

# **A general equilibrium approach to modelling multiple types and uses of water**

Jonas Luckmann <sup>a♦</sup>, Harald Grethe <sup>a</sup>, Scott McDonald <sup>b</sup>, Anton Orlov <sup>c</sup>, Khalid Siddig <sup>a</sup>

<sup>a</sup> Agricultural and Food Policy Group, University of Hohenheim, Germany

<sup>b</sup> Oxford Brookes University, UK

<sup>c</sup> CICERO - Center for International Climate and Environmental Research Oslo, Norway

September, 2013

## **Abstract**

Water scarcity is an increasing problem in many parts of the world and the management of water has become an important issue on the political economy agenda in many countries. As water is used in most economic activities and the allocation of water is often a complex problem involving different economic agents and sectors, Computable General Equilibrium (CGE) models have been proven useful to analyse water allocation problems, although their adaptation to include water is still relatively undeveloped. This paper provides a description of an integrated CGE model (STAGE\_W) that includes multiple types and uses of water, and for the first time, the recycling of wastewater as well as the provision of brackish groundwater as separate, independent activities with specific cost structures. The insights provided by the model are illustrated with an application to the Israeli water sector assuming that fresh water resources available to the economy are cut by 50%. We analyze how the Israeli economy copes with this shock if it reduces potable water supply compared with further investments in the desalination sector. The results demonstrate that the effects are slightly negative under both scenarios. Counter intuitively, the provision of additional potable water to the economy through desalination does not substantively reduce the negative outcomes. This is mainly due to the high costs of desalination which are currently subsidized, with the distribution of the negative welfare effect over household groups dependent on how these subsidies are financed.

**Keywords:** CGE, water, CES-nesting, wastewater reclamation, brackish water, desalination, Israel, STAGE\_W

---

♦Corresponding author. University of Hohenheim, Agricultural and Food Policy Group (420a), D-70593 Stuttgart, E-mail: luckmann@uni-hohenheim.de

# 1 Introduction

Water scarcity is an increasing problem in many parts of the world and, since the Dublin Statement of 1992 (WMO, 1992), water has been internationally recognized as a scarce resource. Globally agriculture accounts for about 70% of global fresh water withdrawals, mainly for irrigation. The industrial and energy sectors use about 19%, which is mostly cooling water, and 11% are used within municipalities, including domestic usage (FAO, 2013). Considering the share of irrigated agriculture in global crop production of about 40% (WWAP, 2012), it is evident that the availability of irrigation water is a key determinant of food security. Thus changes in the water sector affect peoples' welfare directly but also indirectly through food supply. With a growing global population, climate change and increasing competition from other economic sectors, water scarcity problems are expected to worsen in the future. Consequently the management of water has become an important issue on the political agenda in many countries (Dudu & Chumi, 2008) and thus there has been an increase in water related economic models and research.

Analysis of the economic implications of water allocation choices is needed to support the political decision making process. Since water is used in most economic activities and the allocation of water resources involves many economic agents and sectors with complex interactions, Computable General Equilibrium (CGE) models have proven useful to analyze the economic effects of water policies (Dudu & Chumi, 2008). However, the adaptation of these models to include the utilization of water resources is still relatively undeveloped. A major reason for this is the limited availability of databases that include the economic flows related to water and thereby provide the basis for calibrating a CGE model. The UN system of environmental-economic accounting for water (SEEA-Water) provides a well-articulated method for embedding water accounts within national accounts data as satellite accounts to a social accounting matrix: while it was adopted as an interim international statistical standard in 2007, it awaits revaluation after revision (UNSTATS, 2013).

This paper reports on the development of an integrated CGE model that includes multiple types and uses of water, and illustrates the insights from such a model. A brief review of the development of the behavioural relationships used in water focussed CGE models, in section 2, provides the context within which this model has been developed. The model incorporates different aspects of previously developed models and extends them to a form an integrated model capable of analyzing a wide range of scenarios within the water sector (section 3). In the fourth section, an application of the model to the Israeli water economy is presented. The fifth section elaborates on the results of our case study and discusses the features of our modelling approach as well as the possible extensions and further applications.

## 2 Water in general equilibrium models

Since the 1990s CGE models have been used to analyze water related issues and successive studies have introduced new aspects or approaches to water focussed CGE models. The empirical literature has been reviewed recently (Fadali *et al.*, 2012) so the emphasis here is on the various aspects of water supply and demand that have been added to the models. Early water-focussed CGE models concentrated on the economic effects of curtailing water use in the agricultural sector, either transferring it to other economic sectors or the environment. Since water rights in agriculture are mostly attached to land titles, such that land owners also own a certain quantity of water, water was either only indirectly included in the model equations as a fixed share of the value of land, e.g., Seung *et al.*, (1997) or as a factor of production that is used in a fixed ratio together with land in cropping activities, e.g., Berck *et al.*, (1991); Seung *et al.*, (1998).

These early studies treated the water sector as a passive rather than active agent responsible for the provision of usable water. An active water sector can be represented as an activity which builds dams and pumps groundwater to supply irrigation water to the agricultural sector (Decaluwé *et al.*, 1999) and/or produces drinking water that is delivered for use by other activities as an intermediate input commodity and for consumption by households (Gómez *et al.*, 2004), in contrast to an irrigated agricultural sector supplying itself by pumping untreated raw-water. The integration of a water-related activity transforming a raw water resource into a water commodity has subsequently been used in many other models, e.g., Tirado *et al.*, (2006); Juana *et al.*, (2011); Watson & Davies, (2011), and it has become standard to treat the water sector as a productive activity that produces inputs.

Water focussed CGE models typically assume that water can be substituted, to a greater or lesser extent, by other inputs, usually in a nested CES production system. A range of different substitution possibilities have been explored: in crop agriculture water has been a substitute for fertiliser (Decaluwé *et al.*, 1999), pumped water has been a substitute for a capital-land aggregate (Gómez *et al.*, 2004), and farmers have been able to substitute water with capital, to simulate a more efficient irrigation system and thereby decrease water intensity, if a tax on water consumption is introduced (van Heerden *et al.*, 2008). Substitution possibilities between irrigated, irrigable and dry land have also been modelled: irrigable land can become irrigated land, using fixed amounts of water per unit area, or be substituted with dry land and irrigable land without water (Dixon *et al.*, 2010), or by variations in the quantity of irrigation water applied (not fully irrigated land) (Calzadilla *et al.*, 2011). In models that include water consumption of non-agricultural sectors, water can often be substituted by capital, e.g., Gómez *et al.*, (2004), or a capital and labour aggregate, e.g., Qin *et al.*, (2012).

Other models include alternative water sources or different water qualities. A seawater factor can be an input to a desalination activity that produces potable water, comparable to the traditional water treatment activity, but with a different cost structure, e.g., Gómez *et al.*, (2004). Recycling of water can be introduced by differentiating between consumptive and non-consumptive uses of water, whereby the latter returns back to the system and can be used by other activities (Watson & Davies, 2011). This increases total water supply, if water is transferred from activities with high consumptive usage, e.g., irrigated agriculture, to activities with lower consumptive usage, e.g., municipalities. Similarly the electricity generation sector can internally recycle used (cooling) water and thereby save on abstraction and discharge fees (Rivers & Groves, 2013).

But water is not only important as an input but also as an environmental resource. For instance, specifying an ecological sector that absorbs the difference between total water endowment and

water use by consumers and producers enables an evaluation of the environmental implications of different supply and demand side water policies on the economy, e.g., Llop & Ponce-Alifonso (2012).

In many countries water prices charged differ between consumers. This has produced a number of models that assess the impact of different pricing policies: differences in (potable) water prices paid by agricultural users and municipalities can be captured by a water price distortion factor (tax or subsidy), e.g., Watson & Davies (2011), while applying different water tax rates to different sectors facilitates analyses of the effects of a differentiated water pricing system on the use of water as a production factor, e.g., Qin *et al.*, (2012). Differences in water prices inevitably have welfare and distributional implications. In most water focused CGE models the welfare effects are not immediately evident because they have a single household; multi-household CGE models can be used to provide more information on the distributional effects and investigate poverty issues, e.g., Boccanfuso *et al.*, (2005) and Letsoalo *et al.*, (2007).

While most water focussed CGE-models are applied at the country scale or even at the water shed level some have used augmented data from GTAP to calibrate global models. Water can be introduced as a factor used for agricultural production or delivered by the service sector to the rest of the economy, e.g., Berrittella *et al.*, (2007), and crop water demand is calculated based on evapotranspirational needs, assuming no losses due to irrigation inefficiencies. Moreover rainfed- and irrigated agriculture can be differentiated, e.g., Calzadilla *et al.*, (2011). In these studies, the water-factor is introduced with a value of zero, assuming that supply exceeds demand globally in the base situation; only after a water supply shock is introduced does water get a value. To date these studies have not been extended to non-agricultural activities due to a lack of data.

While water focussed CGE models have been developed to address specific aspects of water, none provided an integrated framework to depict the production and use of different water qualities that allows for substitution and price differentiation at different levels. The model developed for this study includes water production as a series of production activities that supply water to other activities and consumers, which enables a wide range of water related simulations. Additionally, as far as is known, this is the first model that includes the recycling of wastewater and the provision of brackish groundwater as separate and independent activities with specific cost structures.

### 3 An integrated approach to modelling the provision and use of multiple water qualities

The STAGE\_W model presented here encompasses multiple water related activities and allows for the production of water of the same quality (homogenous) by multiple activities. The various qualities of water are included as inputs in the production functions of the other sectors and can be consumed by households. Typically only potable water is also consumed as a final product by households. Several water related tax elements are included, allowing for a wide range of water policy simulations.

#### 3.1 Model structure

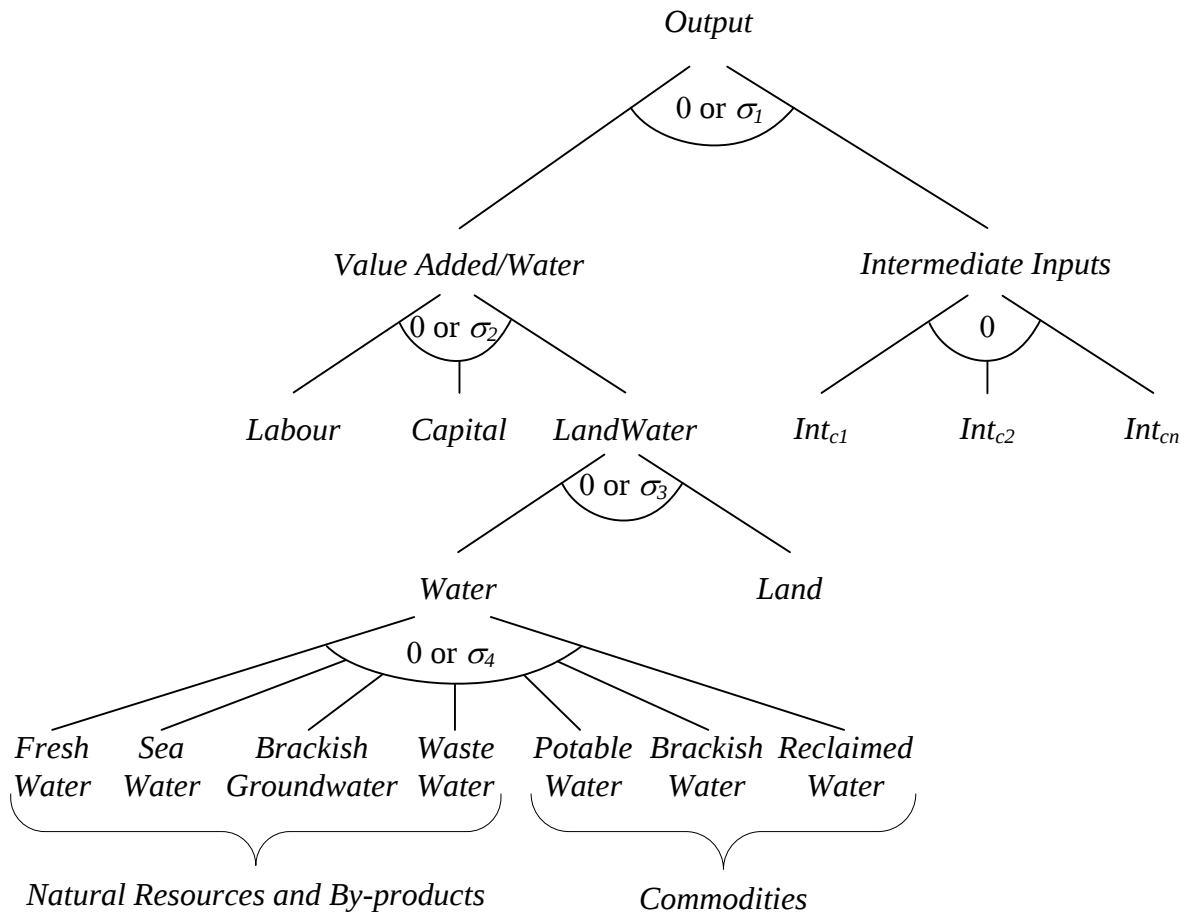
The STAGE\_W model is an extension of the STAGE model described in McDonald (2007)<sup>1</sup>, which is a descendant of the USDA ERS model of the early 90s (Robinson *et al.*, 1990). STAGE is a Social Accounting Matrix (SAM) based CGE model that has a mix of non-linear and linear relationships governing the behaviour of the model's agents. Households maximise utility subject to Stone-Geary utility functions and disposable incomes. Domestic agents consume composite aggregates of domestic and imported commodities that exhibit constant elasticity of substitution (CES), following Armington (1969). The distribution of domestically produced commodities among domestic demand and exports is governed by relative prices on these markets, using constant elasticity of transformation (CET) functions, which reflects imperfect product transformation. In the base version, domestic production is modelled as a two stage production process with either constant elasticity of substitution (CES) or Leontief technologies applied. At the first stage, intermediate input and value added generate the output of each activity based on CES technology. At the second stage, the use of intermediate inputs is in fixed proportions using Leontief technology, while the CES technology is used to form value added by primary production factors where the optimal ratio of factors is determined by relative prices. The base version also includes multiple tax instruments and allows for a wide range of factor market clearing conditions and macroeconomic closures.

The extension of the model to encompass multiple water qualities and production activities requires developing the production system to accommodate differences in the production technologies used to produce and use different types of water; the chosen production system involves a series of nested CES and/or Leontief technologies. The production system must also be modified to allow for the production of homogeneous commodities by multiple activities that have different cost structures. This class of model can only have more than one activity producing a homogenous commodity if some constraints and/or policy instruments are imposed on the model; in this case the model contains policy instruments – taxes/subsidies – in addition to resource/input constraints. The generic production system in the model is illustrated in Figure 1, where it is assumed that there are seven different types of water: fresh water, sea water, brackish groundwater, waste water, potable water, brackish water and reclaimed water: potable, brackish and reclaimed water are produced, waste water is a by-product, e.g., sewage effluent, and fresh water, sea water and brackish groundwater are natural resources. The production system illustrated in Figure 1 requires the development of a database that gives empirical content to the model. Depending on the database the model can easily be adjusted to include further water qualities, e.g., different purity levels of reclaimed water or exclude irrelevant ones for the country of interest.

---

<sup>1</sup> The code for the basic STAGE model is available from [www.cgemod.org.uk](http://www.cgemod.org.uk).

Figure 1: Production System for Activities in STAGE\_W



Source: own compilation.

The SAM (transactions) defines the inputs and outputs used in the base period while the water satellite accounts provide data on the physical quantities of water used by each activity and by domestic institutions, e.g., households. The user specifies the substitution possibilities at each level of the production nest by defining the substitution elasticities ( $\sigma$ ); for any elasticity set to zero the technology at that level of the nest is Leontief. Given this information the selection of the precise production system by each activity is automatically defined by the model code.

Consider first the water production activities. There is one activity for each water resource or by-product. Utilizing additional inputs and production factors it converts the resource or by-product to a water commodity, which is then used as an input in other activities or, in case of potable water, is consumed by households. On the other hand, one water commodity can be produced by several activities. In the example depicted in Figure 1 there are four natural resources and by-products from which three water commodities are produced, as the fresh water activity and the desalination activity both produce potable water. The fresh water activity produces potable water from fresh water without using neither any other water resources, by-products or commodities nor land and hence the value added/water aggregate collapses to an aggregation of labour, capital and fresh water, with the quantity of potable water produced equal to the quantity of fresh water entering the process. Desalination, by definition, requires the use of sea water as an input and, given the high cost, only produces potable water. Thus two activities with, typically, different cost structures produce an homogenous product. The basic STAGE model assumes that if the 'same' commodity is produced by different activities it is heterogeneous – a CES aggregate: this variant is adjusted so that

the option exists to define such commodities as homogenous. Given differences in costs structures it is necessary for the model to include instruments that ensure the supply price for the homogeneous is the same from each activity which will be described in section 3.2.

Where the 'leakage' of potable water plays a role then potable water would be an input to its own production; if (aggregate) water is produced with Leontief technologies the implied rate of leakage is fixed while if it is produced with CES technologies it implies the rate of leakage is a function of the price of potable water<sup>2</sup>.

Similarly the production of brackish and reclaimed water depend on the use, respectively, of brackish groundwater and waste water plus other inputs that may or may not include other types of water. By defining an exogenously determined extraction rate for the different water resources it is possible to condition the model so that water producing activities are limited to a predefined production quantity.

For other activities the various types of water are used according to the input structure contained in the database. Irrigated agricultural activities use (agricultural) land and one, or more, types of water. It is useful to segment these activities and commodities so as to distinguish between activities that can use the different types of water, e.g., to single out crops that are salt resistant and thus can use either brackish or potable water for irrigation or non-food crops that can be irrigated with reclaimed water. Generally non-agricultural activities do not use agricultural land but do use water of different types: in such cases the Land/Water aggregate collapses to the Water aggregate.

The model is flexible and adjusts to the usage of different water commodities and factors, e.g., land, by different activities. For example for service activities, which typically do not use marginal water<sup>3</sup> and land, the production structure collapses to two stages, such that potable water is combined with labour and capital in one value added nest.

Finally water resources that are reserved for environmental or other reasons, e.g., to guarantee a certain level of river flow, are not usually accorded a monetary value. Such resources are subtracted from the water resources available to the economy.

### **3.2 Water costs and pricing**

The price system in the STAGE model is also adjusted by introducing new tax instruments in the water sector. Potable water, irrespective of how it is produced, is usually supplied via only one water network and therefore is functionally homogenous. However if activities face different production structures and costs then multiple activities can only produce simultaneously if there are instruments in the price system that equalise the production costs. To allow for the simultaneous production of water by multiple activities, we introduce a (implicit) production subsidy ( $TX(a)$ ) for the desalination activity, which allows the production of potable water for the same supply price ( $PQS(c)$ ) despite of different costs (Figure 2). This reflects the fact that most desalination plants are either operated by governmental organisations or the government guarantees prices to the private operators so they recover the costs of desalination. Typically desalinated water is supplied to the final user at a price below its production costs, and hence subsidised, although the model allows for equalising prices through a mix of taxes and/or subsidies.

---

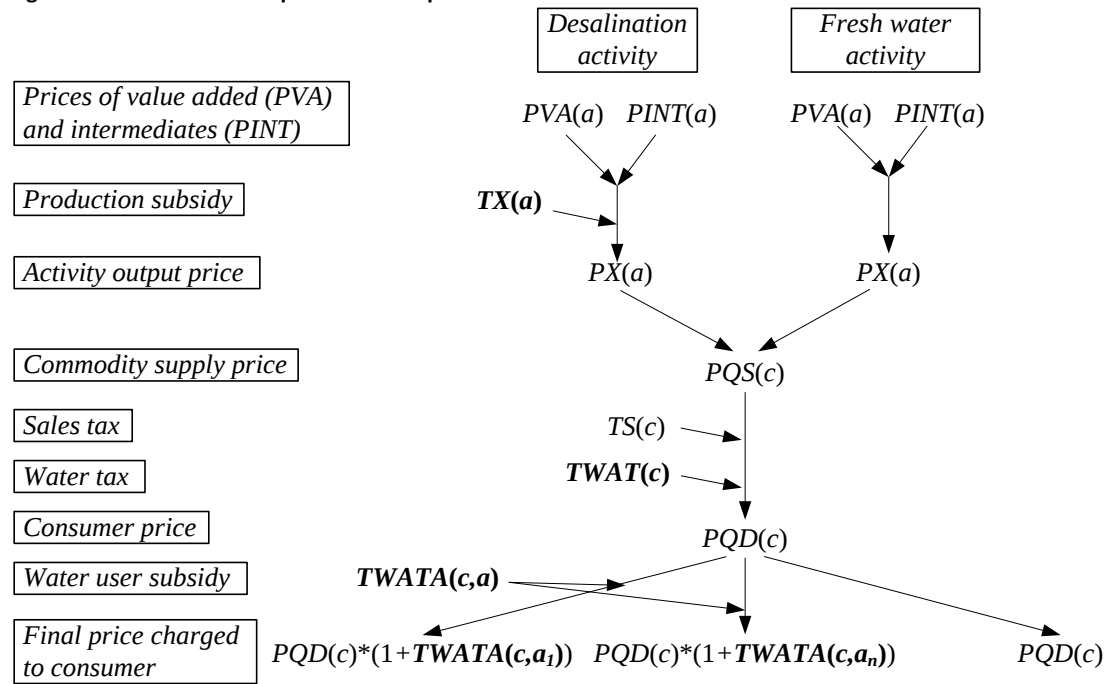
<sup>2</sup> This implies a long run scenario where the water authorities respond to changes in prices by 'adjusting' the rate of leakage. This differs from the approach suggested by Faust *et al.*, (2012).

<sup>3</sup> The term 'marginal water' is used as an umbrella for reclaimed wastewater and brackish water

Furthermore we introduce two water tax instruments to provide additional flexibility in terms of water price policies, such as differential pricing. First, we introduce an implicit commodity tax ( $TWAT(c)$ ) that is added to the existing sales tax ( $TS(c)$ ) and increases the commodity price to the highest level charged in the country under consideration. This is usually the price charged to municipalities ( $PQD(c)$ ). Second, all other agents receive a subsidy ( $TWATA(c,a)$ ) which can be adjusted individually to the  $n$  potable water using activities, allowing for many different final price levels (Figure 2).

The model allows for the use of satellite accounts for water that record physical quantities. Consequently the model can be calibrated with real quantities and prices and hence the model can isolate price and quantity results for the water commodities without further post-simulation-calculations. Where water satellite accounts are absent the model can be calibrated using implied relative prices and (value based) quantities. In such cases shocks to the model needs to be adjusted in line with the quantity units in the model; typically these are expressed as percentage changes in the base quantities.

**Figure 2: Differentiation of potable water prices**



Source: own compilation.

## 4 A case study

The model is applied to the water sector in Israel because of its complex water management and price system. Due to Israel's location in the dry-summer subtropical zone, its few inland water bodies and its relatively large population and level of water demand, water management is a crucial issue in Israel. Therefore a managed water sector, with metered water supplies to all consumers including agriculture and a distinct water pricing scheme have been put in place, whereby potable water prices charged are highest for municipalities (including households and the service sector), lower for the manufacturing sector and the lowest in the agricultural sector. In addition, Israel is among the world leaders in the use of alternative water sources (seawater, brackish groundwater and effluents).

Therefore in this implementation of the model there are four water production activities that produce three water commodities. The four activities are fresh water, desalination, wastewater recycling and pumping of brackish water activities, which produce three qualities of water – potable, brackish and reclaimed water. As described above, potable water can be produced either by the fresh water activity or by the seawater desalination activity and in Israel potable water prices are distinct between municipalities, manufacturing and agriculture. Therefore manufacturing and agricultural activities receive different levels of water user subsidies, while the price charged to municipalities is adjusted with the help of the water tax only. The two marginal water commodities, brackish water and reclaimed wastewater, are produced by respective activities and are used solely for irrigation.

### 4.1 Database and parameters

The starting database for our application is a SAM for Israel in 2004 (Siddig *et al.*, 2011). This SAM provides data on 45 commodities and activities, 38 production factor accounts, and 18 tax categories. The SAM furthermore includes 10 household types, first grouped according to ethnic background (Jewish and Non-jewish) and second according to income (5 quintiles), which allows for the analysis of distributional effects.

Water in the original SAM is represented by one sector. We use additional data provided by the National Water Authority (NWA) (in Zaide, 2009), FAO (2009) and the Israeli Statistical Office (CBS) (2009) to disaggregate this account. Costs of water supply and fees charged are calculated based on the Satellite Account of Water in Israel 2006<sup>4</sup> (CBS, 2011). After introducing the additional production factor and activities, the adjusted SAM is subjected to a balancing procedure that assures that dividing the value data of the water sector by the appropriate prices will yield the exact water quantities produced and consumed as reported by the NWA and CBS.

Furthermore, to make the water sector in the database reflect reality, we perform a pre-simulation because desalination barely existed in Israel before 2005. The pre-simulation adjusts the structure of the SAM, and its water accounts, to represent the situation in 2007. In 2007, 123 million m<sup>3</sup> of potable water were derived from desalination and the production of potable water by purifying fresh water decreased by about the same amount (CBS, 2010). The new SAM accounts for these changes and forms the basis for this case study.

---

<sup>4</sup> Although the Israeli Water Authority has raised water prices between 2004 and 2006 by more than the inflation rate due to the severe water shortage in Israel, the policy of differentiating prices did not change. Thus, water prices used in this study are already closer to cost recovery rates than they were in 2004 and therefore the magnitude of changes is smaller than if 2004 data were used. Therefore, using updated prices depicts the current situation more realistically.

All water producing activities use different shares of inputs and thus have different cost structures. Table 1 reports these cost structures for the case of Israel. The lowest row of the table shows the total production costs for each activity. For all activities, energy is the most important input since all activities require pumping water either from the ground at depths up to 1,000 m in case of brackish water (Brimberg *et al.*, 1994) or through micro-membranes for desalination, which is a very energy-intensive process (Garb, 2010). Capital shares are the highest for wastewater reclamation and desalination due to high investment requirements. The same holds true for consumables, which are mainly chemicals for wastewater reclamation and materials, such as membrane replacements, for desalination. Only the purification of fresh water relies on fresh water resources and thus has to pay an extraction levy that reflects the scarcity of the resource (Kislev, 2001). Finally, other inputs mainly include construction and other services, which are consumed by all water producing activities to a minor extent.

In this simulation the effects of further increasing the desalination capacity are investigated. New desalination plants are built according to current technologies. After that no major changes in production technology is possible, while the plants might produce potable water for decades. The same holds true for other infrastructure in the water sector, e.g., reclamation plants. Therefore we decide to exclude technological progress in this simulation and hence keep the cost structure for the activities which produce water commodities fixed by setting the substitution elasticities on all levels to zero; thus Leontief-technology is applied.

In non-water activities, the following elasticities of substitution are applied. For the combination of the 3 water commodities we use a medium to low substitution elasticity ( $\sigma_4$ ) of 0.8 (Sadoulet & de Janvry, 1995). This is mainly because the SAM used for this analysis includes aggregated activities of which not all components can use marginal water qualities. Also, although there is already a quite extended supply network for recycled wastewater in Israel the option to use marginal water does not exist in all localities. Lastly, farmers might decide not to switch to marginal water usage due to fears with respect to soil degradation caused by soil contamination or salinisation. For the combination of land and water, the substitution is governed by an elasticity ( $\sigma_3$ ) of 0.3 in accordance with Faust *et al.*, (2012). For the value added-water nest we apply an elasticity ( $\sigma_2$ ) of 0.8, which is slightly lower than the elasticity used by Berck *et al.*, (1991) for a high elasticity scenario. At the top-level we choose an elasticity ( $\sigma_1$ ) of 0.5.

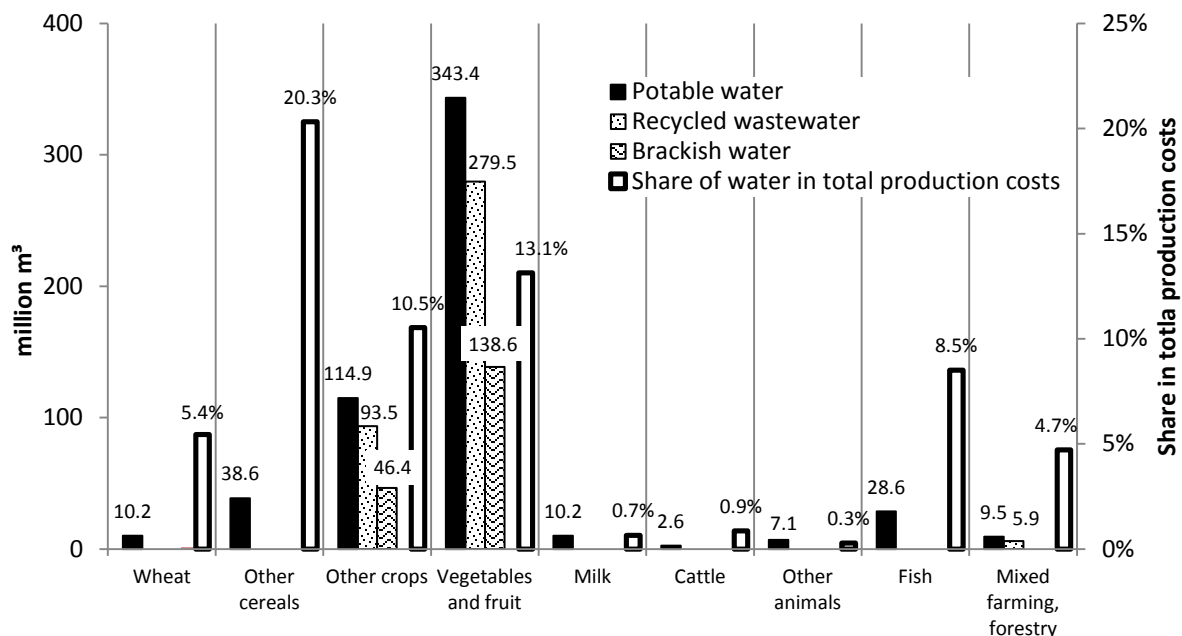
**Table 1: Cost structure and total production cost of water producing activities**

| Activities<br>Inputs [%]                         | Fresh water | Wastewater<br>recycling | Pumping of<br>brackish water | Desalination |
|--------------------------------------------------|-------------|-------------------------|------------------------------|--------------|
| Energy                                           | 30.2        | 30.0                    | 34.8                         | 40.0         |
| Labour                                           | 30.1        | 22.8                    | 34.2                         | 10.0         |
| Capital                                          | 14.6        | 20.0                    | 17.2                         | 20.0         |
| Consumables                                      | 8.3         | 20.0                    | 5.0                          | 14.5         |
| Fresh water                                      | 7.2         | 0.0                     | 0.0                          | 0.0          |
| Machinery                                        | 6.2         | 4.6                     | 5.0                          | 10.0         |
| Taxes                                            | 1.1         | 0.9                     | 1.3                          | 1.8          |
| Other                                            | 2.3         | 1.7                     | 2.6                          | 3.7          |
| Total production cost [2006 USD/m <sup>3</sup> ] | 0.56        | 0.16                    | 0.08                         | 0.91         |

Source: own compilation based on Feinerman & Rosenthal (2002), Beltran & Koo-Oshima (2006), Stevens *et al.*, (2008) and Siddig *et al.*, (2011).

Figure 3 depicts the water use in the Israeli agricultural sector according to the agricultural activities identified in the SAM. Agriculture is the biggest user of water in Israel and only some agricultural activities allow for the usage of marginal water. Within the agricultural sector, vegetable and fruit plantations are by far the largest water users, followed by the production of other crops, which include cotton, sunflowers, and other field crops. The usage of brackish water is limited to two sectors ('vegetables and fruit' and 'other crops'), since they include plants which are tolerant towards increased salinity levels, e.g., tomatoes, melons, and cotton. Due to sanitary restrictions, the usage of recycled wastewater is limited to these two activities and the 'mixed farming and forestry' activity. These activities either produce non-food outputs, e.g., cotton and timber products or crops for which lower sanitary restrictions apply since they can be irrigated without the water being in direct contact with the harvested parts, e.g., olive and citrus trees. No data on the use of marginal water in the different agricultural sectors is available. Therefore, brackish and reclaimed water commodities are split between activities which allow for their usage according to the total water consumption of their respective activities in the SAM.

**Figure 3: Water use in the Israeli agricultural sector in 2004 in million m<sup>3</sup> and share of water in total production costs**



Source: own compilation based on FAO (2009), Zaide (2009) and Siddig et al., (2011).

## 4.2 Closures and market clearing

Given the small share of the Israeli economy in the world market we assume world market prices to be fixed (small country assumption). The other closure rules are selected so that adjustments are all achieved within the solution period, e.g., there are no changes in future capital stocks or investment unfunded in the current period. The external balance also remains fixed, whereas the exchange rate is flexible. Moreover, we assume that savings are investment-driven. Regarding the government, we assume consumption of fixed quantities of all commodities and no changes in the savings rate as well as government transfers. A constant balance of the government account is achieved by adjusting the income tax rate households pay in a multiplicative way, whereas all other tax rates remain constant with the exception of water related taxes described in the scenario section hereafter. In addition, the volumes of enterprise demand and enterprise transfers to households remain unchanged.

Factor markets are cleared under the assumption that all factors of production are fully employed and mobile between activities, such that the model results reflect the long-term perspective after adjustments have taken place. The only exception to this is the fresh water resource, which has a fixed unit value whereas the quantity used is flexible. This allows for reduced usage of renewable water resources in the simulations.

### 4.3 Scenarios

We examine two scenarios to show different aspects of our model. Current water policy debates in Israel are concerned with the practicality of further increasing desalination capacity in spite of its high production costs and whether it would be more efficient to invest in water saving technology or improve water recycling. We investigate the implications of expanding desalination capacity in case of a strong decrease of available fresh water resources, which could be caused by political negotiations giving more water rights to the Palestinian Authorities or a potential Palestinian state that would most likely overlay Israel's most important ground water aquifer. Moreover there is pressure to reduce the off take of water from the Jordan River to prevent the sea level of the Dead Sea from further sinking; this would mean that less fresh water is available to the economy. To analyse this situation we fix the output of the fresh water activity to 50% of the base-volume. As we assume a fixed production technology, this results in a reduction of fresh water intake to the same extent. This reduction of fresh water supply is examined under two different scenarios regarding the development of the desalination activity: a fixed desalination capacity (Scenario Fix-dsal) and an extension of the desalination capacity (Scenario Exp-dsal).

#### 4.3.1 Fixed desalination capacity (Fix-dsal)

In the first scenario (Fix-dsal) we fix the output of the desalination activity to its current state. This means that total supply of potable water is strongly reduced, as the output reduction of the fresh water activity cannot be compensated by the desalination activity. To manage demand, the water authority therefore will be required to either allocate quotas to water users or increase prices. We decide here for the second option and therefore let the implicit water tax ( $TWAT$ ) adjust so that the consumer price ( $PQD$ ) for potable water adjusts to clear the market. We keep the implicit water consumer subsidy rates ( $TWATA$ ) unchanged, such that prices change at the same rate for all water users. The implicit subsidy to the desalination activity ( $TX$ ) is left flexible, such that the final activity price ( $PX$ ) remains the same as the price of the freshwater purification activity, even if price changes resulting from this simulation might affect the two potable water producing activities differently.

#### 4.3.2 Increased investment in desalination capacity (Exp-dsal)

In the second scenario (Exp-dsal) we let the desalination sector expand and keep the rest of the settings as in the Fix-dsal scenario. Only the subsidy to the desalination sector is kept constant, as in this case the model can adjust production quantities of the desalination sector by taking up production factors from the fresh water activity. We compare the results of this simulation to the Fix-dsal scenario to see whether water saving and substitution of potable water with marginal water commodities only, or the additional substitution possibility with desalinated water is more beneficial in terms of welfare and other economic indicators.

### 4.4 Results

#### 4.4.1 Water quantities

Due to the shock in fresh water resources of the two simulations, the output of the fresh water purification activity is halved (Table 2). In the first scenario (Fix-dsal) this leads to huge reductions of

potable water volumes available to the economy. For the three different economic sectors the cuts occur at almost the same rate, as the price ratio between sectors does not change and we assume similar elasticities of substitution. However, reductions in the manufacturing and service sectors are slightly larger compared to agriculture. This is due to the relatively low shares of water in total production costs of these activities (below 0.6%), and hence potable water can be substituted more easily with capital and other inputs, compared to agriculture, where the share can be more than 20% (Figure 3).

In the agricultural sector in the base 50% of the water requirements are fulfilled by marginal water commodities. In the Fix-dsal scenario supply of marginal water to the agricultural sector is further increasing by 5.7%. Therefore, although in this sector the the highest absolute reduction in potable water consumption occurs, total water consumption only drops by about 27%. Households, on the other hand, cut potable water consumption only by about 19% on average, whereby poorer households cut their consumption even less. This reflects the properties of the utility function (Stone-Geary) where poorer households are characterised by a lower own price elasticity of demand for water and the relatively smaller consumption share in poorer households. In the Exp-dsal scenario the reduced utilisation of the fresh water resource is almost entirely balanced by an increase in desalination (Table 2). Therefore only minor reductions of potable water usage occur in the different economic activities and with households. In addition, there is less need for substitution with marginal water qualities and thus the use of these water types only increases by 0.2%.

**Table 2: Changes in water demand and supply**

| Sector        | Water quality | Water quantity<br>[million m <sup>3</sup> ] |              |              | Change compared to base<br>[%] |             |
|---------------|---------------|---------------------------------------------|--------------|--------------|--------------------------------|-------------|
|               |               | Base                                        | Fix-dsal     | Exp-dsal     | Fix-dsal                       | Exp-dsal    |
| Agriculture   | Potable       | 565                                         | 233          | 553          | -58.7                          | -2.1        |
|               | Reclaimed     | 379                                         | 401          | 380          | 5.7                            | 0.2         |
|               | Brackish      | 185                                         | 195          | 185          | 5.6                            | 0.2         |
|               | Sum           | 1,129                                       | 829          | 1,118        | -26.6                          | -1.0        |
| Manufacturing | Potable       | 113                                         | 44           | 111          | -61.5                          | -2.2        |
| Services      | Potable       | 228                                         | 89           | 223          | -61.2                          | -2.3        |
| Households    | Potable       | 483                                         | 391          | 479          | -19.1                          | -0.9        |
| <b>Total</b>  |               | <b>1,954</b>                                | <b>1,352</b> | <b>1,931</b> | <b>-30.8</b>                   | <b>-1.2</b> |
| Fresh water   |               | 1,267                                       | 633          | 633          | -50.0                          | -50.0       |
| Desalinated   |               | 123                                         | 123          | 732          | 0.0                            | 495.4       |

Source: model results.

#### 4.4.2 Prices and taxes

The curbing of the fresh water activity results in less demand for inputs by this activity. The same holds true for other activities, which reduce production due to the reduced availability of potable water. Therefore production factors become cheaper and thus production costs of potable water sink by about 5% in the Fix-dsal scenario. The cost reduction effect is slightly lower for the desalination activity compared to the fresh water activity. Therefore the subsidy to the desalination activity needs to be increased slightly (by 1.8%).

As the total available quantity of potable water is reduced in the Fix-dsal scenario, the government needs to also reduce the demand for this commodity. As described above, we therefore allow for adjustments in the consumer price of water. In this case, the government would need to raise the

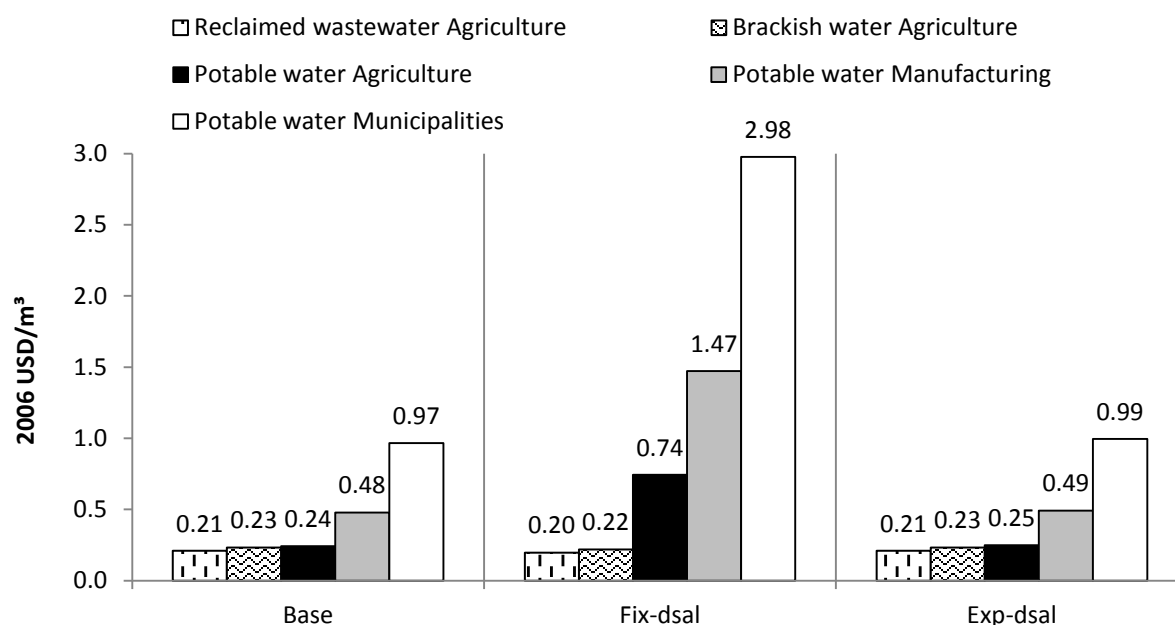
implicit tax on potable water ( $TWAT$ ) to 2.39 USD/m<sup>3</sup> to achieve the consumer prices shown in Figure 4, such that all water users experience the same percentage changes in water prices. For a sectorally differentiated price policy, additional adjustments in the implicit water consumer subsidy ( $TWATA$ ) would be necessary. The government revenue from the water sector including all taxes and subsidies increases from 10 Million USD in the base to 1,230 Million USD under the Fix-dsal scenario, which is 2.7% of total government income. This is recycled to households through a decline of income tax by 2.6%.

Due to the fall in factor prices, the production of marginal water commodities also becomes cheaper in this scenario. As  $TWAT$  is kept constant for these water commodities, this directly translates into a reduction of consumer prices by about 6%.

In the Exp-dsal scenario the expansion of the desalination activity absorbs many of the production factors released by the fresh water activity. Also as total water quantities available do not change much in this scenario, the production by other activities only change marginally, releasing very few additional production factors. Thus production prices of potable water as well as for marginal water commodities remain quite stable in this scenario (-0.1%). As the total volume of potable water supplied is reduced by 1.7% in this scenario, only minor adjustments in consumer prices are required (Figure 4); these are achieved by increasing  $TWAT$  by less than 0.03 USD/m<sup>3</sup>. For marginal water, the prices remain almost constant.

However, the expansion of the desalination capacity requires 216 Million USD of additional subsidies, which is equivalent to 0.4% of total government expenditure and turns the government balance from the water sector to become negative (-180 Million USD). To balance the government budget, household income tax is increased by 1.8% in this scenario.

**Figure 4: Changes in consumer prices of water commodities**



Source: model results.

#### 4.4.3 Production

The output of most commodities is only slightly altered in both scenarios and total production is even slightly increasing in the Exp-dsal scenario. Especially in the manufacturing and service sectors, water

represents only a small share in total inputs and thus can be substituted to the extent required rather easily. Some of the activities in these sectors do not use water. However, in some agricultural activities, such as the production of non-wheat-cereals water constitutes to up to 20% of total production costs (Figure 3). Therefore, in the Fix-dsal scenario in which potable water prices increase drastically, domestic cereal production decreases by 17%, which is largely compensated by increased imports. Water intensive activities which allow for the substitution with marginal water commodities such as the production of vegetables and fruit experience a smaller drop in production (3.2%). However, the production of other crops including cotton, sunflowers, and other field crops, shrinks by 14% in the Fix-dsal scenario, although potable water can be substituted with marginal water in this activity as well. This is due to the high world market dependency of this activity, as about half of the domestic output is exported and about the same quantity is imported, too. As the Israeli currency is appreciating in the Fix-dsal scenario by about 5.6%, imports become cheaper relative to domestic production and exports are less profitable. This results in activities producing goods which are internationally traded being less profitable.

#### **4.4.4 Welfare and macroeconomic results**

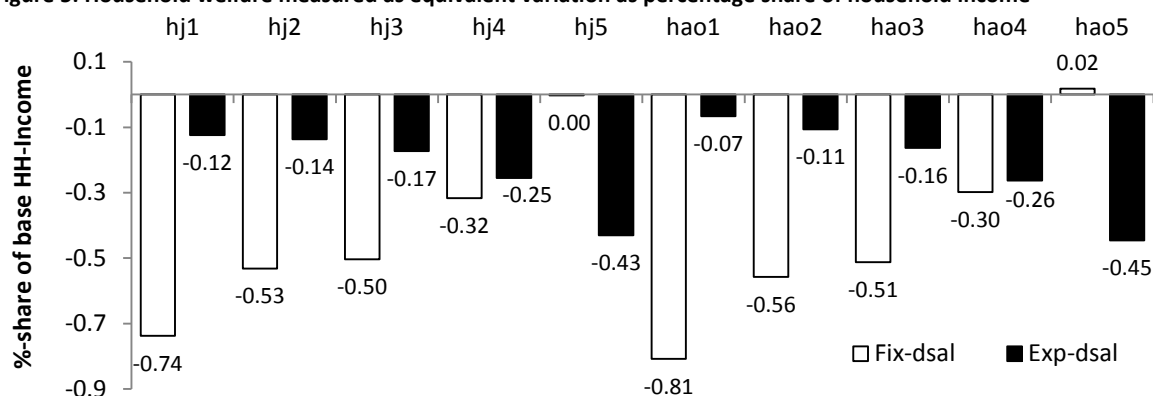
Due to the small share of the water sector in the total economy and the small share of households' expenditures on water, the effect of the two simulations on households' welfare are small. Nevertheless, the increasing potable water price affects households in several ways. Directly, due to the higher prices of tap-water households have less dispensable income available to spend on other commodities. Additionally, household income decreases as wages fall in both scenarios.

In the Fix-dsal scenario this leads to a reduction in household income by between 4.3% and 5.2%, whereby poor household groups are more affected as wages fall by between 5.8% and 7.7% of which the highest drops occur to agricultural workers. Enterprise income, from which especially rich households derive up to 32% of their total income, only drops by 5.8%.

On the other hand consumer prices of non-water commodities fall by up to 5.9%, with the lowest reductions occurring in agricultural and food products. Additionally the direct household tax rate is reduced by 2.6%, as the government receives more income from the increased water taxes. This is not enough to offset the income losses, and welfare declines. Poor households are more negatively affected than rich ones, as they have a higher share of water and food in total expenses, more labour in agriculture, less capital income, and benefit less from the tax reduction. Therefore, the equivalent variation (EV) as a percentage share of total household income in the base becomes negative especially for poorer household groups (Figure 6). Only the richest non-Jewish households can profit very slightly from the new situation, as they have the highest share of income from enterprises and thus are least affected from income losses, such that the positive effects dominate.

In the Exp-dsal scenario, the negative effects are smaller but affect the richer households more. This is due to the fact that household income is sinking only falling marginally (about 0.1%), with income from capital reducing by more than income from labour and thus richer households are affected more. The main negative effect in this scenario comes from the increase in the direct tax on households by 1.8% which is required to finance the increased subsidies due to the expansion of the desalination activity. This results in a transfer from tax payers to water users, which is positive for poor households. The slight drop in most non-water consumer prices (a maximum of 0.1%) is not enough to compensate the losses (Figure 5).

**Figure 5: Household welfare measured as equivalent variation as percentage share of household income**



*hj: Jewish households; hao: Arab and other households; 1-5: Income-quintiles*

*Source: model results.*

Similarly the small size of the water sector means that the macroeconomic effects are marginal. Real GDP, measured by expenditure, and total absorption drop by only 0.2% in both scenarios.

We also tested different ways to compensate gains or losses in water taxes in the simulations reported in this paper, e.g., through government transfers, additive adjustments of the household tax or adjustments of other tax instruments, and found that the macro results and the scale of welfare effects were quite similar. There were only small changes in the way the welfare reduction is distributed over different household groups.

## 5 Discussion/Conclusion

### 5.1 Case study

Our simulation results suggest that although the reduction of water resources is rather drastic, the extent to which it affects the national economy after adjustments is relatively minor. If we allow the desalination capacity to expand, total potable water consumption is reduced by less than 2%, as fresh water resources, which are less available, are substituted by desalinated water, which is a perfect substitute.

However, even if we do not allow for this possibility, potable water is largely substituted with other factors of production and intermediate inputs, such that the output of several industrial and service activities only drops by less than 1% although water consumption is reduced by more than 60% and thus the final macroeconomic effect is also small. One can debate, whether the substitution elasticities selected from the literature for this analysis might be too high for a rather extreme shock as presented in this paper.<sup>5</sup> However, the literature suggests that by investing in internal wastewater recycling industries can reduce their fresh water intake by up to 95% without reducing production (Levine & Asano, 2002). As this model reflects a rather long term perspective one can argue that the chosen elasticities reflect such a shift of production technology of substituting potable water with capital and other inputs required for internal wastewater recycling.

When comparing the two scenarios, we observe that the welfare and macroeconomic outcome is quite similar, although one might expect that the expansion of the desalination capacity might have a more beneficial effect, as this activity produces a perfect substitute for potable water derived from fresh water resources. However, the expansion of the desalination sector causes additional distortions as the production of potable water from seawater is highly subsidised. That in this simulation poorer households are less negatively affected compared to richer household groups if desalination capacity is increased, is also largely due to the way these subsidies are financed (in this case by an additive increase of the household income tax). To mitigate these effects and reduce these distortions in the water sector, additional adjustments in the water pricing scheme would be required such that the water price paid by consumers covers the costs of provision.

It is important to recognise that the results reported here for Israel reflect the specific economic context; Israel is relatively wealthy with water representing a relatively small share of economic activity and costs. In other economies the relative importance of agriculture and water may be appreciably greater and hence the implications of changes in water supply are likely to be orders of magnitude greater. Applications of this type of integrated model to such economies is a future research agenda.

### 5.2 General modelling approach

In recent years, water has increasingly gained attention in CGE modelling. Despite the difficulty of allocating a value for this resource, several models have been developed that incorporate water in different ways. However, so far water related CGE models have been focused mostly on specific aspects of water, e.g., water in the agricultural sector, potable water, etc. The approach presented in this paper aims to depict water in a more holistic way. This allows simulating a wide range of

---

<sup>5</sup> Sensitivity analyses show that under the assumption of substitution elasticities in the production structure being reduced by 50%, output of agricultural activities is reduced by up to 40%, output of industrial and service sectors drops by up to 8%, real GDP falls by 0.5% and the EV would be up to -2.3% of base household income.

scenarios and for more detailed analyses. Simulations show, that substitution and adjustment processes at various levels may significantly mitigate the effects of water scarcity. These include, among others, the substitution of water by other production factors (land, labour, capital), options to increase the share of recycled water, water saving technologies in private households as well as enterprises, changes in the composition of production, especially in agriculture, and investments in the desalination of water or upgrading marginal water sources. Not considering these options in water related CGE applications quite likely substantially affects simulation results.

Possible further simulations could include for example technical change aspects in the desalination sector, as desalination costs have decreased substantially in recent decades, mainly due to energy saving technologies (Karagiannis & Soldatos, 2008). For the next decade it is even expected that desalination will become an energy producing process through forward osmosis (Spiritos & Lipchin, 2013). Additionally, a stricter standard for the quality of recycled wastewater has been introduced in Israel in recent years. It requires upgrading the wastewater quality such that it can be used for irrigation with fewer restrictions (Lavee & Ash, 2013). Recycled water of this quality may be suitable for many industrial purposes and thus one could analyse the effects of the increased substitution possibilities versus the higher cost of upgrading the wastewater.

An integrated approach allows investigations of changes in the pricing policy as a tool to influence water consumption in more detail. The implicit water user tax (*TWATA*) allows for adjustments of the water tax charged in a differentiated way. This allows for example to increase the water price for the agricultural sector alone, which is the biggest water consumer in most countries. In addition, it would be possible to introduce cost recovery pricing for all users, to estimate the welfare effects of the current cross-subsidisation.

This model can be easily adapted to different situations and other countries or databases. However, when applying the suggested approach to other countries, a careful evaluation of substitution elasticities is required, as the water saving potential might be lower due to limited access to water saving technologies. The water saving potential may also be higher if potable water is available at a low price in the country under consideration, such that water inefficient technologies such as flood irrigation still prevail. Furthermore, Israel is among the world leaders in the use of recycled wastewater (Lavee & Ash, 2013), while many poorer countries do not have adequate wastewater recycling facilities, e.g., Weldesilassie *et al.* (2009), let alone the infrastructure to supply treated wastewater to farms. However, the model developed in this study can be used to simulate the economic effects of developing such an infrastructure. Finally, countries may be landlocked and thus the option to desalinate sea water would not apply which would simply result in an empty activity in the current model structure.

## References

- Armington, P.S., 1969. A Theory of Demand for Products Distinguished by Place of Production. *Staff Papers - International Monetary Fund*, 16(1), 159-178.
- Beltrán, J.M. & S. Koo-Oshima, 2006. *Water desalination for agricultural applications*. Land and water discussion paper. FAO Water Resources, Development and Management Service Land and Water Development Division.
- Berck, P., S. Robinson & G.E. Goldman, 1991. The use of computable general equilibrium models to assess water policies. Boston: Kluwer Academic Publisher. Ch. 25. pp.489-509.
- Berrittella, M., A.Y.a.R.K. Hoekstra, R. Roson & R.S.J. Tol, 2007. The economic impact of restricted water supply: A computable general equilibrium analysis. *Water Research*, 41(8), 1799-1813.
- Boccanfuso, D., A. Estache & L. Savard, 2005. *A Poverty Inequality Assesment of Liberalizytion of Water Utility in Senegal : A Macro-Micro Analysis*. Working Paper. Université de Sherbrooke, Groupe de Recherche en Économie et Développement International (GRÉDI).
- Brimberg, J., A. Mehrez & G. Oron, 1994. Economic Development of Groundwater in Arid Zones with Applications to the Negev Desert, Israel. *Management Science*, 40(3), 353-363.
- Calzadilla, A., K. Rehdanz & R.S. Tol, 2011. Water scarcity and the impact of improved irrigation management: A computable general equilibrium analysis. *Agricultural Economics*, 42(3), 305-323.
- CBS, 2009. *Statistical Abstract of Israel 2008*. Tech. rep. The Israeli Central Bureau of Statistics (CBS). Jerusalem, Israel.
- CBS, 2010. *Statistical Abstract of Israel 2010*. Tech. rep. The Israeli Central Bureau of Statistics (CBS). Jerusalem, Israel.
- CBS, 2011. *Satellite Account of Water in Israel 2006*. Tech. rep. The Israeli Central Bureau of Statistics (CBS). Jerusalem, Israel.
- Decaluwé, B., A. Patry & L. Savard, 1999. *When Water is no Longer Heaven Sent: Comparative Pricing Analysis in an AGE Model*. Cahiers de recherche. Université Laval - Département d'économique.
- Dixon, P.B., M.T. Rimmer & G. Wittwer, 2010. *Modelling the Australian government's buyback scheme with a dynamic multi-regional CGE model*. Centre of Policy Studies/IMPACT Centre Working Papers. Centre of Policy Studies/IMPACT Centre, Monash University, Clayton, Australia.
- Dudu, H. & S. Chumi, 2008. *Economics of Irrigation Water Management: A Literature Survey with Focus on Partial and General Equilibrium Models*. Policy Research Working Paper. Sustainable Rural and Urban Development Team, Development Research Group, The World Bank, Washington D.C., USA.
- Fadali, E., K. Rollins & S. Stoddard, 2012. *Determining Water Values with Computable General Equilibrium Models*. A Report submitted for presentation at "The Importance of Water to the U.S. Economy: Technical Workshop, September 19, National Academy of Public Administration, Washington D.C., USA.

- FAO, 2009. ISBN: 978-92-5-106316-3 *Irrigation in the Middle East region in figures AQUASTAT Survey – 2008*. Tech. rep. Food and Agricultural Organization of the United Nations (FAO) Food and Agricultural Organization of the United Nations (FAO). Rome, Italy.
- FAO, 2013. *Aquastat - Water uses*. Available at: [http://www.fao.org/nr/water/aquastat/water\\_use/index.stm](http://www.fao.org/nr/water/aquastat/water_use/index.stm) [Accessed 14 April 2013]. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy.
- Faust, A.-K., C. Gonseth & M. Vielle, 2012. *The economic impact of climate driven changes in water availability in Switzerland*. working paper. École Polytechnique Fédérale de Lausanne. Switzerland.
- Feinerman, E. & G. Rosenthal, 2002. *The Range of Existing Circumstances*. Tech. rep. Water Strategy Man Ruhr-University Bochum, Germany.
- Garb, Y., 2010. Water Wisdom: Preparing the Groundwork for Cooperative and Sustainable Water Management in the Middle East. Rutgers University Press. Ch. Desalination in Israel: Status, Prospects, and Contexts. pp.238-45.
- Gómez, C.M., D. Tirado & J. Rey-Maqueira, 2004. Water exchanges versus water works: Insights from a computable general equilibrium model for the Balearic Islands. *Water Resources Research*, 40(10), W105021-W1050211.
- Juana, J.S., K.M. Strzepek & J.F. Kirsten, 2011. Market efficiency and welfare effects of inter-sectoral water allocation in South Africa. *Water Policy*, 13(2), 220-231.
- Karagiannis, I.C. & P.G. Soldatos, 2008. Water desalination cost literature: review and assessment. *Desalination*, 223, 448-456.
- Kislev, Y., 2001. *The Water Economy of Israel*. Discussion Paper. Center for Agricultural Economic Research, Department of Agricultural Economics and Management, Hebrew University of Jerusalem, Israel.
- Lavee, D. & T. Ash, 2013. *Water Policy in Israel: Context, Issues and Options*. Springer-Publishing, Dordrecht, Netherlands. Ch. Wastewater Supply Management. pp.83-99.
- Letsoalo, A., J. Blignaut, T. De Wet, M. De Wit, S. Hess, R.S.J. Tol & J. Van Heerden, 2007. Triple dividends of water consumption charges in South Africa. *Water Resources Research*, 43(5),
- Levine, A.D. & T. Asano, 2002. *Water Recycling and Resource Recovery in Industry: Analysis, Technologies and Implementation*. IWA Publishing, London, UK. Ch. Water reclamation, recycling and reuse in industry. pp.29-52.
- Llop, M. & X. Ponce-Alifonso, 2012. A never-ending debate: Demand versus supply water policies. A CGE analysis for Catalonia. *Water Policy*, 14(4), 694-708.
- McDonald, S., 2007. *A Static Applied General Equilibrium Model: Technical Documentation STAGE Version 1: July 2007 DRAFT*. Tech. rep. Department of Economics & Strategy Oxford Brookes University, UK.
- Qin, C., Y. Jia, Z. Su, H.T.A. Bressers & H. Wang, 2012. The economic impact of water tax charges in China: A static computable general equilibrium analysis. *Water International*, 37(3), 279-292.

- Rivers, N. & S. Groves, 2013. The Welfare Impact of Self-supplied Water Pricing in Canada: A Computable General Equilibrium Assessment. *Environmental and Resource Economics*, 1-27.
- Robinson, S., M. Kilkenny & K. Hanson, 1990. *The USDA/ERS computable general equilibrium (CGE) model of the United States*. Tech. rep. U.S. Dept. of Agriculture, Economic Research Service, Agriculture and Rural Economy Division. Washington, DC, USA.
- Sadoulet, E. & A. de Janvry, 1995. *Quantitative Development Policy Analysis*. The Johns Hopkins University Press Baltimore and London.
- Seung, C.K., T.R. Harris & T.R. MacDiarmid, 1997. Economic impacts of surface water reallocation policies A comparison of supply-determined and CGE models. *Journal of Regional Analysis and Policy*, 27(2), 55-76.
- Seung, C.K., T.R. Harris, T.R. MacDiarmid & W.D. Shaw, 1998. Economic impacts of water reallocation: A CGE analysis for the Walker River Basin of Nevada and California. *Journal of Regional Analysis and Policy*, 28(2), 13-34.
- Siddig, K., D. Flaig, J. Luckmann & H. Grethe, 2011. *A 2004 Social Accounting Matrix for Israel Documentation of an Economy-Wide Database with a Focus on Agriculture, the Labour Market, and Income Distribution*. Working Paper. Institute of Agricultural Policy and Markets University of Hohenheim, Germany.
- Spiritos, E. & C. Lipchin, 2013. Water Policy in Israel: Context, Issues and Options. Springer-Publishing, Dordrecht, Netherlands. Ch. Desalination in Israel. pp.101-23.
- Stevens, D., J. Kelly & J. Hannaford, 2008. *Sustainable water sources, innovations and applications Opportunities for Australia*. Tech. rep. Arris Pty Ltd, Richmond, Australia.
- Tirado, D., C.M. Gómez & J. Lozano, 2006. Efficiency improvements and water policy in the Balearic Islands: A general equilibrium approach. *Investigaciones Economicas*, 30(3), 441-463.
- UNSTATS, 2013. *About SEEA-Water*. Tech. rep. United Nations Statistics Division (UNSTATS). New York, USA.
- van Heerden, J.H.a., J.a. Blignaut & M.b. Horridge, 2008. Integrated water and economic modelling of the impacts of water market instruments on the South African economy. *Ecological Economics*, 66(1), 105-116.
- Watson, P.S. & S. Davies, 2011. Modeling the effects of population growth on water resources: A CGE analysis of the South Platte River Basin in Colorado. *Annals of Regional Science*, 46(2), 331-348.
- Weldesilassie, A.B., O. Frör, E. Boelee & S. Dabbert, 2009. The economic value of improved wastewater irrigation: A contingent valuation study in Addis Ababa, Ethiopia. *Journal of Agricultural and Resource Economics*, 34(3), 428-449.
- WMO, 1992. *The Dublin statement on water and sustainable development*. Tech. rep. World Meteorological Organization (WMO). Geneva, Switzerland.

WWAP, 2012. *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Tech. rep. World Water Assessment Programme (WWAP) of the UNESCO. Paris, France.

Zaide, M., 2009. *Drought and arid land water management*. Tech. rep. UN Department of Economic and Social Affairs, Division for Sustainable Development. New York, USA.