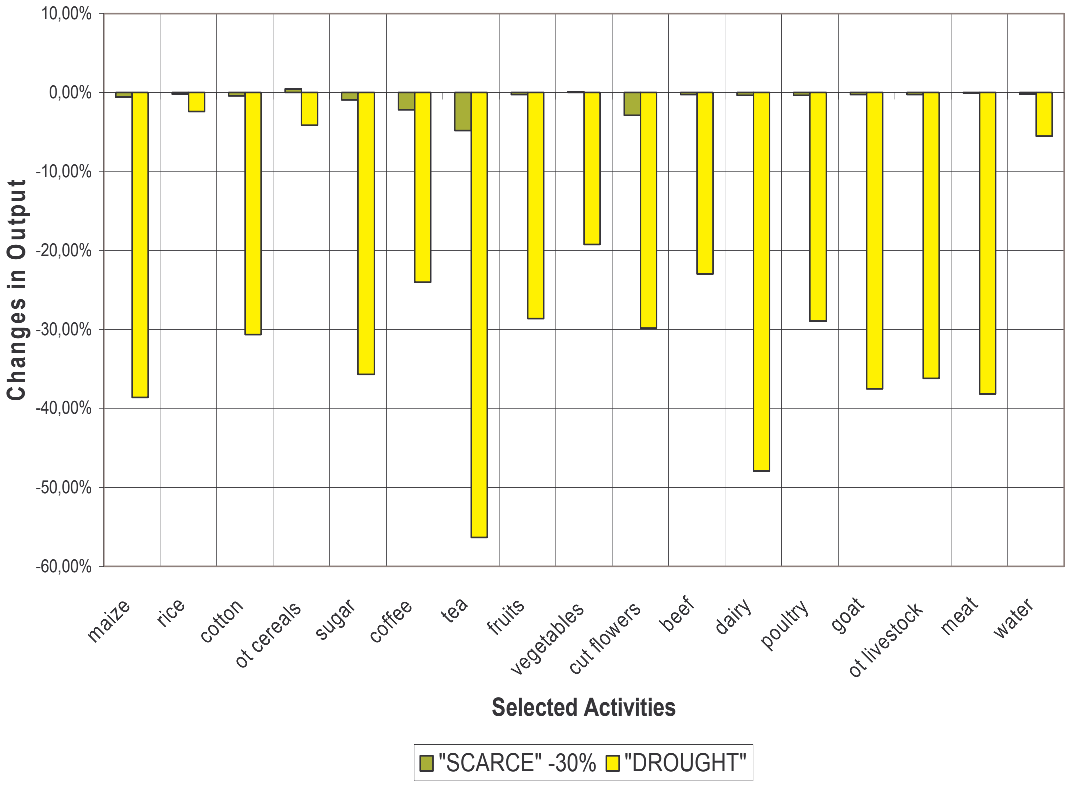
[107] Reduction of maize and pastoralists' productions, degradation of land.

services' activities (i.e. tourism) of domestic water - its price is the only one that drastically increases[108] together with the relative prices of livestock activities (but poultry), maize and meat production and milling activities (figure 20a). This latter price is high (in "DROUGHT") because of the reduced production input (especially maize).

Figure 19: Changes in Sectoral Output for Selected Activities[109]



[108] The other relative prices that increase are those of the livestock's activities (namely: dairy, goat, beef, meat production and other livestock) which are exogenously shocked and the price of barley (+3.9%).

[109] Recall that "fruits", "rice" and "vegetables" productions are served by the "water activity"

Figure 20a: Change in Prices of Selected Commodities

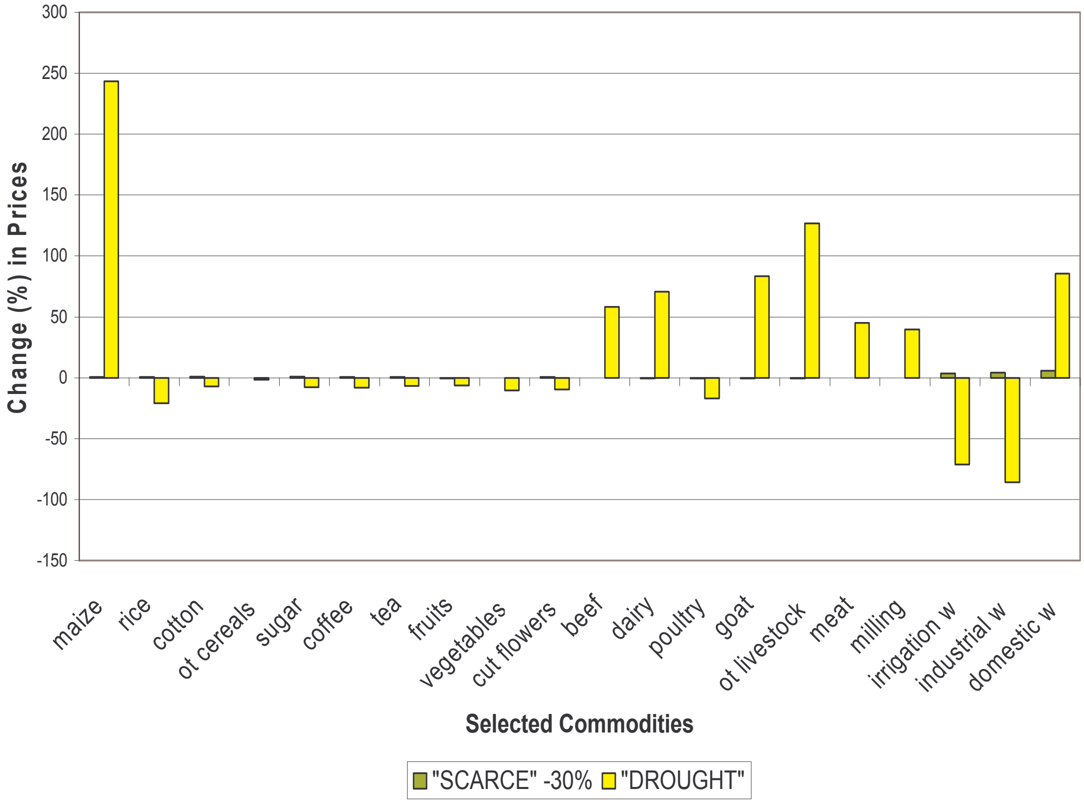
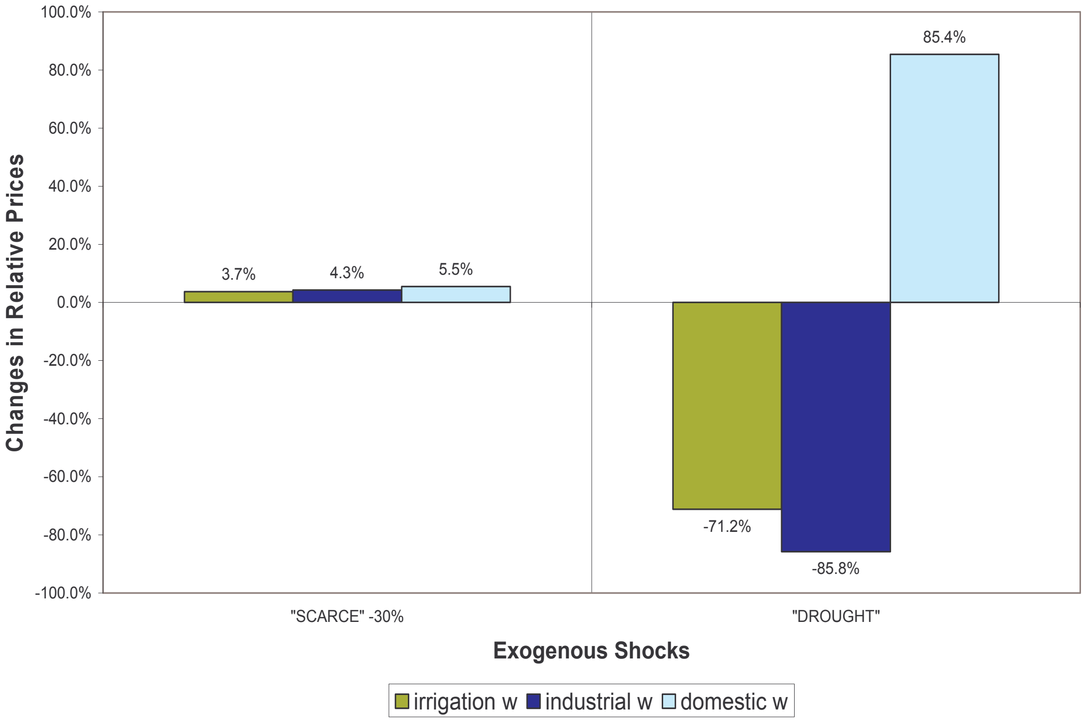


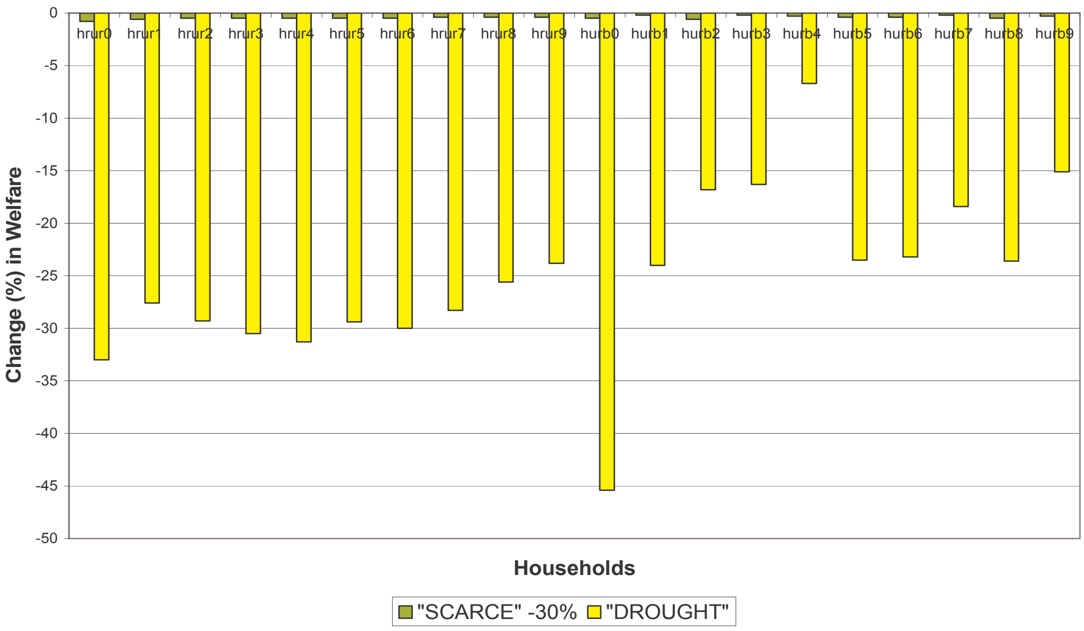
Figure 20b: Change in Relative Prices of Water Commodities



4) Regarding the *government deficit,* it dramatically grows especially in "DROUGHT" scenario (+132%), whereas in "SCARCE" increases by around 1.4%. This is mainly due to the reduction of earning from taxation (around -20% and -0.2% respectively for "DROUGHT" and "SCARCE" scenarios) given the contraction of the Kenyan economy and the augmented government expenditure (just for "DROUGHT" by 2.2%).

5) I concentrate on *welfare implications* of the "DROUGHT" (figure 21). The comparative static allows to analyze the importance of some targeted effects of "DROUGHT" scenario, isolated from the scarcity of water *tout court* as described in the "SCARCE" scenario. The rural poor households would suffer the most without any policy intervention – considering both the "SCARCE" scenario and the "DROUGHT" one. This is due to the reduction in terms of value of the factors' remuneration and to the decrease of the production of those activities driven by poor households. The rural population living in marginal areas (in particular ASAL) will be more affected by the effects of droughts. However, the most drought-sensible category results to be the poorest urban households. Nevertheless, excluding this category, drought affects the most the poorest deciles of rural dwellers.

Figure 21: Changes (%) in Households welfare – A Comparison between "DROUGHT" and "SCARCE" Scenarios (considering a 30% reduction of water endowment)



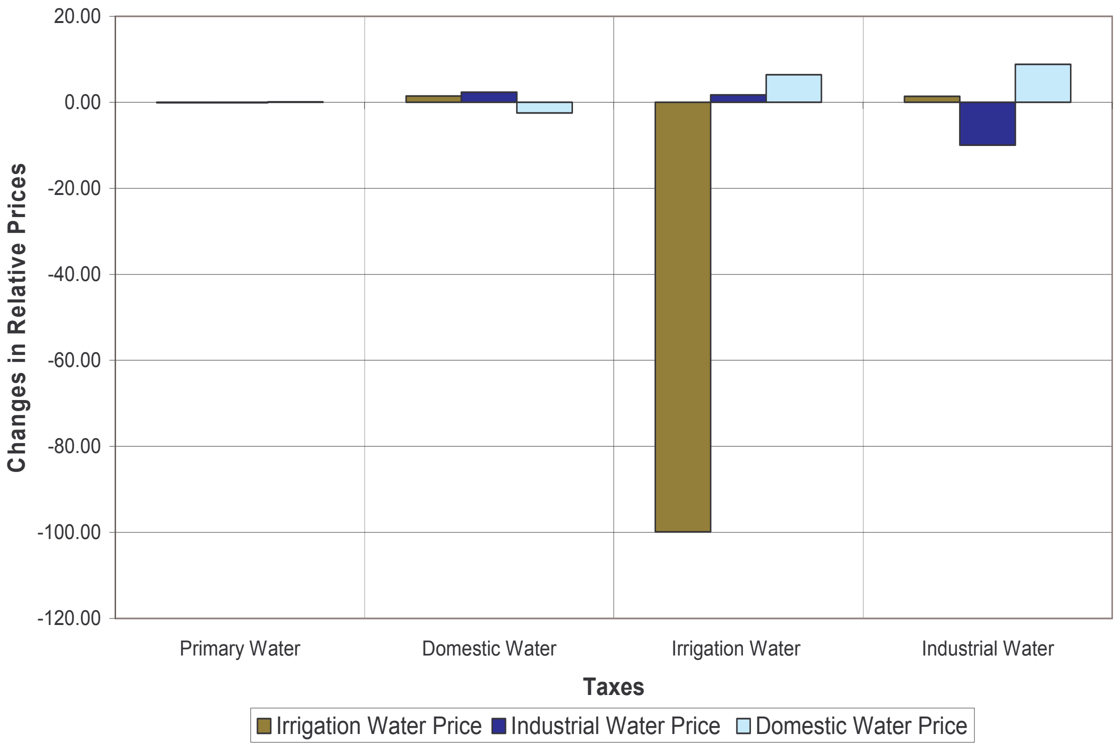
5.5. Fiscal Policies

In this section, I present the results of the simulations referred to the imposition of three different taxes on "Primary Water", Domestic and Industrial Water. The tax on "Primary Water" covers the largest set of institutions (figure 10), and enters in the production process of Self-Providers and the Water Activity. Furthermore, this tax affects the demand side of the economy and the owners of raw water are mostly rural dwellers. They are also the most affected by the imposition of a tax on this factor – in particular the poorest ones (figure 10). The tax rates that have to be imposed to reach the governmental revenue corresponding to respectively 4.2, 7.1 and 42.5 Mil Ksh (which respectively correspond to 0.2, 0.34 and 2 percent of the actual Government expenditure), are described in table 3. The trend of the taxes is strictly monotonic with respect to the increase of the extra revenues. Therefore, I just present the results regarding the intermediate level of extra revenue (7.1 Mil Ksh).

1) All the taxes simulated affect output of domestic activities. Considering *quantities* by each single activity, they just slightly change. Those changes depend on the sort of water the different sectors are using (i.e. rice slightly reduces its production when a tax on the different commodities is levied, whereas slightly increases its production with a tax on "Primary water").

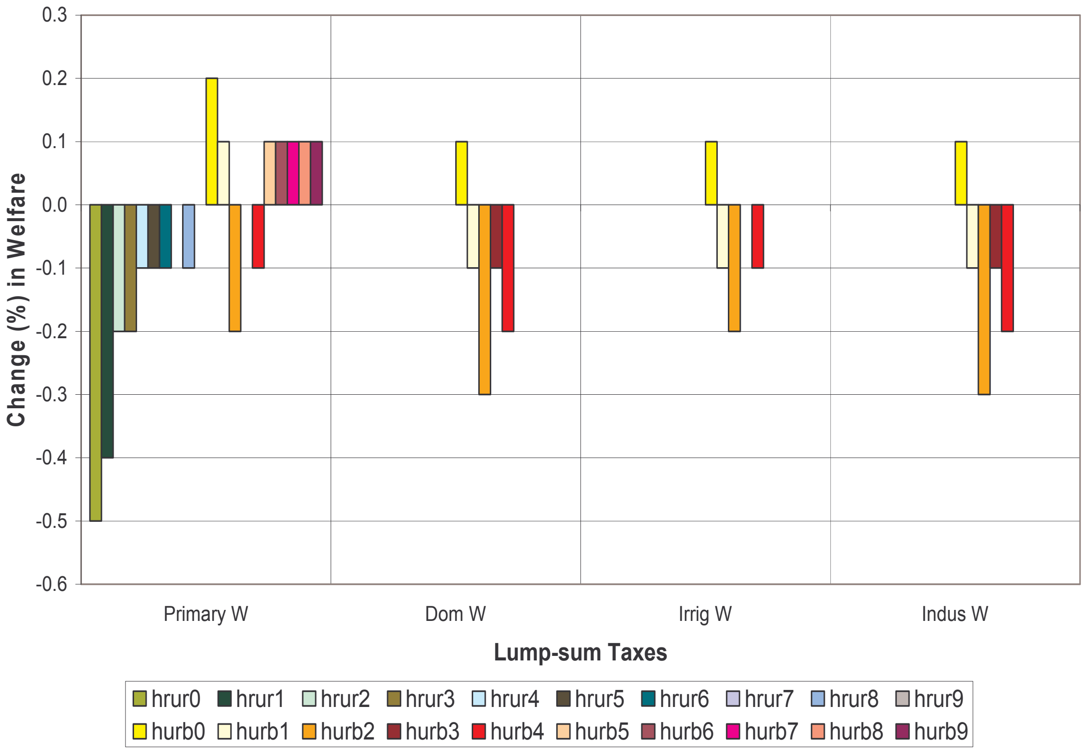
2) Looking at agricultural sector, almost no relevant variation of the *relative prices* is registered with the imposition of any tax. The only prices directly affected by the tax are those of water commodities (figure 22). Then, when a tax on domestic water is imposed, the relative price of domestic water reduces by 1.5, 2.5 and 11.2%; the relative prices of irrigation and industrial respectively grow by 1.4% and 2.4%. Symmetrically, from a tax on industrial water the relative price reducing would be the one on industrial water commodities (-9.9%) whereas for the other two water commodities the prices increase (8.8% for domestic and 1.4% for irrigation water).

Figure 22: Changes in Relative Price of Water Commodities due to Fiscal Policies - the Extra Revenue is fixed at 710 Mil Ksh



3) In terms of *welfare effects*, imposing a tax on water factor is highly regressive with poor rural households hit the most - around 0.4% in terms of reduction in consumption expenditures (figure 23). The other taxes slightly penalize poor urban (around 0.1%).

Figure 23: Welfare Changes due to Fiscal Policies – the Extra Revenue is fixed at 710 Mil Ksh



4) Furthermore, I implement cash transfers such that the PRH would be offset by reduction of *welfare* due to "DROUGHT" scenario. The total monetary transfer would be about Ksh 43.6 Bil (approximately USD 58 Mil) (see table 4), this number being quite consistent with what has been paid for emergency relief related to drought events (see section 2.4). Therefore I assume these transfers being financed by International Community.

Concluding, the major effect in terms of households' welfare change refers to the imposition of a tax on "Primary water" that affects mostly the poorest rural households. Therefore, it seems contradictory to impose such a tax and then implementing a redistribution system in order to reduce poverty in rural areas.

Moreover, the taxes on commodities have a slightly negative effect on poor urban dwellers. As I am interested in implementing a policy aimed at eradicate rural poverty, I should concentrate on water commodities taxation. In particular, the less distorsive taxes seem to be those on industrial and domestic water. Moreover, the demand for domestic water is quite rigid and urban households served by piping systems are considerably wealthier than those fetching water by standposts or public vendors (Gulyani *et al.*, 2005) and than rural ones. However - considering the incidence of the payments for water on industrial activities' expenditures is relatively low[110] - I also consider the implementation of a tax on industrial water along with water scarcity or abundance scenarios.

5.5.1. Fiscal Policies within either "SCARCE" or "ABUND" scenarios

In this section, I look at both the fiscal policies - focusing on water commodities' taxation - and the variation of water endowment within the same simulations' set. Intuitively, levying a tax in a scenario of reduction in water endowment implies an even higher burden for the Kenyan economy. Nevertheless, we will see in the next section how the principle of redistributing resources to rural poor is even more important in extreme critical situations. A representation of the effects of this new set of simulations on welfare of households is given in figure 24 (a) rural and b) urban).

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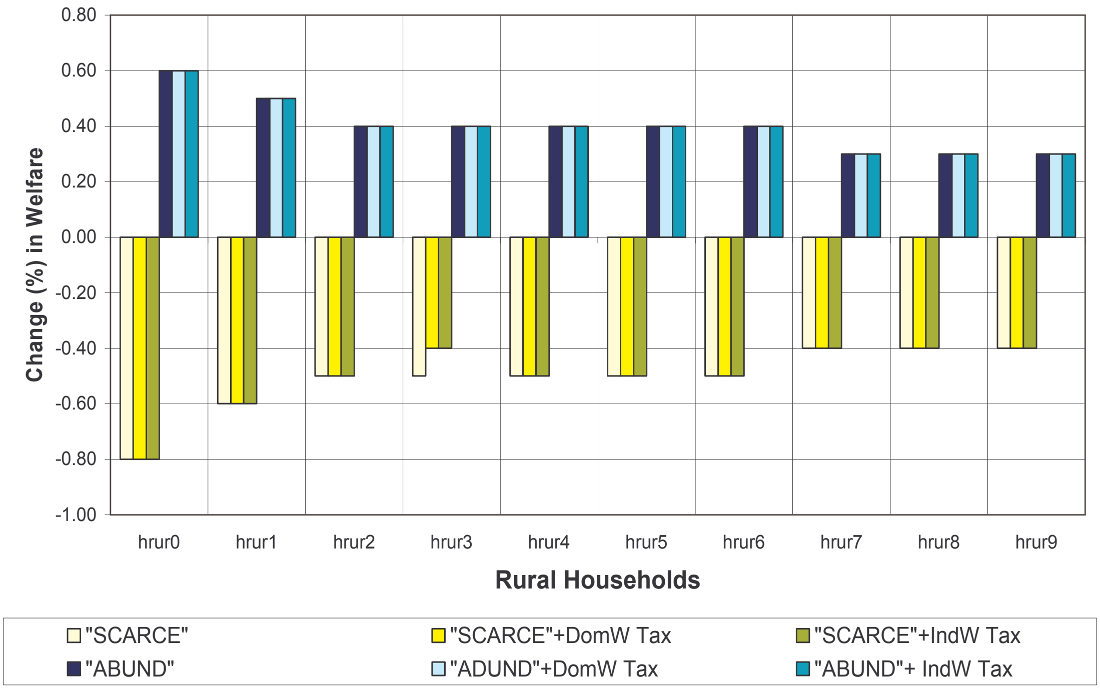
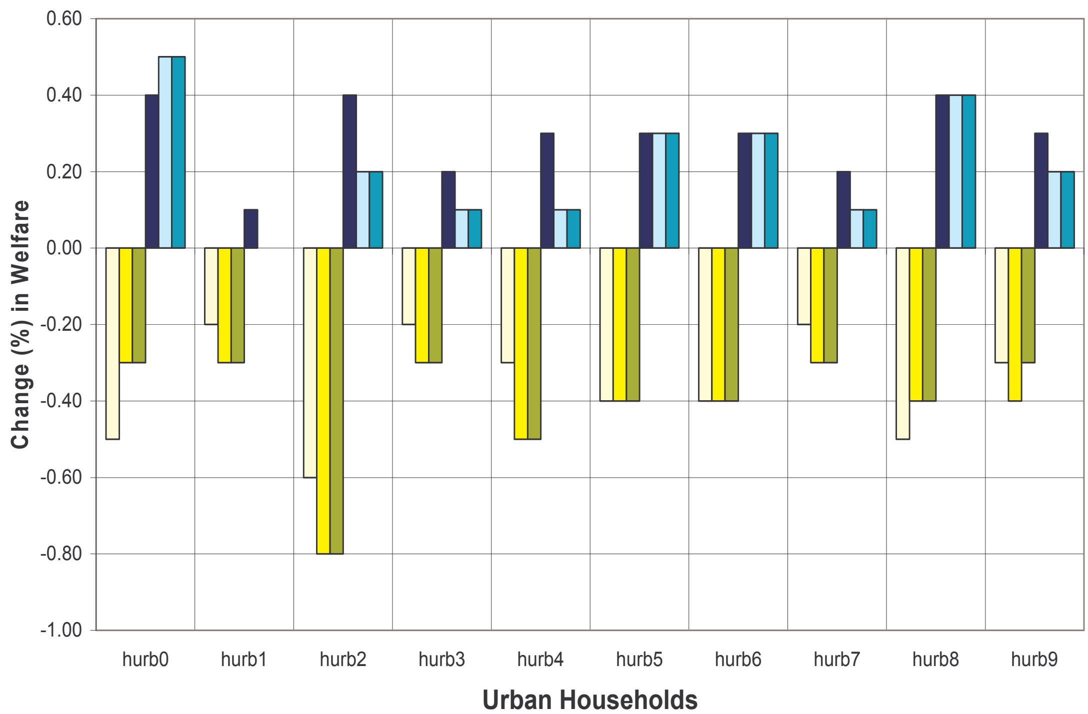
[110] According to the values registered in the 2003 SAM of Kenya. the cost of water industrial activities ranges from the 13.21% of the textile & clothing to the 0.03% of bakery and non metallic productions of the total sectoral expenditures

Figure 24: Welfare Changes due to taxes levied to obtain 710 Mil Ksh within either "SCARCE" or "ABUND" scenarios

a) Rural Households



b) Urban Households



On the other hand, imposing a tax on some agents in the water abundance scenario is an exercise that would allow to analyse how the investment to mitigate the effects of droughts or to increase water availability could be partially financed by the GoK taxation schemes. These can be implemented by GoK in order to: transfer the extra revenues to the rural poor (see section 7.4.) or finance part of the investment in infrastructure to meliorate the irrigation system (see section 9). Both measures could be seen as poverty reduction strategies narrowing down to the rural development.

1) The *remuneration value of* water - in the scenario representing fiscal policies along with either "SCARCE" or "ABUND" scenarios - is slightly lower (respectively -0.09% and -0.08%) than with respect to the "SCARCE" and "ABUND" scenarios.

2) Considering changes in *sectoral outputs*, in general the demand for domestic water is the more inelastic to price variation with respect to other uses. Moreover, the strongest effect on the level of single sectors' production is given by the tax on commodities rather than on the factor.

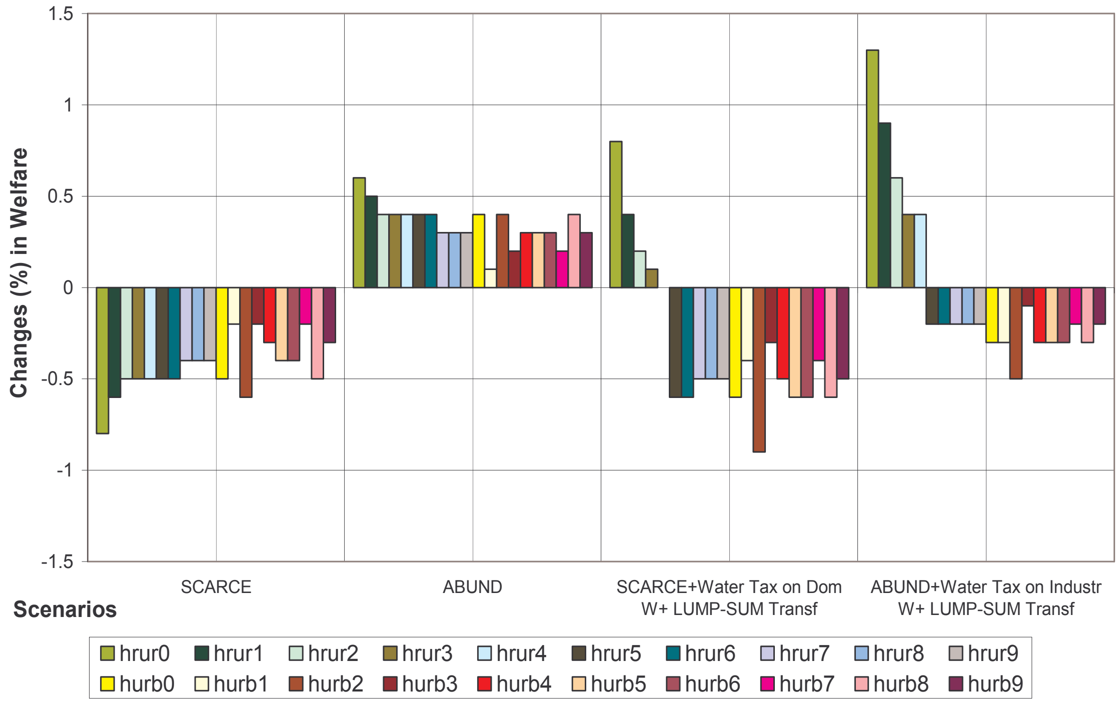
Since one of the aims of levying these taxes is to redistribute the extra revenue through cash transfers, in the next section I analyze this issue. In particular, I target the poor rural households as beneficiaries of those cash transfers since they are the most affected by drought effects.

5.6. Cash Transfers to Poor Rural Households

In this section, I present the result of the extra revenue redistribution to the four poorest deciles of rural households. I implemented the cash transfers into two different settings.

The *first*, within the "SCARCE" scenario aimed at redistributing the extra-revenue - collected through the taxation of Domestic or Industrial water to the poorest five categories of rural households "REDISTR1". The extra revenue is redistributed in cash, in equal quantities to each category. Each category gets 14.2 Million Kenyan Shillings (figure 25).

Figure 25: Welfare Changes due to (Domestic & Industrial) Water Taxes and Cash Transfers



Secondly - within the "DROUGHT" scenario – I redistribute to the poorest rural households such that they return to a level of welfare as before the drought event. Cash transfers to the poorest consumption deciles would have a positive impact more than the increased quantity of water simulated in "ABUND" ("REDISTR").

In the "REDISTR2" simulation, I want to obtain the level of transfer such that the five poorest rural deciles reach their pre-"DROUGHT" level of welfare (Table 5). The total amount of transfers corresponds to more than 40 Billion Ksh (around 53.5 Mil USD). This has been based payments given by international community for emergency intervention in Kenya.

However, the option of mitigating the negative effects of droughts through a mechanism providing cash transfers to poor rural communities is risky as these communities may increase their dependency from central authorities and/or international community. Therefore, policy makers do not have just to provide food aid and funding but have to address more complex challenges: the needs of the communities - mainly pastoralists, the most at risk from negative consequences of drought and displacement - in the fragile environment of the ASAL in Kenya.

5.7. Coping with Droughts: The "Arid Land Resources Management Project"

In the most recent "Crop prospect and food situation" (July 2009)[111] FAO's analysts stress the critical situation of food security in Kenya due to dramatic droughts and to post election conflicts. In particular, two sectors are the most affected by negative effects of droughts: maize and pastoralist productions which are projected to fall dramatically[112].

An effort toward the mitigation of drought effects on ASAL communities is represented by the FAO (TCIS Division) and World Bank "Arid Land Resource Management Project" (ALRMP) – phase II (2003 - 2010) representing the follow up of the ALRMP – phase I (1994-2003)[113]. The project represents a new approach toward mitigation instead of reaction to negative effects of droughts.

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[111] http://www.fao.org/docrep/012/ai484e/ai484e02.htm

[112] http://www.fao.org/docrep/012/ai484e/ai484e02.htm.

[113] According to the ICR of the first phase, a key achievement of the project has been its role in coordinating assistance to the arid lands and the overall national coordination of donors, in particular through the establishment of the Kenya Food Security Meeting (KFSM). Adequate and timely information provided by the project has enabled proper scheduling of drought mitigation assistance. The project has also been highly successful in developing a devolved system of implementation with full participation, involvement and ownership by district governments, institutions and communities. At district level the primary impact has been the establishment of functional local entities such as the District Steering Groups, the enhanced capacity of line-ministries' human resources involved in project implementation (Mobile Extension Teams), the start of effective decentralized planning and implementation and improved linkage between communities and their local institutions. The achievements of ALRMP I in these fields are considerable, but in view of the nearly persistent drought

The *first phase* objective, as revised during the Mid-Term Review, was to build the capacity of communities in the Kenyan arid zones to better deal with drought. The principal shortcomings of Phase I, according to the Independent Cost Review (ICR),

were: *(i)* the limited progress on setting up a framework for natural resources management; *(ii)* lack in understanding how to proceed to monitor, protect and sustainably develop the arid land resource base; and *(iii)* weaknesses in the project monitoring and evaluation system.

These shortcomings are addressed in the design of the *second phase*. The ALRMP – phase II wants "to reduce livelihood vulnerability, enhance food security and improve access to basic services in 28 drought-prone arid and semi-arid districts in Kenya"[114] The project has three components for an estimated budget of 77.9 USD Millions:

1) Natural Resources and Drought Management (38.9 USD M);
2) Community-Driven Development (24.2 USD M); and
3) Support to Local Development (14.8 USD M).

The *two latter* components will be implemented in the 11 arid districts of Kenya – which were included as a target in Phase I.

The *Natural Resources and Drought Management* component has been implemented in a wider region including also semi-arid districts suffering from regular acute food insecurity drought related crises. This component is focused on reducing the vulnerability of those communities living in ASAL district and has two sub-components: *(1.a)* "Natural Resource Management" and *(1.b)* "Drought Preparedness and Management".

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emergency situation during the ALRMP I implementation period, it has not been possible to move towards full institutionalization of processes and responsibilities and a discontinuation of project supported activities at this stage may lead to a stalling of positive initiatives (World Bank, 2003a).

[114] http://www.aridland.go.ke/mod.php?topic=66

(1.a) The *first* element is aimed at mitigating the risk posed by drought and other related factors by strengthening and institutionalizing natural resources and drought management systems. This in turn will reduce the vulnerability of the population in an area which is characterized by frequent, acute drought related events and food insecurity.

(1.b) The *second* element is "Drought Preparedness and Management". Both preparedness and management are factors centred on a better understanding of production systems, the resilience of the ecosystem (i.e. land) and the use of easy, extensively replicable management responses. The objective of the sub-component is to create a more effective drought cycle management system, which will minimize the need for emergency intervention, and enhance response mechanisms for better action in acute drought emergencies.

The starting point for those drought management activities is the drought management system implemented during Phase I of the Project: the Early Warning System (EWS)[115]. Under the Phase II, the drought management system will be expanded to an additional ten semiarid districts (six of which have already started EW operations on a pilot basis). Where the system is already operational, it will be revised to increase its effectiveness. The first improvement will be to enhance the EWS in Phase I well suited for the dynamics of a pastoral economy, with a focus on livestock[116]. The EWS in Phase II should broaden its target considering the increasing varieties of farms and waged labour activities. The component will strengthen human and technical

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[115] The system is based on three pillars: 1) An effective institutional and decision-making framework at community, district and national level to coordinate and support drought monitoring, mitigation, response and recovery; 2) Timely availability of reliable drought status information to aid decision-making at all levels; and 3) Capacity to plan and implement interventions in a timely, effective and efficient manner, including the timely availability of funding to finance mitigation and response interventions.

[116] An example of relatively easy application is represented by the enhancement of the district livestock markets. Introducing Early Warning signals through which livestock's producers know when is better to sell their cattle at lower price and weight rather than loose the whole stock of animals.

capacity at district and national levels to ensure the continued credibility and sustainability of the system.

However, it's not easy to evaluate in economic terms the ALRMP.

Firstly, many benefits are difficult to be quantified in monetary terms – e.g. community empowerment enhanced capacity, improved natural resource management, greater access to health and education, less targeting errors in emergency operations, the utility of a faster recovery after a drought and less income variability during a drought at the household level.

Secondly, the investments are constrained by lack of savings and the investment priorities will only emerge during the course of the project. Thirdly, project benefits are substantially influenced by the drought cycle, and the economic rate of return will depend upon the timing and severity of drought events, both which are difficult to predict.

5.8. Effects of Drought & Augmented Factors' Productivity

In the policy simulated scenarios, I focus on the ALRMP's first driver - "Natural Resource and Drought Management" - narrowing down to the "Drought Management and Preparedness" component.

I assume the proposed intervention being associated with an increase in productivity of labour, land and water – for example through capacity building activity, through support activities towards a widely better management of the available resources (i.e. Early Warning System, animal health support) – in beef, dairy, goat and other livestock sectors and maize productions. Furthermore, an increase in land availability due to a more performing resilience system may be tested as a possible outcome of the project. Thus, in order to replicate these efficiency improvements, I run a group of simulations considering an increase in factors' productivity of the various livestock and maize activities[117] concentrated in ASAL. The project's impacts are tested in order to analyse how some positive shocks would mitigate drought problems.

A generalized effect regards a better performance of those activities which are more factors intensive.

Considering the 2003 SAM of Kenya, poultry, goat and other livestock are the most factor intensive production among those targeted by the Project.

Table 8: Simulation of droughts: the composite effect of more shocks

	Endowment		Output					
Simulations	Water	Land	Maize	Beef	Dairy	Goat	Poultry	Livestock
"DROUGHT"	-30%	-5%	-35.7%	-13%	-33%	-24%	-49%	-28%
"ALRMP"		2%	11.5%	4%	10.4%	5.8%	8.7%	6.8%

The ALRMP enhances factors' productivity[118] in the main ASAL productive sectors – maize, beef, dairy, poultry, goat and other livestock. Additionally, it mitigates the negative effects of land degradation restoring land resilience (+2 percent of land endowment) (Table 8).

5.8.1. The Simulations' results

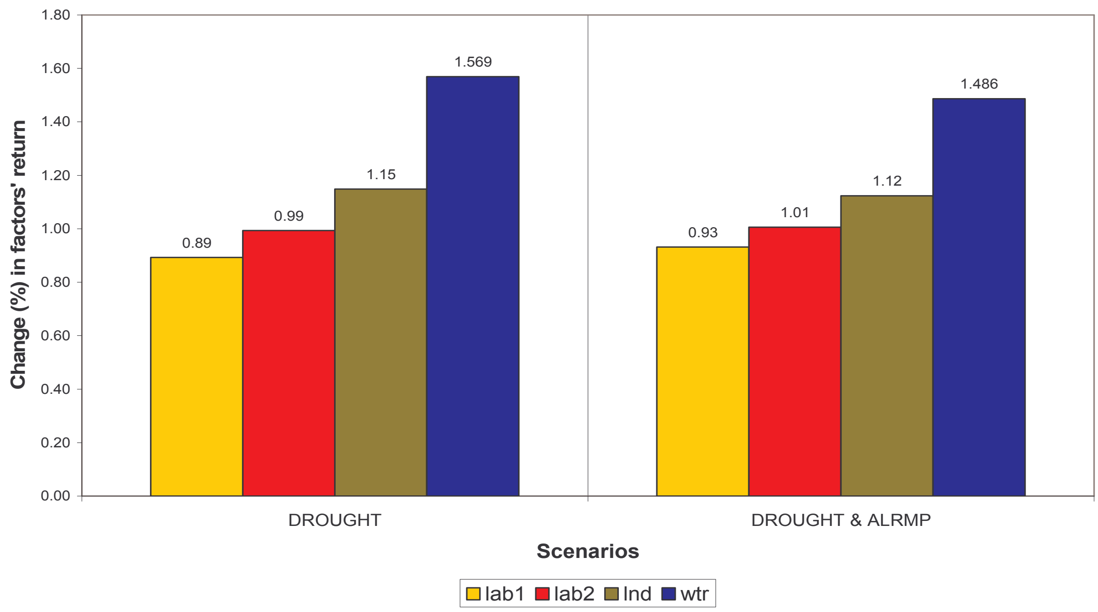
I study effects of implementing the ALRMP with the shocks related to the drought simulation ("DR-ALRMP").

1) Looking at the *water's remuneration*, while it increases (48.6%) with respect to the benchmark, it reduces (-5.3%) with respect to that resulted in the "DROUGHT" scenario. This is due to a more productive use of all factors. In

[117] The increase of productivity is exogenously determined by a change in *"iva"*, the coefficient
[118] The smaller the factors' efficiency parameter the more efficient is the use of the factors. We test an enhancement in factors' efficiency for maize (-0.2), and livestock sectors (-0.3).

fact, a more efficient and widely spread natural resource and drought management in ASAL would boost those productions (maize and livestock sectors) receiving the investments. In general, the rent of the other factors increases but the one of land which slightly (-2.2%) reduces with respect to the "DROUGHT" scenario: the reason is that the ALRMP allows to sustain the resilience of land which is improved through the project (figure 26).

Figure 26: Changes (%) in Factors' Return in "DROUGHT" and "DR-ALRMP" Scenarios



2) Concerning the *production levels,* the exogenous shocks given to maize and livestock productions have a positive effect on output level of those productions with respect to the level of output in the "DROUGHT" scenario. Secondarily endogenous shocks are registered. On one hand, those sectors transforming maize and livestock commodities, namely milling and meat productions, increase their output levels (23% for milling and 18% for meat) with their prices in turn reducing (respectively -21% and -3.6%). On the other hand, other agricultural activities increase their output levels as well; among the others – tea (+48%), sugar (+26%), fruits (+25%), cut flowers (+25.3%) and coffee (+18.6%)

(figure 26). This trend is due to an increase in demand of cheaper factors released by those activities which experienced an increase in factors' productivity. The increase in supply - caused by the augmented productivity of those factors of production used in livestock and maize activities - needs to be set-off against an increase in the demand which is redistributed on those sectors not affected by a reduction in their relative prices. However, it is likely that a flourishing demand would emerge from the expansion of the economy as a whole with respect to the "DROUGHT" scenario.

3) The change in production level for those sectors is completely absorbed by the variation of *relative prices* for those sectors (figure 27). However, their prices substantially increase - with fishing (+19.8%), forestry (+13.6%) and rice (+13.2%) relative prices increasing the most. This is due to an increase in the demand for those commodities induced by an increase in supply in turn determined by an increase in efficiency. Regarding water commodities, the price of domestic water decreases (-63.5%) while those of irrigation and industrial water commodities increase (respectively by 50.6% and 72.8%). This is a demand driven endogenous effect given by the expansion of those activities demanding more those types of water commodities relatively to the domestic one.

Figure 27: Changes in Output Levels due to "ALRMP" – from "DROUGHT" (benchmark)

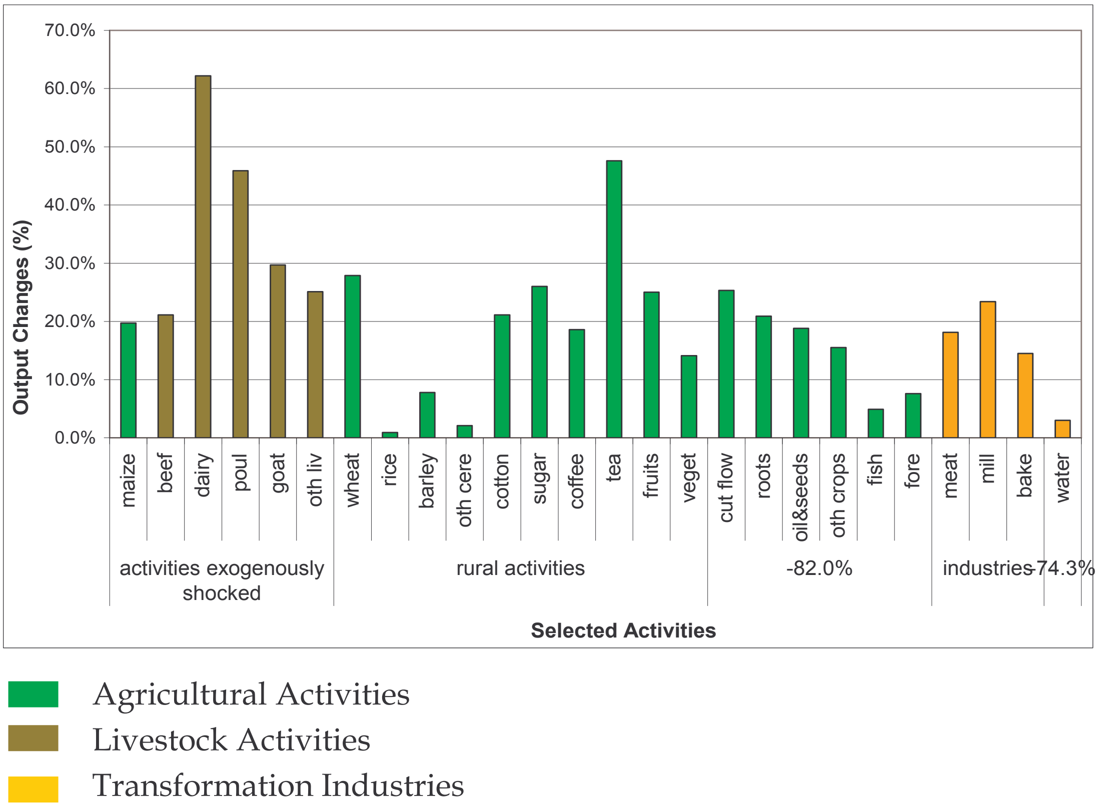
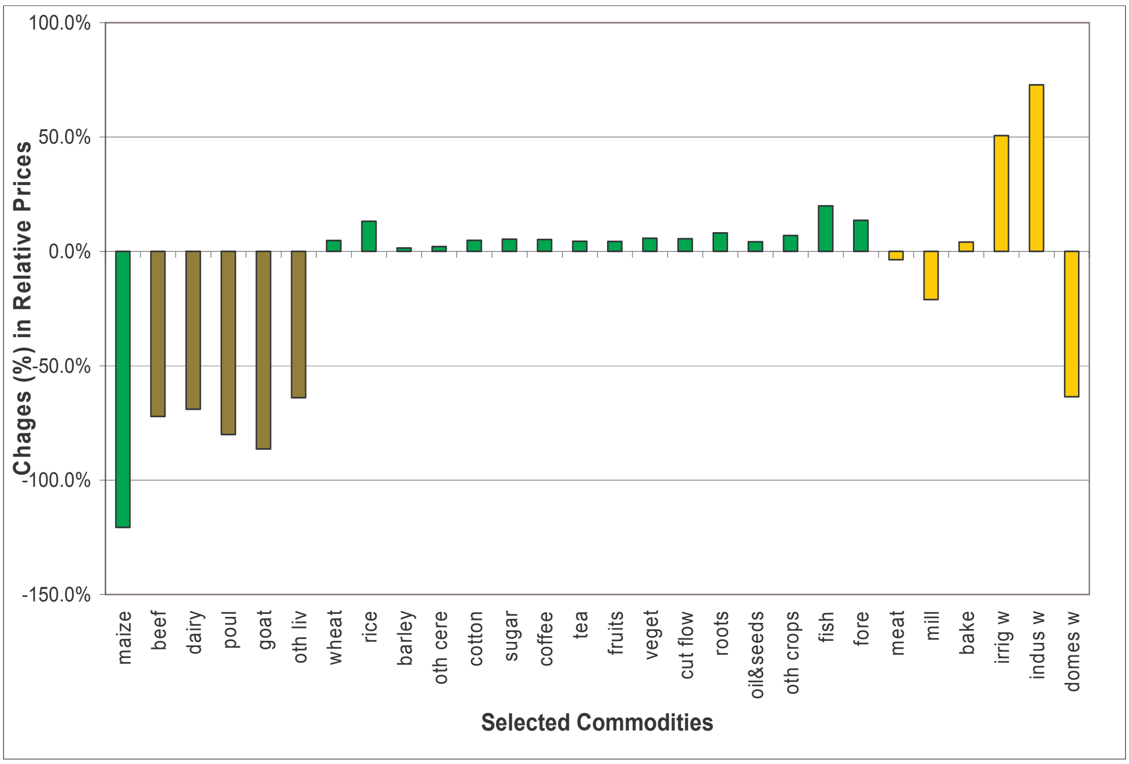


Figure 28: Changes (%) in Relative Prices



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4) Regarding the *Government deficit*, it explodes because of the "DROUGHT" (+130%), while it results to be always higher than the benchmark level (+60%) but considerably reduced (around 70%). One can notice an improvement of the exchange with the RoW. The export increases by 12.4% while the import by 7.7% with respect to the "DROUGHT".

5) Looking at *welfare effects* (figure 29a), the rural poor households would suffer the most from "DROUGHT" (see section 7.2) without any policy intervention. The focus of the ALRMP is on the main ASAL smallholders' activities as ASAL's communities are the project's target. Thus, the negative effects of droughts on those population are smoothed in "DR-ALRMP". The households benefiting the most from the implementation of the ALRMP are rural households (especially PRH) and the poorest urban. The least affected by the pro-ASAL policy are the wealthier urban dwellers (figure 29b)). The overall effect of the project on the poverty reduction is clearly rural oriented.

Figure 29a: Changes in Welfare (EV) within "DROUGHT" & "DR-ALRMP" Scenarios

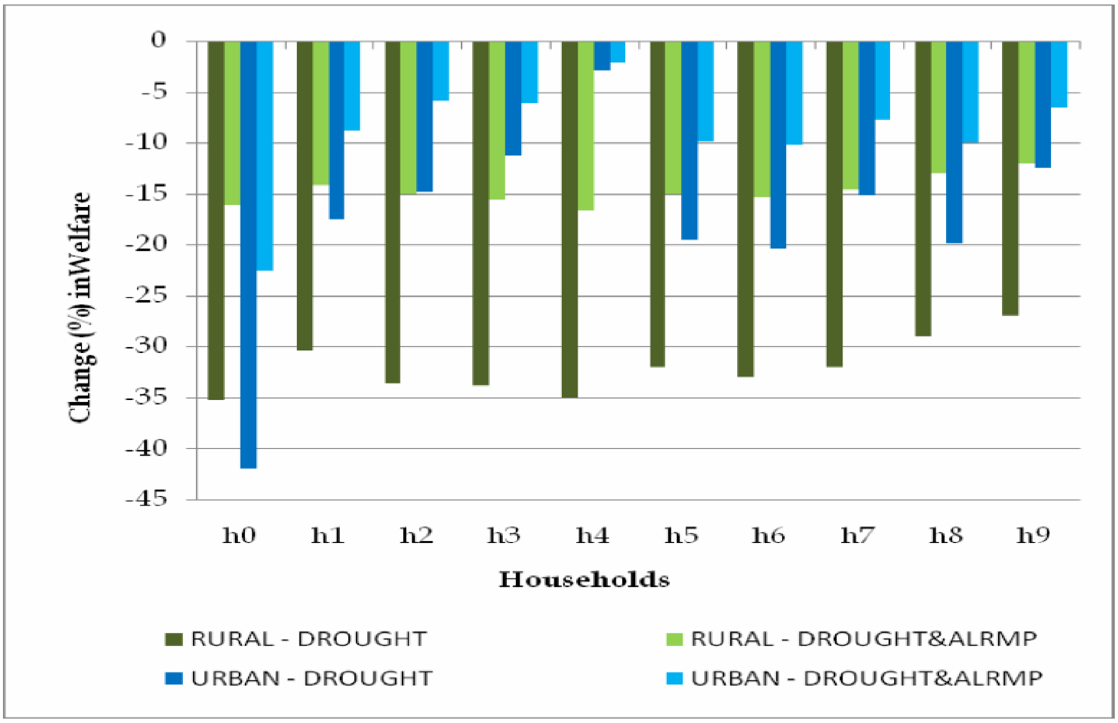

Figure 29b: Changes in Welfare (EV) due to "ALRMP" – from "DROUGHT" (benchmark)

CONCLUSION

Water is essential for all the economic activities. Growing economic activities, population and climate change severely. Moreover, the water scarcity problem is increasingly becoming an urgent issue on the agenda of policy makers. Given the cross-sectoral nature of the subject, the general equilibrium approach has been applied for studying the use of this fundamental natural resource. In particular, I focused my work on Computable General Equilibrium approach.

CGE models focusing on water are relatively recent: the first pivotal contribution has been from Berck et al., (1991). Since early 90s, many modellers face the challenge of modelling water through CGE. I reviewed the main contribution and found four possible categories based on the policy aim of the studies: *(i)* competition between sectors; *(ii)* water pricing policies and tariffs; *(iii)* water and trade issues; and *(iv)* water CGE and other models, i.e. farm models and bio-economic models.

Moreover, I focused on Kenya's economy in particular on agricultural and rural activities. Water scarcity and drought related problems in Kenya are becoming pivotal to be addressed in order for the country to ensure a sustainable and equitable development. A general indication starts from the consideration that rain-fed crop sectors are predominant in the contribution to agricultural GDP. This translates in relatively high volatility in terms of agricultural growth, being the fluctuation in crop output mainly due to weather conditions.

Therefore, more emphasis should be placed on agricultural water management systems (i.e. irrigation, water harvesting, reservoirs, early warning drought systems) – rather than just irrigation scheme - as they can: reduce over-reliance on rain-fed agriculture in the face of limited high potential agricultural land and stabilize agricultural production in times of adverse weather conditions; increase Kenya's agricultural productivity per unit of land and expand arable land; restore reliance of rural communities after drought events. The growing occurrence of droughts makes the yields of rain-fed crops even more uncertain.

The correlation between agricultural performance and climate explains the wide regional variability in terms of productivity. Therefore, the Kenyan Rural Development Strategy (KRDS)[119] points out the need for investment in infrastructure (i.e. reservoirs to stock rain water and irrigation schemes).

Following I used a CGE model with the aim of addressing the scarcity issue. I adjusted the 2003 SAM of Kenya, the main source of data of the present study, in order to introduce "primary water" with the objective of explicitly model water. Reduced water availability resulted to affect negatively Kenya's economy.

For 10, 30 and 50 percent *reduction in water endowment*, the model estimated that - moving from *"no water transfer"* to a *"water transfer"* setting - the resource is utilized progressively more by water intensive sectors facing a more rigid demand, namely the water activity, barley, cotton, sugar and maize productions. Here "water transfer" means that activities can vary their share in water consumption with respect to the benchmark. Therefore, enabling activities to adopt more water efficient cropping patterns would enable reallocation of water to a more productive use and mitigate the impact of reduction in water availability.

In addition, as the results of water scarcity simulations underestimated the importance of water, I set up and simulated a *drought* scenarios. I shocked the productivity of several sectors (based on expectations of and data from the Kenya's MoA) – through the modification of productivity parameters – which have been demonstrated to be particularly "susceptible" to drought's events: pastoralists activities (beef, dairy sectors, goats, poultry and other livestock, principal activities in ASAL) and maize production (the main staple food cultivated by smallholders). Furthermore, I also assumed a reduction in land

[70] The KRDS - within the National Poverty Eradication Plan (NPEP), 1999-2015 – recognizes the existence of a number of fundamental constraints faced by rural sectors (i.e. poor infrastructure, poor governance) and proposes an intervention in the agricultural sector by developing irrigation scheme.

available for cultivation (for instance due to the abandonment of some marginal land, to erosion and desertification). The effects of droughts were exacerbated and more robust with respect to the scarce water scenario *tout court.* In particular, the incidence of droughts on maize production turned out to be crucial in reducing households' welfare. Besides, also sugar, cotton, livestock and dairy sectors were harshly hit and saw a reduction in their output levels.

Looking at *fiscal policy* interventions, I proposed alternative lump-sum taxation schemes - on "Primary Water" and on domestic, Industrial and Irrigation Water - in order to reach three fixed different levels of extra revenues: 4.1 Mil Ksh - for the management of cross boundaries water related conflicts; 7.1 Mil Ksh – for the restocking of livestock; 54 Mil Ksh – for the reconstruction of forests and the reconstitution of aquaculture production. Since Irrigation water is used just by rice, vegetable and fruit sectors, the tax rate on Irrigation water would be too high in order to reach the lowest fixed level of extra revenue.

Moreover, I found that levying a *tax on "Primary Water"* is always negative for rural communities, since, especially for the poorest rural dwellers the natural resource constitutes an important font of livelihood (up to 5% of their income) (figure 9). Given the need for the recovery of the operational and maintenance costs, a water taxation scheme should target either Industrial or Domestic water.

Water and land are two key natural resources upon which rural poor people depend on for their livelihoods more heavily than non-poor and urban (even if poor) households. It would be naïve to perceive that all rural poverty problems could be solved through improving the poor's access to water alone. However, though water is only a single element in poverty equation, it plays a powerful role through its wider impacts.

In the case of taxation, the *extra revenue* collected could also be *redistributed* to the less wealthy rural dwellers or otherwise reinvested, in projects for improving the poor rural dwellers' water management practices.

Hereby, I also proposed *alternative cash transfers* in order to offset the decrease in welfare provoked by the drought's effects for the five poorest rural deciles. The total cash transfer would correspond to about USD 58 Mil which is a number in line with what has been spent for emergency relief related to drought events in the past (see section 2.4).

However, from an Independent Cost Review - cited by the World Bank - ALRMP (2003b) – it emerged how cash transfers have been deemed not to substantially ameliorate the condition of those communities more harshly hit by droughts. In particular, the cash transfers *tout court* would increase the dependency of those rural communities receiving it. Therefore, I focused on the World Bank ALRMP - Phase II in order to propose a proper mitigation strategy of the adverse effects of droughts on the poorest rural dwellers. The positive outcomes of the ALRMP - Drought Management and Preparedness component of the driver "Natural Resource and Drought Management" - has been evaluated by considering the expected enhancement in the productive factors' efficiency for livestock sectors and maize production which are spread in Kenya's ASAL.

I found that investing in improving managerial capacity (i.e. through capacity building), in land resilience, in water efficiency and in a monitoring system (i.e. the Early Warning System) within ASAL based communities, that such an intervention would not only enhance the livelihood of those rural communities worst affected by droughts but also those of rural dwellers.

I found that those most positively affected by the implementation of the ALRMP are indeed the poorest urban households, followed by the poorest rural households. Regarding production activities, the exogenous shocks given to maize and livestock productions have a positive effect on the output level of those productions with respect to the level of output in the "DROUGHT" scenario. These positive effects in production levels are directly absorbed by decrease in relative prices. Regarding the endogenous related shocks, complementary activities of those shocked (i.e. milling and meat sectors) increase their output levels while their price levels fall. The expansion of demand needed in order to set off against the supply increase mainly affects those sectors not directly related to those shocked. They expand their supply with an overall slightly positive change in relative prices.

The model has confirmed what had emerged from FAO (2008) on the importance of enhancing the productive efficiency in the maize sector in order to promote and diversify agricultural activities (see section 2.2 and note 18) into other crops that generate higher remunerations to land and labour than maize – for instance sugarcane, tea, cut-flowers, and dairy.

Therefore an intervention into the maize sector by enhancing the productive factors' efficiency is highly recommended. However, the model being static, does not allow seizing the importance of seasonality in water availability. Furthermore, the water commodities do not come out from differentiated production processes.

It would be useful to compare the ALRMP project with another project aimed at mitigating the negative effects of droughts in more market oriented activities (i.e. coffee, tea and horticultural sectors). Could it be the case that rural poor would be better off by implementing a drought mitigation policy with a focus on market oriented sectors, rather than on ASAL activities? Another further development may regard the implementation of more sophisticated taxation tool (i.e. two part tariff). An interesting development may focus on the hydro energy production sector - whereas here I focused more on agricultural sectors. Hydroelectric power provides 72% of the country's electricity production and should be modelled *ad hoc* in order to be more responsive to change in water availability and to droughts.

Finally a structuralist approach explicitely considering the financial sector may be adequate for modelling water given this natural resource is also becoming an investment good.

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Appendix 1: The Meso SAM of Kenya and the Introduction of Water[120]

A SAM pictures an economy through a coherent accounting framework that captures the information embedded in the input-output table, in the national income and product accounts and in monetary flows between institutions. A SAM is a system of equations squared and full ranked. Moreover, any variable is explained by one and only one equation. If one of these two conditions does not hold the system has infinite or no solutions. In the matrix, each agent or account has its own row and column. The payments (expenditures) are recorded in columns and the receipts are listed in rows. The sum of all expenditures by a given account (or sub-account) must equal the total income for the corresponding account. Therefore, the total of each row must be equal to the total of the corresponding column in the table.

Key features are:

1. The totals for corresponding rows and columns are always the same
2. The numbers in the cells are set in nominal or current value terms; all entries in a row are valued in the same unit of account (typically an index based on producers's prices).

[120] Here, we just present the Meso SAM which has been transformed. The Micro SAM will be made available upon request

Table 1A: The Meso SAM of Kenya with NO Water Factor

	aagri	aliv&da	aind	aserv	cagri	cliv&da	cind	cserv	trns costs	lab	cap	land	water	ent	hrur	hurb	tax	gov	s-i	dstk	row	tot
aagri					223224										46946	361						270530
aliv&da						53254									38929	327						92509
aind							608313								5759	163						614236
aserv								908973														908973
cagri	19658	4878	39272	1066											40283	35997		7280	1021	2538	110149	262141
cliv&da		5862	8480	882											38416	2345		688	132			56804
cind	39364	15116	315044	147432											97915	196514		5119	177904	14906	127924	1137239
cserv	54262	1017	31571	225771					97623						81667	262864		185947	53		43042	983816
trans costs					14465	3550	79608															97623
lab	85391	37649	74038	233253																		430332
cap	24850	27987	145830	300570																		499236
land	47007																					47007
water																						0
ent											494960							43575			4938	543473
hrur										180793		44287		83494				3141			43448	355162
hurb										249539		2720		205786				8688			57663	524396
tax					4349		120976	6396						35809	5701	27912						201143
gov											4276			7264			201143				5677	218359
s-i														204069	-454	-2085		-36255			31279	196554
dstk																			17444			17444
row					20103		328342	68447						7052				176				424120
tot	270530	92509	614236	908973	262141	56804	1137239	983816	97623	430332	499236	47007	0	543473	355162	524396	201143	218359	196554	17444	424120	7881097

Table 1B: The €Meso SAM of Kenya Adjusted to Embed Water Factor

	aagri	aliv&da	aind	aserv	cagri	cliv&da	cind	cserv	trns costs	lab	cap	land	water	ent	hrur	hurb	tax	gov	s-i	dstk	row	tot
aagri					223224										46946	361						270530
aliv&da						53254									38929	327						92509
aind							608313								5759	163						614236
aserv								908973														908973
cagri	19658	4878	39272	1066											40283	35997		7280	1021	2538	110149	262141
cliv&da		5862	8480	882											38416	2345		688	132			56804
cind	39364	15116	315044	147432											97915	196514		5119	177904	14906	127924	1137239
cserv	54262	1017	31571	225771					97623						81667	262864		185947	53		43042	983816
trans costs					14465	3550	79608															97623
lab	85391	37649	74038	233253																		430332
cap	24850	27987	144251	300570																		497657
land	40916																					40916
water	6091		1579																			7670
ent											494960							43575			4938	543473
hrur										180793		38549	5738	83494				3141			43448	355162
hurb										249539		2367	352	205786				8688			57663	524396
tax					4349		120976	6396						35809	5701	27912						201143
gov											2697		1579	7264			201143				5677	218359
s-i														204069	-454	-2085		-36255			31279	196554
dstk																			17444			17444
row					20103		328342	68447						7052				176				424120
tot	270530	92509	614236	908973	262141	56804	1137239	983816	97623	430332	497657	40916	7670	543473	355162	524396	201143	218359	196554	17444	424120	7881097

Appendix 2 – The Water CGE Models

Here a scheme with the CGE models on water issues providing the following information - by the categories described in Chapter 2:

Table 2A: Competition between Sectors

Table 2B: Water Pricing Policies and Tariffs

Table 2C: Water and Trade Issues

Table 2D: Water CGE and Other Models

Information		
- Aim - Contribution to the literature - Main findings - Modeling approach - Production function - Utility function	- Factor of production - Assumption about factors - Role of water in the model - Households details - Time dimension - International trade - Sectoral details - Coverage/ regional detail	- Related studies - Simulations - Investment

Table 2A: Competition between Sectors

	Berck et. al. 1991	Mukherjee 1996	Seung et al. 1998	Seung et. al. 2000	Dwyer et. al. 2005	Wattankuljarus 2005
Aim	Effects of Water restriction	explore Water market option in the light of the transformation of South African farming system	How sensitive the agricultural impact of a Water reallocation policy are to alternative possibilities of input substitution in agricultural production	Compare effects of Water transfers from agricultural to recreational uses	Assess the impact of water inter-sectoral/interregional reallocation in Australia	impacts of changes in tourism on other industries, income distribution & labor market; impacts of changes in tourism on land, forest & Water; impacts of changes in the environment on tourism and social welfare.
Contribution to the literature	Methodology for evaluating the economic impact of withdrawing water from agricultural use	First model to consider in a CGE framework the use of W for non agricultural activities	Introduces integration of recreational demand with a CGE model and explicitly models alternative use of water	Introduces integration of recreational demand with a CGE model and explicitly models alternative use of Water		Application of a CGE Model focused on Water to Thailand
Main findings	Decrease in cotton/grain acreage, increase in acreage devoted to livestock.	Mechanism for better water allocation is needed (not necessarily a market), call for reforming the Reforming the Water Act (1956)	Different assumptions about input substitution in agricultural production result in qualitatively policy impacts on agricultural sectors	Using Water for recreational uses instead of for agriculture decreases the total welfare (but there is no consideration for extra-regional effects)	Losses from a hypothetical reduction in water availability to gross regional product and household demand are reduced when water trade is allowed	Growth of GDP, trade balance deterioration, positive results for households and for real wages and return on other factors. Reduced agri-production negative for rural income which is offset by extra-income through Water transfers
Modelling approach	Regional CGE	Regional CGE Model (The Region, the Rest of South Africa and the Rest of the World)	County level CGE with recreational demand module	County level dynamic CGE – with a recreational demand module	Large scale standard CGE – TERM water model	Standard CGE
Production function	C-D	CES for Labor & Capital linear aggregation for Water & land	C-D with fixed ratio for intermediate inputs	CD with fixed ratio intermediate inputs	Nested CES/Leontief multi level 3 level	CES
Utility function			CES	CES	Demand follows a LES	Klein-Rubin
Factors of production	Capital, Labour, Land, Water and Intermediate Inputs	Capital, Labour (13 sub-categories), Land& Water	Labour, Capital, Land, Water	Labour, Capital, Land	Capital Labor, Land, Water	Labor, Capital & Natural Resources (Land+ forest)

Assumption about factors	Capital sectorally fixed and immobile, Labour supply fixed, Unskilled Labour supply mobile, Land no substitutable with intermediate input, Water freely mobile across sectors		Water in fixed proportion with land, no Water substitutability Labor comes from in/outside the region & is mobile across sectors	Water in fixed proportion with land, no Water substitutability, Labour perfectly mobile across regions & partially mobile across sectors, Capital immobile	Capital is fixed and the ability of Labor to migrate between regions and industries is limited	
Role of Water	Fixed aggregate supply in 3 types of quality	determines the land usage - simple & indirect	determines the land usage - simple & indirect	determines the land usage - simple & indirect	Explicit factor of production and a component of household consumption	Indirectly considered
Household detail	1 type	11 types: 6 blacks, 5 white, in turn grouped by urban/rural & poor/medium/rich	3types: low, medium, high income	3types: low, medium, high income	1 type	1 type
Time dimension	Static	Static	Static	Dynamic: goods market adjust in short run via prices, factors market in the long run by factor mobility	Static	Static
International trade	Perfect trade	Perfect trade	Perfect trade with Rest of the World, Armington specification	Perfect trade with Rest of World, Armington specification		Small open economy, Armington Specification
Sectoral detail	14 sectors, 6 agriculture, 2 processing sectors , 1 other manufacturing sector, mining sector, & 4 service sectors	10 economic sectors (4 agricultural, 6 non-agricultural)	8 sectors, 3 agriculture, 5 others including Finance	8 sectors, 3 agriculture, 5 others including Finance	34 industries	Agriculture (Water intensive & non Water intensive), manufacturing & services (tourism direct/indirect)
Coverage/ Regional detail	San Joaquin Valley, California - USA	Olifants river Catchment in the Transvaal, South Africa	Region North Nevada USA	Region North Nevada USA	Adelaide, Canberra, Melbourne,& the major irrigation districts in the southern Murray-Darling Basin & Gippsland (Australia), 18 regions	Thailand
Simulations	Reduction in Water endowment	Reduction -15% of Water endowment (till reaching -75%), Land and W reform reduction by 5% (till reaching -25%)	Water from agriculture to recreational use 350'000 acre/feet	Water from agriculture to recreational use 300'000 acre/feet	Urban: water available to urban users in Adelaide, Canberra and Melbourne is -10%. Rural + Urban: Water available to all regions under consideration -10%. Allowing for trade among regions	tourism consumption +10%, -5% technical efficiency in primary factors of agriculture& piped W sector, -10% tourism price.
Investment		Endogenously determined		Endogenously determined dynamically by capital stock, sectoral profit & return rate		

Table 2A: Competition between Sectors (continued)

	Goodman 2000	Berrittella et al. 2006	Calzadilla et al. 2008	Sahlen 2008	Reid et al. 2007	Petterson et al 2004
Aim	Compare effects of Water storage increase and Water transfers	Estimate the impact of North-South W transfer project on China and the RoW	Analyze the economy-wide impacts of enhanced irrigation efficiency	the effects of international food and oil price increases and the role of Water scarcity explicitly expressed	How climate change will affect the contribution of Namibia's natural resources to its economy	Long run effects of trade under reductions in Water availability & Short run reductions based on observed allocation
Contribution to the literature	Comparison of settlement of new infrastructure and reallocation		Introduction of a differentiated model for irrigation and rain-fed crops based on an evolution of GTAP-W (version 1, Berrittella et al, 2007a & 2007b) and on GTAP-6.	Explanation on how to derive the "W factor" and the concept of Water self-provision vs. Water service provided by a Water authority		Introduces a highly detailed regional model for Water policies analysis
Main findings	Benefits from increased transfers is higher than those from increased storage	"non-market" simulation: positive welfare effect from increased production and export; "market" positive effects on China's welfare but the world as a whole would lose (because of deterioration of its terms-of-trade)	Water policy for improving irrigation efficiency in Water stressed regions is not beneficial for all. For Water stressed regions positive (welfare &demand for Water). For non-Water scarce regions the results are more mixed and mostly negative. Global water savings are achieved	Increase in oil and food prices are negative for the GDP. Where the supply of water is assumed to be constant, there will be even less ability to adapt, thus resulting in a more significant decrease in GDP than in the case where additional water sources are assumed to be available.	GDP, presented as % from base level, are negative for all climate change scenarios, while positive the first scenario, where commercial crop production is supposed to increase due to irrigation expansion	Allowing for both intra & inter-regional Water trade among irrigators substantially lessens the impact of reducing Water
Modelling approach	County level dynamic CGE	Multi-regional CGE model for China	GTAP-W and GTAP-6	Single Coutry CGE	Single Country CGE	Large scale standard CGE – TERM water model
Production function	CES	no substitutability	CES	CES for VA, Leontief for Intermediate Inputs, Leontief links VA and II.	CES for VA, Leontief for Intermediate Inputs, Leontief links VA and II.	Nested CES 3 level
Utility function	CES	C-D	C-D	Stone-Geary	Stone-Geary	Demand follows a LES
Factors of production	Labour, Land, Capital, Water	natural resources, land, labor and capital	natural resources, pasture land, rain-fed land, irrigated land, irrigation, labor and capital	Unskilled/ Skilled Labor, Capital, a Mixed Factor (farm owners' labor, capital & land) & Water	Unskilled/ Skilled Labour, Capital, Natural Resources (e.g. in the fish production fish is a factor..) & Water	Capital, Labor, Land, Water

Table 2A: Competition between Sectors (continued)

	Goodman 2000	Berrittella et al. 2006	Calzadilla et al. 2008	Sahlen 2008	Reid et al. 2007	Petterson et al 2004
Assumption about factors	Labour perfectly mobile, Capital sector specific, Land& Water usage specific	Capital and labour are perfectly mobile domestically, but immobile internationally. Land (imperfectly mobile) and natural resources are industry-specific	Capital and labor are perfectly mobile domestically, immobile internationally. Pasture land, rain-fed land, irrigated land, irrigation and natural resources are imperfectly mobile.	Capital and land fixed, labor mobile: skilled fully employed, unskilled unemployed	Capital and land fixed, labor mobile: skilled fully employed, unskilled unemployed	Land & Capital mobile at varying degrees, Labor fully mobile among regions
Role of Water	Production factor, can be stored, W availability modelled separately	Water is a product input for agriculture and distribution service. Water distribution has a price even with the excess of supply for Water which is mobile between agriculture sectors but immobile between agriculture and Water distribution services sector	only used for irrigation, it adds value to irrigated land in agriculture	Primary factor mainly used in agriculture, whose endowment is reduced.	Water directly considered, No climate change in the W sector	Production factor, supply fixed exogenously
Household detail	2 types: rural & urban	1 type	1 type	see above	1) Urban-wage& salaries in cash; 2) Urban-business activities including farming; 3) Urban-pensions, cash remittances (&others source); 4)Rural wage& salary; 5) Rural business activities & commercial farming; & 6) Rural subsistence farming, pensions, cash remittance	1 type
Time dimension	Dynamic	Static	Static	Static	Dynamic (20 years)	Static
International trade	Perfect trade with Rest of World	Armington specification	Armington specification	Armington specification	Armington specification	Each region treated as a small open economy
Sectoral detail	4 sectors: irrigation/ non-irrigation agriculture, services, manufacturing	17 sectors (of which 6agriculture, 1W distribution)	22 sectors, seven agricultural sectors (rice, wheat, cereal grains, vegetables & fruits)	26 sectors of production	26 sectors of production	48 Sectors
Related Studies		He/Chen 2004, Berrittella et al. 2007a&b		Reid et al 2007	Sahlen 2008	

Table 2A: Competition between Sectors (continued)

	Goodman 2000	Berrittella et al. 2006	Calzadilla et al. 2008	Sahlen 2008	Reid et al. 2007	Petterson et al 2004
Related Studies		He/Chen 2004, Berrittella et al. 2007a&b		Reid et al 2007	Sahlen 2008	
Simulations	Increased storage &/or transfers	"non-market solution": additional Water supply determines productivity gains. "market solution". Investment in infrastructure + increased productivity	Improvement in irrigation efficiency up to 73% in: (i) Water stressed (if at least for 1country within the region Water availability is less than 1,500 m^3/person/ y) developing regions. (ii) a bigger area (iii) all the 16 regions	Increase in (i) Oil and selected (ii) food prices (cereals, oil seeds and meat) and Water endowment is either (iii) perfectly elastic, or (iv) fixed free to move (v) between sectors or (vi) not.	5 climate change scenarios and no climate change. Interaction of different shocks. 2 technological paths: change in factor productivity land use for crop production, cereals, livestock; (-50%) in fish stock production	
Investment				Exogenous	Exogenous	Investment demand exogenously determined

	Diao et. al 2007	Horridge et al. 2003	Wittwer 2005			
Aim	Empirically evaluate conjunctive Water management in a GE setting	Simulate the short run effects of drought in 2002-3 in Australia	Effects of structural adjustments (e.g. W trade, 25 Million population) on other stock variables (e.g. natural resources, inputs, welfare) in the Australian economy			
Contribution to the literature	Extend Diao et al 2005 to include ground Water and surface Water as 2 intermediate sectors		Capturing W trade btw annual crops producers and perennial producers			
Main findings	Ground Water has a critical role in mitigating negative effects of climate change	Some households experimented relevant losses (up to 20% of their income). Reduction of agriculture output by 30%, of GDP by 1.6%, reduction in unemployment & worsening in the balance of trade.				
Modelling approach	Spatially disaggregated CGE	TERM multi-regional CGE model	TERM multi-regional CGE model			

Table 2A: Competition between Sectors (continued)

	Diao et. al 2007	Horridge et al. 2003	Wittwer 2005			
Production function	CES	nested multilevel CES/Leontief	nested multilevel CES/Leontief			
Utility function						
Factors of production	Labour, Capital, Land and Water	Labor, Capital, Land	Labor, Capital, Land			
Assumption about factors						
Role of Water	production factor					
Household detail	2 types: rural & urban	1 type /region	1 type /region			
Time dimension	Static	Dynamic	Dynamic			
International trade	small open economy	within regions in a nation free trade	within regions in a nation free trade			
Sectoral detail	71 agriculture, 66 crop, (irrigated/non-irrigated), 33 crop within the perimeters under Water Irrigation Authorities' control (21irrig, 11 rain-fed)	144 sectors	167 sectors			
Coverage/ Regional detail	7 Regions, 21 Perimeters (Morocco)	57 regions, Australia	58 regions, Australia			
Related Studies	Diao et al 2005, Roe et al 2005	GTAP model (Hertel, 1997)	GTAP model (Hertel, 1997), Horridge et al, 2003			
Simulations	increasing ground Water costs (+20%), Reduction in surface Water extraction (reduction of 1 standard deviation from a 10years average)	Outputs' shocks, productivity shocks related to rainfall deficit	Outputs' shocks, productivity shocks related to rainfall deficit			
Investment						

Table 2B: Water Pricing Policies and Tariffs

	Robinson & Gehlhar 1995	Decaluwé et al.1999	He & Chen 2004	Kojima 2005	Tirado et. al. 2004	Diao et al. 2005
Aim	likely impacts of policies focusing on Land& Water use in agriculture & economy-wide effects	comparative analysis of alternative water pricing policies to replace actual inefficient water pricing policies	Propose a shadow pricing approach to price of Water	simulating Water policy towards sustainable development	Analyze welfare gains associated wt better allocation of W rights through voluntary water exchanges (mainly agriculture urban sector)	Economy-wide gains from the allocation of surface irrigation Water decentralized mechanism for achieving this result in a spatially heterogeneous environment
Contribution to the literature		Comparison of Boiteux-Ramsey Pricing (BRP), Marginal Cost Pricing (MCP) & an arbitrary W pricing scheme	Application of a D-CGE Model focused on Water to China	Introduction of risk and international aid flow	First CGE study on Balearic Island, model different technologies for Water production (i.e. desalinization)	
Main findings		(i) BRP combined with a reduction in distorted production taxes (ii) is the most efficient in reducing Water consumption with a positive impact on Equivalent Variation and eliminating Water Management Authority subsidies	Need for accelerating the Water price reform in China	the safety improvements in the access to W for maintaining an appropriate level of investment in irrigation scheme; a positive trade liberalization. The international aid flow greatly mitigates negative welfare impacts of sustainable development.	Agricultural production is lower when there is a market for water rights than when there is no such a market	Water markets are likely to increase agricultural-output significantly
Modelling approach		Static CGE	Dynamic Shadow Prices approach based on multi-periods I-O optimizing model	single country dynamic CGE model	AGEM (Applied General Equilibrium Model),	Inter-temporal CGE (micro-macro)
Production function	CES for Labor & Capital linear aggregation for W & land	3 level CES and upper level Leontief (agriculture), multi nested CES, Leontief, C-D (industry) Leontief/ weibull/ additive aggregation (Water prod)		Leontief for Intermediate Inputs, C-D for factors	Nested CES, 5 level for agriculture, 4 for others	
Utility function		Cobb-Douglas Linear Expenditure System (CD-LES)			Stone-Geary	
Factors of production	Land, Labour (urban-rural), Capital, W	Labour, Land, Capital, Water	Labor, Capital, Water	Labor, Capital, Land, Water	Labor, Capital, Land, Water & sea Water	Rural-urban Labor, Capital, Land

Table 2B: Water Pricing Policies and Tariffs (continued)

	Robinson & Gehlhar 1995	Decaluwé et al.1999	He & Chen 2004	Kojima 2005	Tirado et. al. 2004	Diao et al. 2005
Assumption about factors	Land Capital, Labour freely allocatable				Labor perfectly mobile Land & Capital mobile across agricultural sectors	Labour mobile within agriculture. Capital & Labor are mobile within regions among agricultural sectors, Water mobile within irrigation district
Role of Water		factor (raw Water), intermediate input (domestic, irrigation Water), output (distributed Water)	Factor of production	two types of Water: untreated Water (used as either irrigation Water or raw Water to the public Water supply) & treated Water	Production factor (constant supply), input, output	production factor
Household detail	1 type	1type consuming two different Water at 2 different prices (North/South)		1 type	1 type	2 types: rural and urban
Time dimension	Static	Static	Dynamic	Dynamic	Static	Dynamic
International trade	Perfect trade				Small open economy, Armington Specification	small open economy, Armington specification
Sectoral detail	6 agricultural, 5 non agricultural	16 sectors	19 sectors	2 rural 1 urban sectors	10 sectors, 3 agricultural (irrigated, non-irrigated, livestock) 2 water sectors (traditional and desalinization)	88 activities, 82 agriculture, 66 crop, 5 livestock, 11 processing; 49 products, 23 agriculture
Coverage/ Regional detail	Egypt	Morocco 2 regions: North (Water rich)/ South (Water poor)	China	Morocco	Balearic Islands, Spain	Morocco, 20 Regions
Related Studies		Goldin and Roland-Holst (1995)			Tirado et al. 2006, Gómez, et al 2004	
Simulations		(i) BRP, (ii) BRP & tax reductions, (iii) BRP & income tax decrease, (iv) Marginal Cost Pricing, (v) Marginal Cost Pricing with tax decrease, (vi) arbitrary Water price increase.		(i) BRP & MCP , (ii) public expenditure on W infrastructure for raw, treated, & irrigation Water; (iii) 20 % reduction of import tax rate, (iv) +20% initial public capital stocks (because of international aid)	11 reduction of Water endowment (each of 5%), market for Water	creation of Water transfers (benchmark pre-reform)

Table 2B: Water Pricing Policies and Tariffs (continued)

	Muller 2006	Briand 2004	Briand 2007	Boccanfuso et al. 2005	Letsoalo et al. 2005	Velasquez et al. 2007	Van Heerden et al. 2008	Tirado et al- 2006
Aim	Effects of drought and cotton market reform on the agricultural sector and on the whole economy in Uzbekistan	Estimate production & employment impacts of Water policy pricing on the development of formal and informal Water distribution segments	$Marginal cost (mc) vs. average cost (ac) pricing comparison within climatic shocks	Study the distributional impact of privatization of Water utility & isolate winners/losers in Senegal	Analyze the triple dividend of Water consumption charges in South Africa: reduced Water use, more rapid economic growth, and a more equal income distribution	analyze the effects of an increase in the price of Water delivered to the agriculture-sector on the efficiency of Water consumption and the possible reallocation of Water to the remaining sectors	Study the impact of government investment to stimulate growth: Invest R1 billion in each of the 9 sectors of "Accelerated and Shared Growth Initiative in South Africa" (AsgiSA)	Study the impact of increasing technical efficiency of Water use in the tourism sector. Provide information on Water management options under the Water Directive Framework
Contribution to the literature	Empirical study on Uzbekistan economy	dual Water distribution systems	policy implications of the dynamic evolution of Water endowment	empirical study on Senegalese economy			assess of public government investment in water related project	extend Tirado et al (2004)
Main findings	Farmers do not necessarily benefit from liberalization of cotton market	primary Water is a production factor, drinking Water a consumption good	Marginal cost efficient in allocating Water and positive impact on food security, average cost not efficient		room for triple dividend of water policy, simultaneously reducing water scarcity, improving economic growth and reducing poverty	No significant Water saving in the agricultural sector, Better Water reallocation is achieved	continuing business as usual will lead to Water shedding. GDP +0,53% with largest contribution from livestock & timber plantation sectors. Employment of unskilled labor +1,3%, Water demand +2,2%, mainly from irrigation, timber & Water provisioning sectors.	Water efficiency measures do reduce pressure on Water ecosystem
Modelling approach	Standard static CGE	Static CGE	Sequential dynamic CGE model in imperfect competition	Integrated multi-households CGE model	UPGEM - Static CGE	Standard static CGE	UPGEM the University of Pretoria's CGE Model of South Africa.	
Production function	nested multilevel CES/Leontief	Nested CES, 3 Level for drinking water, 4 level for distribution, 5 level for agriculture	Nested CES, Natural monopoly and increasing return to scale	3 level of nested CES	Nested CES with an overall Leontief	Nested C-D under Armington assumption	CES	Multilevel CES
Utility function				C-D		C-D		Stone-Geary
Factors of production	Labor, Capital, Land, Water	capital, labor, primary Water	capital, labor, land, primary water	qualified/unqualified labor, capital, Water	Labor, Capital, Land	Labor, Capital, Land, Primary Water	labor, capital and land	Labor, Capital, Land, Water & sea Water

Table 2B: Water Pricing Policies and Tariffs (continued)

	Muller 2006	**Briand 2004**	**Briand 2007**	**Boccanfuso et al. 2005**	**Letsoalo et al. 2005**	**Velasquez et al. 2007**	**Van Heerden et al. 2008**	**Tirado et al- 2006**
Assumption about factors	rigid market for capital, all other factors may move freely from one sector to another. (exception: land allocated for cotton and wheat production		factor, intermediate input, output	Labor is mobile, Capital Fixed by sector	Capital fixed, rate of return on capital variable, Labor supply perfectly elastic, supply of land inelastic	Capital supply perfectly inelastic, in the labor market feedback btw real wage rate and the unemployment rate which represent rigidities in the labor market		Land used in agriculture & mobile among the irrigated & rain-fed crops. Capital is sector-specific except agriculture where it is mobile between irrigated & non-irrigation. Labour is mobile
Role of Water	production factor	factor, intermediate input, output	8 households groups 6 rural (distinguished by ecological areas)	intermediate input, 2 Water suppliers, W price is exogenous	Production factor	Factor subject to taxation	raw, distributed, irrigation tax	Raw Water primary non-transferable production factor that must be extracted. Drinking Water is produced& distributed by using raw Water, capital, labour and intermediates.
Household detail	1 type			3278 Households directly modelled	12 income, 4 ethnic groups	1 type		1 type
Time dimension	Static			Static	Static	Static	Static	Static
International trade	Armington specification	Small open economy, Armington specification		small open economy, Armington specification	Small open economy	Small open economy trading with Rest of the World, EU & rest of Spain		Small open economy, Armington Specification
Sectoral detail	20 sectors (7 agricultural)			18 sectors	39 sectors	16 sectors	9 Sectors	10 sectors, 3 agriculture (irrigated, non-irrigated, livestock) 2 water sectors (traditional and desalinization)
Coverage/ Regional detail	Uzbekistan Khorezm	Senegal		Senegal	South Africa	Andalusia, Spain	South Africa	Balearic Islands, Spain
Related Studies	"Economic and Ecological Restructuring of Land and Water Use in the Region of Khorezm Uzbekistan" (Vlek et al., 2000)	Briand 2007	Briand 2004	Boccanfuso et al. 2005			ORANI-G model (Horridge, 2002)	Tirado et al. 2004, Gómez, et al 2004

Table 2B: Water Pricing Policies and Tariffs (continued)

	Muller 2006	Briand 2004	Briand 2007	Boccanfuso et al. 2005	Letsoalo et al. 2005	Velasquez et al. 2007	Van Heerden et al. 2008	Tirado et al- 2006
Simulations	(i.) political: changes of variables or parameters in the model that is subject to domestic (economy-related) political decisions (tax and tariff rates). (ii.) physical/technological: changes in available factors of production (decrease of arable land, increase of population) and technological parameters (increase of total factor productivity because of technological progress). (iii.) external: changing export- and import-prices, thus changes in terms-of-trade.			Increase in Water tariff (recover operational costs), transfers to targeted poor households	ORANI-G model	5 Water tariff in agricultural sector	(i) Investment in the 9 components of AsgiSA (ii) water tariffs increase by 1 c/m3 (iii) extra revenue recycle (less government revenue and less taxes)	water saving measures in the tourism sector (-10% of current Water consumption) with +10% in the Water price
Investment				Determined by agents savings				Exogenous

Table 2C: Water and Trade Policies

	Diao & Roe 1994	Diao & Roe 2003	Berrittella et al. 2007(a)	Berrittella et al. 2007(b)	Berrittella 2008	Cirpici 2009
Aim	Effects of Water taxes on different countries sharing a Water aquifer	linkages between Water and trade policies	Effects of Water scarcity due to reduced availability of ground Water	Estimate the impact of hypothetical Doha-like liberalization of agriculture trade on Water use.	Role of Water resource & Water scarcity in the context of international trade	Assess agricultural tariff reductions
Contribution to the literature	Investigating through CGE the issue of water policies and externality in a shared Water aquifer setting		GTAP-W & virtual Water		GTAP-W & virtual Water	Empirical study on Turkish economy and agriculture
Main findings	Unilateral Water tax reduces own country GNP and rise other country. When both countries impose a tax cooperatively, GNP of both rises	Trade reform: opportunity to pursue Water policy reform. Creating a Water user-rights market post trade reform: (i) compensates for the decline in farmers' profits caused by the trade reform, (ii) raises the efficiency of Water allocation, with economy-wide benefits	Welfare losses larger in the non market situation. There are regional winner & losers from Water supply constraints. Because of the current distortions of agricultural markets, Water supply constraints could improve allocative efficiency; this welfare gain may more than offset the welfare losses due to the resource constraint.	(i) Change in regional Water use is less than 10%, even if agriculture tariffs are reduced by 75%. (ii) patterns are non-linear. Water use may go up for partial liberalization &down for more complete liberalization. (iii) trade liberalization tends to reduce Water use in Water scarce regions, & increase Water use in Water abundant regions, even though there no Water markets in most countries	Water taxes reduce Water use, & lead to shifts in production, consumption, and international trade patterns. Countries that do not levy Water taxes are nonetheless affected by other countries' taxes. Tradeoff between Water savings and welfare change	Turkish farmers are worse off with trade liberalization but those producing fruits and vegetables
Modelling approach	Simple stylized, 2 countries, 3 goods model	Inter-temporal, applied general equilibrium model, micro-macro/macro-micro linkages	GTAP-W model – GTAP5 with Water resources added	GTAP-W model – GTAP5 with Water resources added	Multi-region world CGE model	Static no-classic CGE model
Production function		C-D	8 level, nested CES	no substitutability (in the benchmark)	no substitutability (in the benchmark)	Nested Leontief/C-D for agriculture, C-D for non agricultural activities
Utility function		Inter-temporal	C-D	C-D	C-D	
Factors of production	Labour and Capital	Labour, capital, Land (irrigated/non-irrigated), Water	capital, labor, land, primary Water	natural resources, land, labor and Capital	natural resources, land, labor and capital	Labour, Capital, Land, Water

Table 2C : Water and Trade Policies (continued)

	Diao & Roe 1994	Diao & Roe 2003	Berrittella et al. 2007(a)	Berrittella et al. 2007(b)	Berrittella 2008	Cirpici 2009
Assumption about factors	Mobile across production sectors, immobile across countries	Labour & Capital can be re-allocate within the agricultural & non-agricultural sectors (but not between sectors)	Capital/Labor perfectly mobile domestically, immobile internationally	Capital and labor are perfectly mobile domestically, but immobile internationally. Land (imperfectly mobile) and natural resources are industry-specific	Capital and labor are perfectly mobile domestically, but immobile internationally. Land (imperfectly mobile) and natural resources are industry-specific	Labour and Capital fixed and mobile by sectors fully employed, water initially unemployed
Role of Water	Intermediate Input whose production is negatively affected by use of Water by the other country	use of Water in agriculture	Water is a production factor, a non-market good, Water combined with VA-energy nest and the intermediate inputs	Water is a production input for agriculture and distribution service. Water distribution has a price even with the excess of supply for Water which is mobile between agricultural sectors but immobile between agriculture and Water distribution services sector	Taxed input	No production activity for water which is a non man made factor.
Household detail	1 type	rural/urban	17 types, 1 for each region	17 types, 1 for each region	17 types, 1 for each region	1 type
Time dimension	Static	Dynamic	Static	Static	Static	Static
International trade	Perfect trade		Armington assumption	Armington specification	Armington specification	Armington assumption
Sectoral detail	3 sectors: agriculture, industry and Water production	20 sectors: 12 agriculture (6 irrigation, 6 rain-fed), 4 agriculture related, 4 non-agriculture	17 sectors (of which 6agriculture, 1 Water distribution)	17 sectors (7 agriculture, 10 non-agriculture)	17 sectors (7 agriculture, 10 non-agriculture)	5 sectors (4 agricultural, 1 non agricultural sectors)
Coverage/ Regional detail	Israel Jordan	20 Regions , Morocco	16 regions	16 regions	16 regions	Turkey – National level
Related Studies		Diao et al. 2005, Diao et al. 2008, Roe et al. 2005	GTAP (Hertel, 1997), GTAP-E (Burniaux & Truong, 2002), Berrittella et al (2005,2006, 2007b,2008)	GTAP (Hertel, 1997), GTAP-E (Burniaux & Truong, 2002), Berrittella et al (2005,2006, 2007a,2008)	GTAP (Hertel, 1997), GTAP-E (Burniaux & Truong, 2002), Berrittella et al (2005,2006, 2007a,2007b)	

Table 2C: Water and Trade Policies (continued)

	Diao & Roe 1994	Diao & Roe 2003	Berrittella et al. 2007(a)	Berrittella et al. 2007(b)	Berrittella 2008	Cirpici 2009
Simulations	Reduction of Land endowment given the reduced use of Water in agriculture	Water reform and trade liberalization	deny the use of ground Water	4 trade liberalisation scenarios on Water use. As the tariff reductions are differentiated between developed and developing countries	4 levels of tax	Reduction in tariff by 24% and comparison with the effective 8% increase in agricultural tariff on average
Investment		Financed by firms' retained profits		Determined by savings & distributed to equalize the expected future rates of return for all regions		Determined by private savings through exogenously fixed savings rate

Table 2D: CGE and Other Models

	Roe et al. 2005	Cakmak et. al 2008	Smajgl et al. 2005	Finoff & Capland 200
Aim	Analyzing the effects of top-down, bottom-up reforms on irrigation water allocation	Analyze potential effects of surging agricultural prices, climate change and urbanization	show that while CGE allow for quantifying the trade offs btw economic sectors, catchment and values, agent based models make land use decisions spatially explicit	Determines salinization & biomass - effects stochastic changes in salinity levels and an initial shock to species-population levels on the ecological and economic value
Contribution to the literature				new technique for modeling the "bio-economics" of a watershed
Main findings	trade reform higher effect with respect to Water reform, sequence of reform process is crucial	Reductions in GDP; increase in production in irrigated sectors – for climate change scenario; and in rain-fed activities – for the urbanization scenario and in the world price increase scenario.	reliability of results of the integrated model	how the model can be used to estimate the economic benefits of managing an ecosystem within its watershed. the model is capable of estimating compensating-variation welfare measures for threatened species that account for the full breadth of interdependencies that exist within the watershed.
Modelling approach	CGE+farm model	TACOGEM-W (based on Löfgren et al 2002)	CGE+Agent based model for integrated policy impact assessment	Bioeconomic model: ecosystem-regional economy model
Production function	Homogeneous of degree 1	CES	Nested CES 5 level	C-D (and CES for the composite good)
Utility function		CES		CES
Factors of production	Labour, Capital, Land	Labor, capital, irrigated land, rain-fed land & Water	Labor, Capital, Land, Water	Labor, Capital, Land, Water
Assumption about factors	Labour is an economy-wide factor, Capital is fixed at the perimeter level			
Role of Water	production factor	activity	Water cycle approximated at catchment level	
Household detail	5 household types	4 (geographical location) rural, 1 urban	1 type	1 type
Time dimension	Static	Static		"myopically dynamic" sequence of static optimizations
International trade	small open economy			Small open economy
Sectoral detail	88 activities, 82 agriculture, 66 crop, 5 livestock, 11 processing; 49 products, 23 agriculture	29 activities (20 agriculture, 9 non-agriculture)		5 sectors
Coverage/ Regional detail	Morocco 20 Regions	5 regions	Great Barrier Reef Region in Australia	Great Salt Lake (GSL) watershed ecosystem

Table 2D: CGE and Other Models (continued)

	Roe et al. 2005	Cakmak et. al 2008	Smajgl et al. 2005	Finoff & Capland 200
Related Studies				Finnoff and Tschirhart (2003, 2004)
Simulations	Water reform and trade liberalization	(i) increase in international prices of agriculture commodities; (ii) drought: (iii) climate change in agriculture.		shock the populations of algae, brine flies, and corixid bugs downward by 10% each, and simultaneously shock the populations of brine shrimp and Water birds upward by 10% each
Investment				Investment is a good which is purchased and represents a capital investment for future periods

Appendix 3: The Elasticities of the Model

A	Armington and CET elasticities by commodity
B	Elasticity of Substitution between Factors
C	Elasticity of market demand for commodity by Rural Households
D	Elasticity of market demand for commodity by Urban Households

Table 3A: Armington and CET elasticities by commodity

Commodity	SIGMAQ	SIGMAT
maize	1.750	0.750
wheat	1.750	0.750
rice	1.750	0.750
barley	1.750	0.750
cotton	1.750	0.750
other grain	1.750	0.750
sugarcane	1.750	0.750
coffee	1.750	0.750
tea	1.750	0.750
roots & tubers	1.750	0.750
pulses &oil seeds	1.750	0.750
fruits	1.750	0.750
vegetables	1.750	0.750
cut flowers	1.750	0.750
other crops	1.750	0.750
beef	1.750	0.750
dairy	1.750	0.750

poultry	1.750	0.750
other livestock	1.750	0.750
sheeps goats & lambs	1.750	0.750
fish	1.750	0.750
forestry	1.750	0.750
mining	1.750	0.750
meat	1.750	0.750
milling	1.750	0.750
sugar bakery & confectionary	1.750	0.750
beverage & tobacco	1.750	0.750
other manufactured goods	1.750	0.750
Textile & clothing	1.750	0.750
Leather & footwear	1.750	0.750
Wood & paper	1.750	0.750
Printing and publishing	1.750	0.750
Petroleum	1.750	0.750
Chemicals	1.750	0.750
Metals and machines	1.750	0.750
Non metallic products	1.750	0.750
Other manufactures	1.750	0.750
Irrigation Water	1.750	0.750
industrial water	1.750	0.750
Domestic water	1.750	0.750
Electricity	1.750	0.750
Construction	1.750	0.750
Trade	1.750	0.750
Hotels	1.750	0.750
Transport	1.750	0.750

Communication	1.750	0.750
Finance	1.750	0.750
Real estate	1.750	0.750
Other services	1.750	0.750
Adminsitration	1.750	0.750
Health	1.750	0.750
Education	1.750	0.750

Table 3B: Elasticity of Substitution between Factors

Activity	
maize	1,5
wheat	1,5
rice	1,5
barley	1,5
cotton	1,5
other grain	1,5
sugarcane	1,5
coffee	1,5
tea	1,5
roots & tubers	1,5
pulses &oil seeds	1,5
fruits	1,5
vegetables	1,5
cut flowers	1,5
other crops	1,5
beef	1,5
dairy	1,5

poultry	1,5
other livestock	1,5
sheeps goats & lambs	1,5
fish	1,5
forestry	1,5
mining	1,5
meat	1,5
milling	1,5
sugar bakery & confectionary	1,5
beverage & tobacco	1,5
other manufactured goods	1,5
Textile & clothing	1,5
Leather & footwear	1,5
Wood & paper	1,5
Printing and publishing	1,5
Petroleum	1,5
Chemicals	1,5
Metals and machines	1,5
Non metallic products	1,5
Other manufactures	1,5
Water	1,5
Electricity	1,5
Construction	1,5
Trade	1,5
Hotels	1,5
Transport	1,5
Communication	1,5
Finance	1,5

Real estate	1,5
Other services	1,5
Adminsitration	1,5
Health	1,5
Education	1,5

Table 3C: Elasticity of market demand for commodity by Rural Households

	hh0	hh1	hh2	hh3	hh4	hh5	hh6	hh7	hh8	hh9
Commodity	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
maize	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
wheat	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
rice	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
barley	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
cotton										
other grain										
sugarcane										
coffee										
tea										
roots & tubers	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
pulses &oil seeds	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
fruits	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
vegetables	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
cut flowers										
other crops										
beef	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
dairy	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
poultry	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7

other livestock	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
sheeps goats & lambs	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
fish	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
forestry	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
mining										
meat	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
milling	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
sugar bakery & confectionary	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
beverage & tobacco	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
other manufactured goods	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Textile & clothing	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Leather & footwear	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Wood & paper	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Printing and publishing	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Petroleum	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Chemicals	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Metals and machines	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Non metallic products										
Other manufactures	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Irrigation Water	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
industrial water	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
Domestic water	0,16	0,16	0,16	0,16	0,16	0,16	0,16	0,16	0,16	0,16
Electricity	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Construction Trade	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Hotels	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Transport	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1

Communication	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Finance	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Real estate	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Other services	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Adminsitration	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Health	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Education	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1

Table 3D: Elasticity of market demand for commodity by Urban Households

	hh0	hh1	hh2	hh3	hh4	hh5	hh6	hh7	hh8	hh9
Commodity	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
maize	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
wheat	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
rice	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
barley	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
cotton	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
other grain	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
sugarcane	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
coffee	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
tea	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
roots & tubers	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
pulses &oil seeds	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
fruits	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
vegetables	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
cut flowers	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
other crops	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
beef	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90

dairy	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
poultry	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
other livestock	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
sheeps goats & lambs	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
fish	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
forestry	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
mining	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90	0,90
meat	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
milling	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
sugar bakery & confectionary	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
beverage & tobacco	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
other manufactured goods	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Textile & clothing	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Leather & footwear	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Wood & paper	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Printing and publishing	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Petroleum	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Chemicals	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Metals and machines	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Non metallic products	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Other manufactures	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Irrigation Water	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
industrial water	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
Domestic water	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
Electricity	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Construction	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Trade	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05

Hotels	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Transport	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Communication	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Finance	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Real estate	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Other services	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Adminsitration	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Health	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05
Education	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05	1,05

Appendix 4 – The Algebraic Model Description

Table 4A: The Sets of the Model

$\alpha \in A$	activities
$\alpha \in ACES\ (\subset A)$	activities with a CES function at the top of the technology nest
$\alpha \in ALEO\ (\subset A)$	activities with a Leontief function at the top of the technology nest
$c \in C$	commodities
$c \in CD\ (\subset C)$	commodities with domestic sales of domestic output
$c \in CDN\ (\subset C)$	commodities not in CD
$c \in CE\ (\subset C)$	exported commodities
$c \in CEN\ (\subset C)$	commodities not in CE
$c \in CM\ (\subset C)$	imported commodities
$c \in CMN\ (\subset C)$	commodities not in CM
$c \in CT\ (\subset C)$	transactions service commodities
$c \in CX\ (\subset C)$	commodities with domestic production
$f \in F$	factors
$i \in INS$	institutions (domestic and rest of the world)
$i \in INSD\ (\subset INS)$	domestic institutions
$i \in INSDNG\ (\subset INSD)$	domestic non government institutions
$h \in H\ (\subset INSDNG)$	households

Table 4B: The Parameters of the Model

Tax rates	
ta_a	tax rate on producers output gross value
te_c	export tax rate
tf_f	direct tax rate for factor f
$\overline{tins}_i$	exogenous direct tax rate for domestic institution i
$tins01_i$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
tm_c	import tariff rate
tq_c	rate of sales tax
tva_a	rate of value-added tax for activity a

Parameters other than tax rates	
$cwts_c$	Consumer Price Index (CPI) weights
$dwts_c$	Domestic Sales Price weights
$ica_{c\,a}$	quantity of c as intermediate input per unit of activity a
$icd_{c\,c'}$	trade input of commodity c per unit of commodity c′ produced & sold domestically
$ice_{c\,c'}$	trade input of commodity c per unit of commodity c′ exported
$icm_{c\,c'}$	trade input of commodity c per unit of commodity c′ imported
$inta_a$	quantity of aggregate intermediate input per activity unit
iva_a	quantity of value-added per activity unit
$\overline{mps}_i$	base marginal propensity to save for domestic non governmental institution i

$mps01_c$	0-1 parameter with 1 for institutions with potentially flexed direct tax rates
pwe_c	export price (foreign currency)
pwm_c	import price (foreign currency)
$qdst_c$	inventory investment by sector of origin
$\overline{qg}_c$	base-year quantity of government demand
$\overline{qinv}_c$	base-year quantity of private investment demand
$shif_{i\,f}$	share for domestic institution i in income of factor f
$shii_{i\,i'}$	share of net income of i' to i ($i' \subset INSDNG.$; $i \subset INSDNG$)
$trnsfr_{i\,f}$	transfer from factor f to institution i
$\alpha^a{}_a$	efficiency parameter in the CES activity function
$\alpha^{va}{}_a$	efficiency parameter in the CES value-added function
$\alpha^{ac}{}_a$	shift parameter for domestic commodity aggregation function
$\alpha^q{}_c$	Armington function shift parameter
$\alpha^t{}_c$	CET function shift parameter
$\beta^h{}_{ach}$	marginal share of consumption spending on home commodity c from activity a for household h
$\beta^m{}_{ch}$	marginal share of consumption spending on marketed commodity c for household h
$\delta^a{}_a$	CES activity function share parameter
$\delta^{ac}{}_{ac}$	share parameter for domestic commodity aggregation function
$\delta^q{}_c$	Armington function share parameter
$\delta^t{}_c$	CET function share parameter
$\delta^{va}{}_{fa}$	CES value-added function share parameter for factor f in activity a
$\gamma^m{}_{ch}$	subsistence consumption of marketed commodity c for household h
$\gamma^h{}_{ach}$	subsistence consumption of home commodity c from activity a for household h

θ_{ac}	yield of output c per unit of activity a
ρ^{a}_{a}	CES production function exponent
ρ^{va}_{a}	CES value-added function exponent
ρ^{ac}_{a}	domestic commodity aggregation function exponent
ρ^{q}_{c}	Armington function exponent
ρ^{t}_{c}	CET function exponent

Table 4C: The Variables of the model

- Exogenous	
$\overline{CPI}$	consumer price index (PQ based)
$\overline{DTINS}$	change in domestic institution tax share (= 0 for base)
$\overline{FSAV}$	foreign savings (FCU)
$\overline{\mathrm{GADJ}}$	government consumption adjustment factor
$\overline{\mathrm{IADJ}}$	investment adjustment factor
$\overline{MPSADJ}$	savings rate scaling factor (= 0 for base)
$\overline{\mathrm{QFS}}_{\mathrm{f}}$	quantity supplied of factor
$\overline{TINSADJ}$	direct tax scaling factor (= 0 for base)
$\overline{WFDINST}_{f\,a}$	a wage distortion factor for factor f in activity a
MPS_i	marginal propensity to save for domestic non government institution
$DMPS$	change in domestic institution savings rates (= 0 for base)

- Endogenous

DPI	producer price index for domestically marketed output (PDS based)
EG	total current government expenditures
EH_h	households consumption expenditure
EXR	exchange rate (*LCU* per unit of *FCU*)
$GOVSHR$	government consumption share in nominal absorption
$GSAV$	government savings
$INVSHR$	investment share in nominal absorption
PA_a	activity price (unit gross revenue)
PDD_c	demand price for commodity produced and sold domestically
PDS_c	supply price for commodity produced and sold domestically
PE_c	export price (LCU)
$PINTA_a$	aggregate intermediate input price for activity a
PM_c	import price (LCU)
PQ_c	composite commodity price
PVA_a	value-added price (factor income per unit of activity)
PX_c	aggregate producer price for commodity
$PXAC_{a\,c}$	producer price of commodity c for activity a
QA_a	quantity (level) of activity
QD_c	quantity sold domestically of domestic output
QE_c	quantity of exports
$QF_{f\,a}$	quantity demanded of factor f from activity a
QG_c	government consumption demand for commodity
$QH_{c\,h}$	quantity consumed of commodity c by household h

$QHA_{a\,c\,h}$	quantity of household home consumption of commodity c from activity *a* for household *h*
$QINTA_a$	quantity of aggregate intermediate input
$QINT_{c\,a}$	quantity of commodity *c* as intermediate input to activity *a*
$QINV_c$	quantity of investment demand for commodity
QM_c	quantity of imports of commodity
QQ_c	quantity of goods supplied to domestic market (composite supply)
QT_c	quantity of commodity demanded as trade input
QVA_a	quantity of (aggregate) value-added
QX_c	aggregated marketed quantity of domestic output of commodity
$QXAC_{a\,c}$	quantity of marketed output of commodity *c* from activity *a*
$TABS$	total nominal absorption
$TINSi$	direct tax rate for institution i ($i \subset INSDNG$)
$TRII_{i\,i'}$	transfers from institution i' to i (both in the set INSDNG)
WF_f	average price of factor f
YF_f	income of factor f
YG	government revenue
YI_i	income of domestic nongovernment institution
$YIF_{i\,f}$	income to domestic institution i from factor

Table 4D: The Equations of the Model

PRICE BLOCK		
Import Price	$PMc = pwm_c * (1 + tm_c) * EXR + \sum_{c' \in CT} PQ_{C'} * icm_{cc'}$	$c \in CM$
Export Price	$PEc = pwe_c * (1 + te_c) * EXR + \sum_{c' \in CT} PQ_{C'} * ice_{cc'}$	$a \in ACES$
demand price for commodity c produced and sold domestically	$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} * icd_{cc'}$	$c \in CD$
value of sales in domestic market	$PQ_c * (1 + tq_c) * QQ_c = PDD_c * QD_c + PM_c * QM_c$	$c \in (CD \cup CM)$
value of marketed domestic output	$PX_c * QX_c = PDS_c * QD_c + PE_c * QE_c$	
output price for activity a	$PA_a = \sum_{c \in C} PXAC_{ac} * \vartheta_{ac}$	$a \in A$
price of aggregate intermediate input	$PINTA_a = \sum_{c \in C} PQ_c * \mathrm{ica}_{\mathrm{ca}}$	$a \in A$
value-added price	$PA_a * (1 + ta_a) * QA_c = PVA_a * QVA_a + PINTA_a * QINTA_a$	$a \in A$
consumer price index	$\overline{CPI} = \sum_{c \in C} PQ_c * \mathrm{cwts}_c$	

domestic producer price index	$DPI = \sum_{c\in C} PDS_c * \mathrm{dwts}_c$	

PRODUCTION AND TRADE BLOCK		
CES technology: Activity Production Function	$QA_a = \alpha^a{}_a [\delta^a{}_a * QVA_a^{-\rho^a{}_a} + (1-\delta^a{}_a) * QINTA_a^{-\rho^a{}_a}]^{-1/\rho^a{}_a}$	$a \in ACES$
CES technology: VA/Intermediate Inputs Quantity Ratio	$\frac{QVA_a}{QINTA_a} = (\frac{PINTA_a}{PVA_a} * \frac{\delta^a{}_a}{1-\delta^{a}{}_a})^{\frac{1}{1+\rho^a{}_a}}$	$a \in ACES$
Demand for Aggregate VA	$QVA_a = i\mathrm{va}_a * QA_a$	$a \in ALEO$
Demand for Aggregate Intermediate Inputs	$QINTA_a = i\mathrm{nta}_a * QA_a$	$a \in ALEO$
CES: VA Production Function	$QVA_a = \alpha^{va}{}_a (\sum_{f=1}^{n} \delta^{va}{}_{fa} * QF_{fa}^{-\rho^{va}{}_a})^{1/\rho^{va}{}_a}$	$a \in A$
CES: First Order Condition (FOC) for VA	$WF_f * \overline{WFDINST}_{fa} = PVA_a * (1-tva_a) * QVA_a * (\sum_{f=1}^{n} \delta^{va}{}_{fa} * QF_{fa}^{-\rho^{va}{}_a}) * \delta^{va}{}_{fa} * QF_{fa}^{-\rho^{v}}$	$a \in A$ $f \in F$
Intermediate demand for commodity c from activity a	$QINT_{ca} = i\mathrm{ca}_a * QINTA_a$	$a \in A$ $c \in C$
production function for commodity c and activity a	$QXAC_{ca} + \sum_{h\in H} QHA_{ach} = \vartheta_{ac} * QA_a$	$a \in A$ $c \in CX$

Output Aggregation Function	$QX_c = a_a^{ac} * (\sum_{a \in A} \delta_{ac}^{ac} * QXAC_{ac}^{-\rho_c^{ac}})^{-\frac{1}{\rho_c^{ac}-1}}$	$c \in CX$
FOC for Output Aggregation Function	$QXAC_{ac} = PX_c * QX_c * (\sum_{a \in A} \delta_{ac}^{ac} * QXAC_{ac}^{-\rho_c^{ac}})^{-1} * \delta_{ac}^{ac} * QXAC_{ac}^{-\rho_c^{ac}-1}$	$a \in A$ $c \in CX$
Output Transformation (CET) function	$QX_c = \alpha^t{}_c * [\delta^t{}_c * QE_c^{-\rho^t{}_t} + (1-\delta^t{}_t) * QD_c^{-\rho^t{}_c}]^{-1/\rho^t{}_c}$	c $\in (CE \cap CD)$
Export-Domestic Supply Ratio	$\frac{QE_c}{QD_c} = (\frac{PE_c}{PDS_c} * \frac{\delta_c^t}{1-\delta_c^t})^{\frac{1}{\rho_c^t-1}}$	c $\in (CE \cap CD)$
Export Supply	$QX_c = QE_c + QD_c$	c $\in (CE \cap CEN$ $) \cup$ $(CD \cap CND$
Composit Supply Armington Function	$QQ_c = \alpha^q{}_c [\delta^q{}_c * QM_c^{-\rho^q{}_c} + (1-\delta^q{}_c) * QD_c^{-\rho^q{}_c}]^{-1/\rho^q{}_c}$	$c \in$ $(CM \cap CD)$
Import/Domestic Demand Ration	$\frac{QM_c}{QD_c} = (\frac{PDD_c}{PM_c} * \frac{\delta_c^q}{1-\delta_c^q})^{\frac{1}{\rho_c^q-1}}$	$c \in$ $(CM \cap CD)$
Composit supply for non imported output and non produced inputs	$QQ_c = QD_c + QM_c$	c $\in (CM \cap CD$ $N) \cup$ $(CD \cap CMN)$
Demand for transaction services	$QT_c = \sum_{c' \in C'} (icm_{cc'} * QM_{c'} + ice_{cc'} * QE_{c'} * icd_{cc'} * QD_c)$	$c \in CT$

INSTITUTION BLOCK		
Factor Income	$YF_f = \sum_{a \in A} WF_f * \overline{WFDINST}_{fa} * QF_{fa}$	$f \in F$
Institutional Factor Incomes	$YIF_{if} = shif_{if} * [(1 - tf_f) * YF_f - trnsfr_{rowf} * EXR]$	$i \in INSD$ $f \in F$
Income of non government Domestic Institution	$YI_i = \sum_{f \in F} YIF_{if} + \sum_{i' \in INSDNG'} TRII_{ii'} + trnfr_{igov} * CPI + trnsfr_{irow} * EXR$	$i' \in INSDNG$
Intra institutional Transfers	$TRII_{ii'} = shii_{ii'} * [(1 - MPS_{i'}) * (1 - TINS_{i'}) * YI_{i'}$	$i' \in INSDNG$ $i \in INSDNG$
Households Consumption Expenditures	$EH_h * (1 - \sum_{i \in INSDNG} shii_{ih}) * (1 - MPS_h) * (1 - TINS_h) * YI_h$	$h \in H$
Households Consumption Demand for Marketed Commodities	$PQ_c * QH_{ch} = PQ_c * \gamma^m_{ch} + \beta^m_{ch} * (EH_h - \sum_{c \in C} PQ_{c'} + \gamma^m_{c'h} * \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} * \gamma^h_{ac'h})$	$c \in C$ $h \in H$
Households Consumption Demand for home Commodities	$PXAC_{ac} * QHA_{ach} = PXAC_{ac} * \gamma^h_{ach} + \beta^h_{ach} * (EH_h - \sum_{c \in C} PQ_{c'} + \gamma^m_{c'h} * \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} *$	$a \in A$ $c \in C$ $h \in H$
Investment Demand	$QINV_c = \overline{\mathrm{IADJ}} * \overline{\mathrm{qinv}}_c$	$c \in CINV$

Government Consumption Demand	$QC_c = \overline{\mathrm{GADJ}} * \overline{\mathrm{qg}}_c$	$c \in C$
Government Revenue	$YG = \sum_{i \in INSDNG} \mathrm{TINS}_i * YI_i + \sum_{f \in F} tf_f * YF_f + \sum_{a \in A} tva_a * PVA_a * QVA_a + \sum_{a \in A} ta_a * PA_a * QA_a + \sum_{c \in CM} tm_c * pwm_c * QM_c * EXR + \sum_{c \in CE} te_c * pew_c * QE_c * EXR + \sum_{c \in C} tq_c * PQ_c * QQ_c + + \sum_{f \in F} YIF_{govf} + trnsfr_{govrow} * EXR$	
Government Expenditure	$EG = \sum_{c \in C} PQ_c * QG_c + \sum_{i \in INSDNG} trnsfr_{igov} * \overline{CPI}$	

CONSTRAINTS BLOCK		
Factors Market	$\sum_{a \in A} QF_{fa} = \overline{\mathrm{QFS}}_{\mathrm{f}}$	$f \in F$
Composite Commodity Markets	$QQ_c = \sum_{a \in A} QINT_{ca} + \sum_{h \in H} QH_{ch} + QG_c + QINV_c + qdst_c + QT_c$	$c \in C$
Current Account Balance for the Rest of the World (FCU)	$\sum_{c \in CM} pwm_c * QM_c + \sum_{f \in F} trnsfr_{rowf} = \sum_{c \in CE} pwe_c * QE_c Q + \sum_{i \in INSD} trnsfr_{irow} + \overline{FSAV}$	
Government Balance	$YG = EG + GSAV$	
Direct Institutional Tax Rates	$TINS_i = \overline{tins}_i * (1 + \overline{TINSADJ} * tins01_i) + \overline{DTINS} * tins01_i$	$i \in INSDNG$
Institutional Savings Rates	$MPS_i = \overline{mps}_i * (1 + \overline{MPSADJ} * mps01_i) + DMPS * mps01_i$	$i \in INSDNG$
Savings Investment Balance	$\sum_{i \in INSDNG} MPS_i * (1 - TINS_i) * YI_i + GSAV + EXR * \overline{FSAV} =$ $\sum_{c \in C} PQ_c * QINV_c + \sum_{c \in C} PQ_c * qdst_c$	
Total Absorption	$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c * QH_{ch} + \sum_{a \in A} \sum_{c \in C} \sum_{h \in H} PXAC_{ac} * QHA_{ach} + \sum_{c \in C} PQ_c * QG_c + \sum_{c \in C} PQ$	
Ratio of Investment to Absorption	$INVSHR * TABS = \sum_{c \in C} PQ_c * QINV_c + \sum_{c \in C} PQ_c * qdst_c$	
Ratio of Government Consumption to Absorption	$GOVSHR * TABS = \sum_{c \in C} PQ_c * QG_c$	