Modeling sectorally differentiated water prices:

An application to the Israeli water economy

By

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Abstract

The Israeli water sector is largely controlled by the state. Potable water is supplied to different user groups at differentiated prices, whereby municipalities pay fees above the supply costs and thereby partially cross-subsidize the water delivered to the agricultural and the manufacturing sector at lower fees. However, due to climate change and population growth water scarcity is an increasing problem in Israel and therefore pricing systems which better manage the water demand are much discussed in the country.

This study employs a general equilibrium model, which specifically depicts the Israeli water sector to simulate the economy-wide effects of the introduction of new pricing systems. We analyze two pricing schemes under discussion and compare the results regarding the economic outcomes and the water saving potential to the base situation. We find that an abolishment of the cross-subsidization and a water fee which covers supply costs charged to all users would be the most favorable one regarding all aspects analyzed.

Keywords: CGE, CES-nesting, water, wastewater reclamation, desalination, Israel

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1. Introduction

Water in Israel is a very scarce resource (Fleischer et al., 2008). With an annual provision of less than 250 m³ per capita, Israeli supply lies 50% below the threshold of severe scarcity according to the internationally recognized Falkenmark indicator (Tal, 2006). The long term potential of total annual renewable supply of freshwater from natural sources is estimated to be around 1,800 million m^3 (Israeli Water Authority in Shachar, 2009). However, depending mainly on winter-precipitation in the north this amount is subject to variation.

At the moment Israel is facing the worst water supply crisis since the beginning of record keeping more than 80 years ago. The Israeli National Water Authority (NWA) declared recently that drought conditions are continuing for eight consecutive years now (Jerusalem Post, 2012). In 2008 therefore replenishment rates of aquifers were found to be at only about 830 million m³ (Shachar, 2009). This, together with an increasing demand for potable water due to economic growth and immigration has led to a situation of overexploitation of the renewable water resources within the country. Already by 2010 the cumulative deficit amounted to about 1.5 - 2 million m³, which is close to Israel's annual total water consumption (NIC, 2010). Also the quality of potable water resources is deteriorating. With groundwater tables falling due to over-extraction, especially the coastal aquifer is prone to seawater intrusion resulting in an increasing salinity level of potable water in Israel (Zaide, 2009).

To meet the annual demand of about 2,220 million m^3 and to mitigate overexploitation of aquifers, alternative water sources have been explored in recent years. As a result of these efforts, about 387 million m^3 reclaimed wastewater and 123 million m^3 desalinated seawater have been supplied in addition to natural sources in 2007 (CBS, 2010). By the same year the extraction of brackish groundwater, mainly directly used for irrigation of salt tolerant crops, has increased to 235 million m³ (Shachar, 2009).

On the consumption side, agriculture uses about 1,190 million m^3 of water (about 50% of which is recycled wastewater and brackish water), followed by municipalities[1] with 760 million m^3. Around 120 million m^3 are consumed by the manufacturing sector. Furthermore, about 100 million m^3 are diverged to Jordan as agreed in the 1994 peace treaty and to the Palestinian water authority. Finally, 50 million m^3 are reserved for the rehabilitation of natural habitats (Figure 1) (MEP, 2005; Zaide, 2009; CBS, 2010).

The problem of water scarcity is expected to become more severe in the future, as climate models predict an increase in temperature and changes in rainfall amount and distribution (Fleischer et al., 2008). In addition, domestic water demand in Israel is increasing mainly driven by population growth (Bar-Shira et al., 2006; MARD, 2006) and the question of transferring more water rights of shared aquifers to the Palestinian National Authorities is yet to be negotiated within the peace process (Saleth and Dinar, 1999; MARD, 2006). However, the agricultural sector receives potable water at subsidized prices (Zhou, 2006). The same holds true for the manufacturing sector to a lower extend, which is conflicting with the declared aim to restrain water consumption (NIC, 2010).

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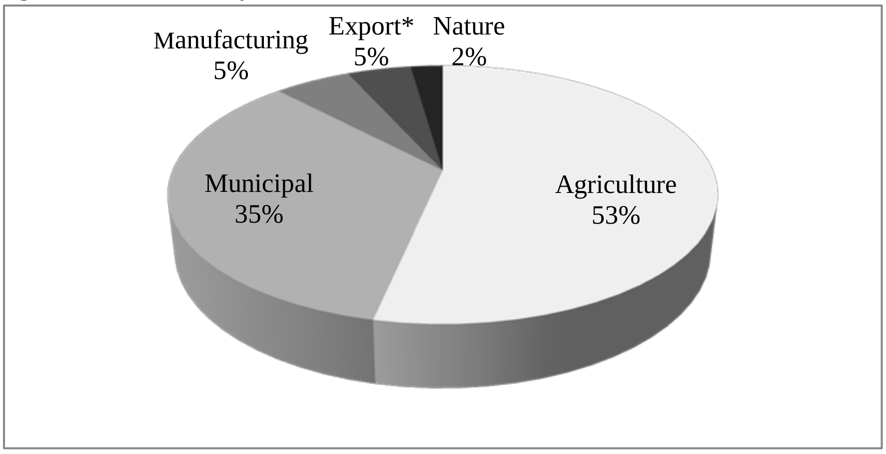
[1] Municipality consumption is composed of intermediate consumption by the service sector and final household consumption

Figure 1: Water consumption in Israel in 2007



**water diverged to Jordan and the Palestinian Water Authority*
Source: MEP, 2005; Zaide, 2009; CBS, 2010, own calculations.

This study applies an extended version of the standard STAGE model (McDonald, 2009), which is a single country computable general equilibrium (CGE) model. The model is combined with a detailed Social Accounting Matrix (SAM) for Israel that is developed for the year 2004 (Siddig et al., 2011). With this approach, two pricing schemes under discussion are simulated and the outcomes of both scenarios are compared to the current situation with respect to the economic outcomes and the total water use.

The remaining part of this paper is structured as follows: Chapter 2 further elaborates on the Israeli water economy with background information about the relevant policies. Chapter 3 introduces the database used for analysis, highlights the extensions accommodated to the standard STAGE model for the purpose of this study, and describes the specifications of the simulation scenarios. In chapter 4, the scenario results are presented and discussed. Chapter 5 gives some concluding remarks.

2. The Israeli Water Economy

The Israeli law recognizes groundwater as well as surface water as state property (FAO, 2009). In 2007 a National Water Authority (NWA) was established to implement the water law and centrally govern the water resources within Israel. Also the NWA is in charge of setting the fees for water consumption.

Most of the country's water resources are managed by Mekorot, a state owned company, which distributes about 70% of the water supply to agriculture, industry and municipalities (Zaide, 2009). The remaining 30% are provided by municipal and private wells. Private water extraction from the ground is metered and subject to an extraction fee. This fee is kept on a level, which assures that in most cases costs are comparable to the price of water provided by Mekorot (Kan, 2011).

In recent years, amplified by a lasting drought, the exploration of new water sources came on the agenda of the NWA. Although a large share of wastewater is reclaimed and distributed via a separate network to farmers for irrigation since the mid-1980s already, the NWA aims to further increase this share, from 78% in 2007 to 100% by 2020 and by that to provide about 600 million m³ of reclaimed wastewater to the agricultural sector (Shachar, 2009).

Furthermore, in 2002 the Israeli government took the decision to install five new reverse osmosis seawater desalination plants to be constructed within few years. These desalination plants are built on the base of BOT (Build-Operate-Transfer) contracts by private companies. The first plant opened in 2005 in Ashkelon with a capacity of 100 million m^3 per year (Tal, 2006). The aim is to produce 505 million m^3 annually by 2013 (Zaide, 2009) and finally 750 million m^3 per year till 2020 (FAO, 2009). By that, most of the municipal demand shall be covered by desalinated seawater.

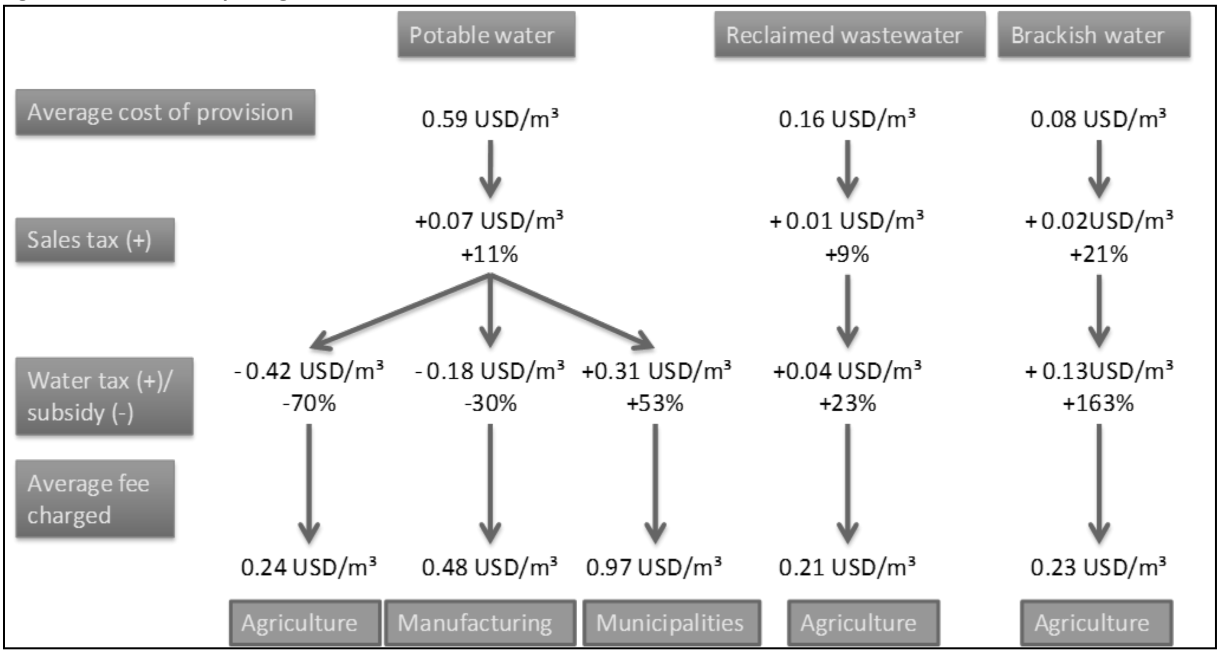
Besides increasing supplies the NWA aims at decreasing potable water consumption. This particularly applies to the agricultural sector as the main water user, which the NWA tries to shift towards a higher usage of reclaimed wastewater. This is achieved by firstly cutting the fresh-water quotas allocated to agriculture and secondly by increasing the subsidized freshwater price for farmers (Amir and Fisher, 2000; Zhou, 2006). This makes using reclaimed wastewater more attractive, as this water is supplied at a lower price (Figure 2). However, due to sanitary constraints not all reclaimed wastewater can be used for unrestricted irrigation, as this requires a special tertiary treatment. Up to now this quality is only reached by the biggest reclamation facility operated by Mekorot, which is producing about 35% of the total reclaimed wastewater in Israel (Shachar, 2009).

In addition, the usage of brackish groundwater mainly for the irrigation of salt tolerant crops such as cotton, tomatoes and melons has been fostered, such that the consumption of brackish water in agriculture rose from 76 million m^3 in 1996 to 201 million m^3 in 2007 (MARD, 2006; Shachar, 2009). Especially in the southern Negev desert, there are large fossil aquifers which still can be exploited.

To manage the water demand the NWA implements a complex pricing regime, with prices being differentiated according to user-group (municipalities including households and services, industry and agriculture) as well as between different water qualities (saline, reclaimed, fresh). This pricing scheme particularly favors the agricultural sector which is charged relatively low water prices, whereas the price charged from municipal users is higher than the costs of supply (Figure 2). As most of the water in Israel is supplied by a state owned company which receives financial support from the government, taxes and subsidies in the water sector are not explicitly charged but can be calculated as the difference between the costs of water provision and the fee charged to each consumer group (Zhou, 2006).

To increase efficiency in the Israeli water economy, a report by the National Investigation Committee on the subject of the management of the water economy in Israel (NIC) published in 2010 suggested several principals for the management of national water resources. Among these are that, water needs to be regarded as a raw resource and its extraction needs to be limited to an amount below the average annual recharge. To achieve this, a water pricing scheme reflecting total water supply costs, including extraction, transportation and also environmental costs was recommended (NIC, 2010). Some scientists even go further and recommend to increase the price level to the costs of desalination, which would be the marginal water costs in Israel, as for this price every quantity required could be supplied (Goldfarb and Kislev, 2006; Zhou, 2006).

Figure 2: Israeli water pricing scheme



Source: own compilation based on CBS, 2011.

3. Methods

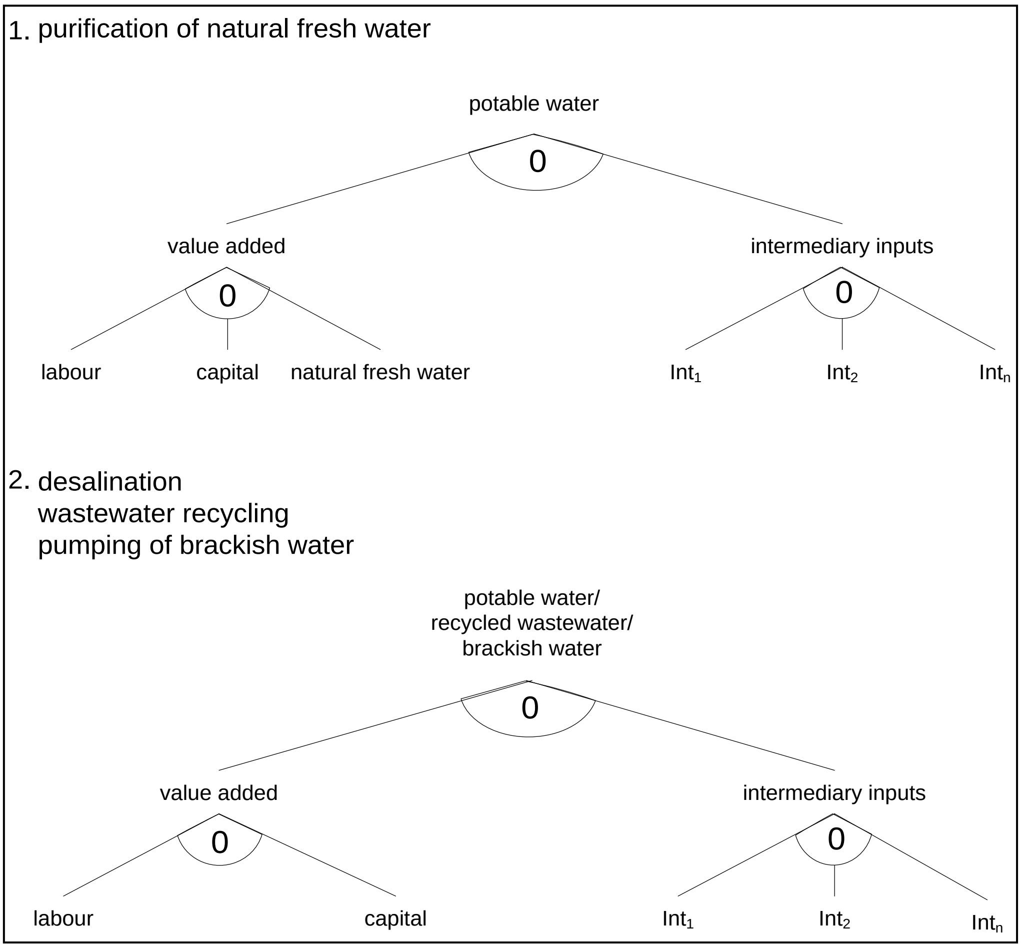
To reflect the relations between the Israeli water sector and the rest of the economy, this study employs a single country CGE model which builds on the standard STAGE model (McDonald, 2009). In the original STAGE model, production functions are nested in two levels. The functional form applied at the top-level is Constant Elasticity of Substitution (CES) or Leontief function, combining aggregate value added and intermediate inputs. On the second level, a multi-factor CES-function is used to combine production factors on the one side and a Leontief function to combine fixed rates of intermediate inputs on the other side (McDonald, 2009). The model is adjusted to fit an Israeli SAM developed by Siddig et al. (2011). This SAM depicts the Israeli economy in the year 2004 and includes data on 45 commodities and activities, 38 factor accounts, 10 household types and 18 tax categories.

Model Structure

Water is represented by only one sector in the original SAM; therefore, for the purpose of this study the SAM is further disaggregated, relying on additional data provided by the NWA, FAO and the Israeli Statistical Office (CBS, 2011). The water sector is disaggregated to four activities producing three types of water commodities. Additionally, a freshwater resource is included as a factor of production, which is exclusively used by an activity which pumps and purifies the natural fresh water and produces potable water. Alternatively the same commodity can be produced by a desalination activity. This reflects the fact, that water derived from both production activities is distributed via the same network. Potable water is used as intermediate input in the production functions of other activities or is consumed as final product by households. Furthermore, a wastewater reclamation activity and a pumping of brackish water activity are included. The output of these activities, recycled wastewater and brackish water, respectively, is to be used in some of the agricultural sectors as intermediate input.

All four water related activities employ fixed proportions of capital, labour and intermediaries, assuming no substitutability as suggested by Tirado et al. (2006), as shown in Figure 3. This ensures that the activity specific cost structure is kept. The use of natural fresh water is only relevant to the purification of natural fresh water activity. As effluents, brackish groundwater and seawater do not pose a limit on the production of water commodities (at least in the current situation) and are freely available, they are not explicitly modeled. The three water commodities produced by these activities are included as intermediate inputs in the production functions of the other sectors. In addition, potable water is consumed as a final product by households.

Figure 3: Nesting structure of water production activities



Source: own compilation.

All water producing activities use different shares of inputs and thus have different cost structures as depicted in Table 1. For all activities energy is the most important input, as all activities require pumping of water, either from the ground, which can be from a depth of up to 1000 m in case of brackish water (Brimberg et al., 1994) or through micro-membranes in case of desalination, which is a very energy-intensive process (Garb, 2010). Capital requirements are the highest for wastewater reclamation and desalination, as these activities require larger investments. The same holds true for consumables, which are mainly chemicals in case of wastewater reclamation and materials such as membrane replacements in case of desalination. Only the purification of natural fresh water activity relies on the natural fresh water resource and thus has to pay an extraction levy to the state, which intends to reflect the scarcity of the resource (Kislev, 2001). Finally, other inputs mainly include construction activities and other services, which are consumed by all water producing activities to a minor extend.

Table 1: Production cost and cost structure of water producing activities

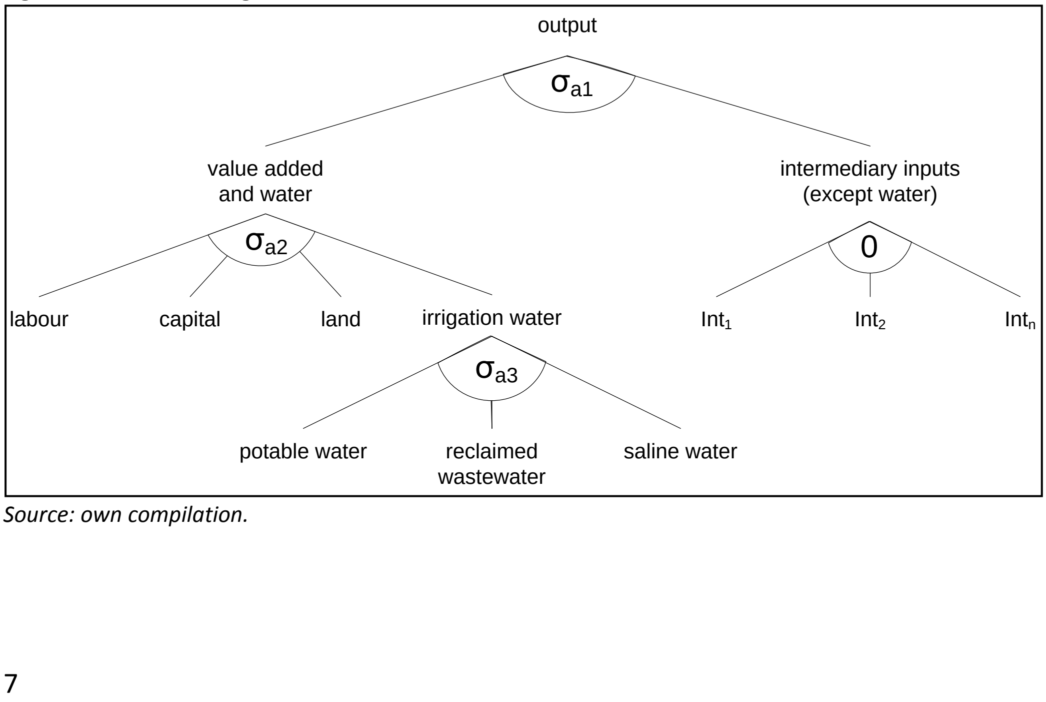
Inputs	purification of natural fresh water	wastewater reclamation	pumping of brackish water	desalination
Total production cost [USD/m³]	0.56	0.16	0.08	0.91
Energy	30.2%	30.0%	34.8%	40.0%
Labour	30.1%	22.8%	34.2%	10.0%
Capital	14.6%	20.0%	17.2%	20.0%
Consumables	8.3%	20.0%	5.0%	14.5%
Natural fresh water	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%

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

For all other production activities the two stage production nest is extended to three levels: Firstly, the water commodity is taken out of the intermediate input nest and added to the value added side. This allows for the possibility of substituting water with production factors, as for example the irrigation sector in Israel constantly substitutes capital and technology for water by increasingly using water saving drip irrigation systems (Saleth and Dinar, 1999). Secondly, the water commodity is further disaggregated into potable water, reclaimed wastewater and brackish water. The three water types are combined to constitute irrigation water using CES technology (Figure 4). This reflects the possibility for farmers to substitute potable water with marginal water (reclaimed wastewater and brackish water) in the sectors where the use of these water commodities is possible or allowed, as previously stated. The production for all other sectors has the same structure, except for the third level, where sectors cannot use reclaimed wastewater and brackish water.

This analysis uses for the top-level of production an elasticity value σ_{a1} of 2.0, to represent a rather high substitutability between intermediaries and production factors. For the substitution between factors of production (σ_{a2}) a medium to low elasticity of 0.8 (Sadoulet and de Janvry 1995) is chosen, which is also applied on the third level, for the substitution of water commodities (σ_{a3}).

Figure 4: General nesting structure



Source: own compilation.

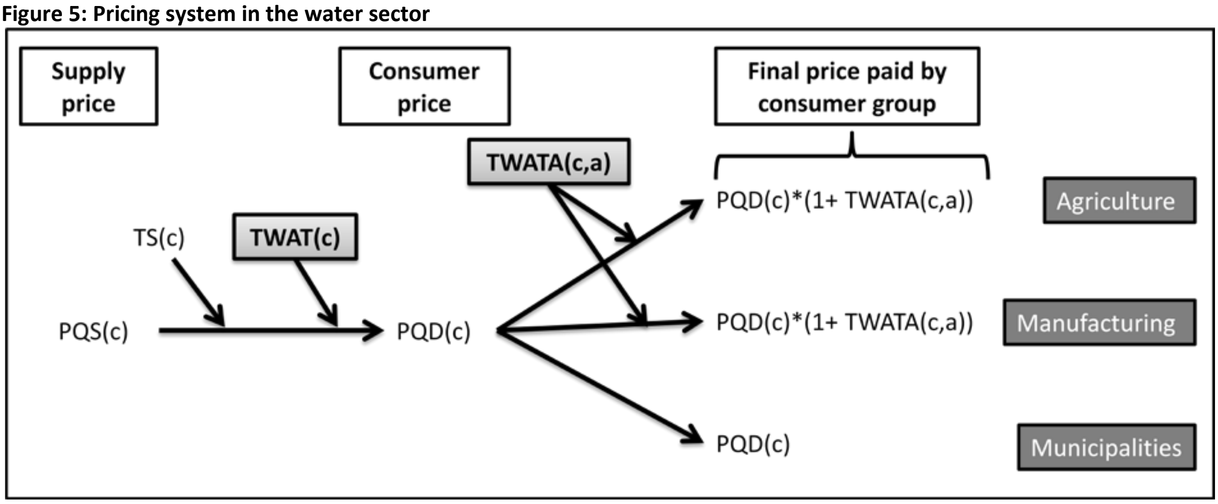
Water Pricing

Data on costs of water supply and fees charged from consumers are obtained from CBS (2011). The costs of water supply are represented by the supply price (PQS) of water commodities in this model. Therefore, the supply price of water commodities in this study diverges from 1, to which all other supply prices are fixed for the base situation, according to the standard CGE-approach.

As described in chapter 2, different prices are charged for different water qualities in Israel, and in case of potable water different consumer groups also are charged differently. To follow the law of one price, we model this differentiation using two additional tax-instruments. Firstly with the help of a commodity tax on potable water (TWAT(c)) which is added to the existing sales tax (TS), the price is raised to the level charged from municipalities (PQD), which includes final consumption by households. Agricultural and manufacturing sectors then receive a subsidy (TWATA(c,a)) which is adjusted in a way that these activities pay as a final price the one which they pay in reality (compare Figure 2).

As the water quantities exported and reserved for the environment are fixed due to political obligations on the one side and do not result in any monetary transactions on the other side, we consider these quantities by deducting them from the total quantity of water supplied, such that our model only includes the water quantity which is supplied to the Israeli economy.

Figure 5: Pricing system in the water sector



Source: own compilation.

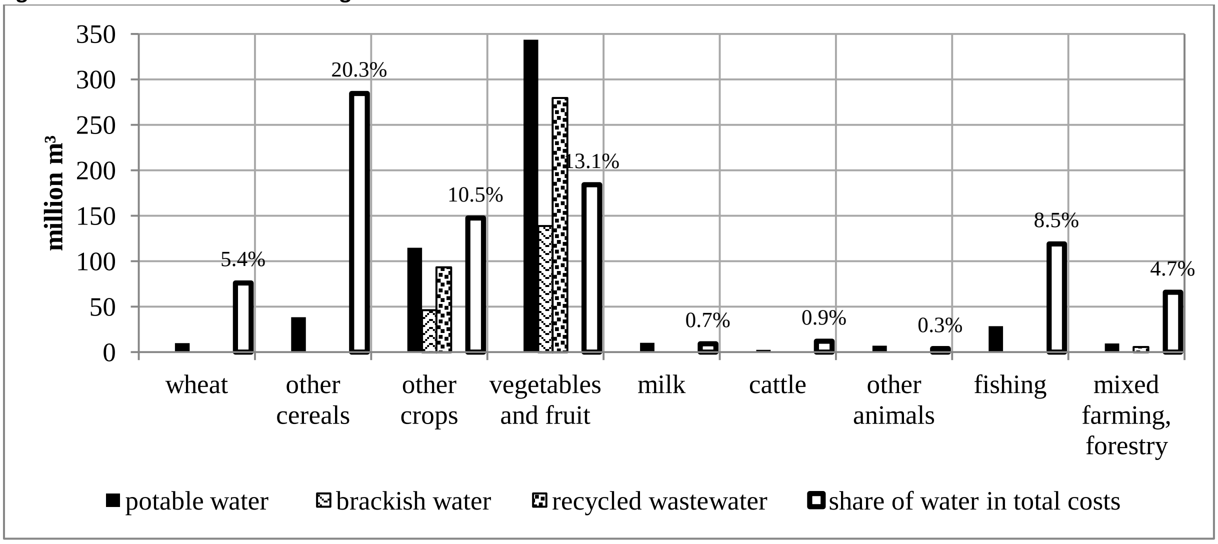
Data

The adjusted SAM used in this model is balanced in a way that dividing the value data of the water sector by the appropriate prices will yield the exact quantities produced and consumed as reported by the NWA in Zaide (2009) and CBS 2009 for 2004, the base year of the SAM.

Figure 6 depicts the water use in the agricultural sector according to the agricultural activities considered in the SAM, as it is the biggest user of water and only (some) agricultural activities allow for the usage of marginal water. Vegetable and fruit plantations are the by far biggest water users, followed by the production of other crops, which include cotton, sunflowers and other field crops. The usage of brackish water in this study is limited to these two sectors ("vegetables and fruit" and "other crops"), as they include plants which are tolerant towards increased salinity levels (e.g. tomatoes, melons, cotton). Due to sanitary restrictions also the usage of recycled wastewater in this model is limited to these two activities besides 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, as they can be irrigated without the water touching 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, the brackish and reclaimed water commodities are split amongst the activities which allow for their usage according the total water consumption of the respective activities in the SAM.

Figure 6: Water use in the Israeli agricultural sector in 2004 in million m³



Source: own compilation based on FAO 2009; Zaide, 2009; Siddig et al, 2011.

Scenarios

1. Lib: liberalization of the water sector

In this scenario we try to estimate the economic costs to the Israeli society of the water subsidy applied. Therefore, we compare the reference scenario, depicting the applied water prices in 2006 to a simulation in which taxes and subsidies on water are removed, such that the final price paid by consumer group is equal to the producer price plus the value added tax, which is held constant.

2. Marg: marginal price scenario

This second scenario is similar to the first one, however, it lifts in addition the consumer price of potable water to the cost of desalination (0.98 USD), representing the marginal price for water in Israel (Zhou, 2006). This price also includes the investment costs for further desalination plants, such that at this price, in the long run nearly every quantity of water can be supplied to the Israeli economy. Therefore in this scenario becomes more expansive for all consumer groups.

4. Simulation Results

In both scenarios the potable water price charged from different consumers is unified. In the liberalization scenario this means a price reduction for municipalities, but a price increase for agricultural and industrial users, whereas in the marginal price scenario the price increases for all user groups. The changes for the agricultural sector particularly are huge, as the price for potable water used in this sector almost triples in the lib-scenario and quadruples in the marg-scenario. On the other hand prices for marginal water commodities drop in both cases (Table 2).

Producer and consumer prices of all other commodities rise in the lib-scenario. While this increase remains below 1% for most manufactured and service goods; it reaches up to 5.5% in the agricultural sector. For prices of agricultural and manufactured commodities this is due to the increased potable water costs in these sectors, while for the service sector they are due to the increased household demand for these commodities.

In the marg-scemario consumer demand is generally decreasing (due to the price increase in all sectors), therefore prices in the services sector and many manufactured good fall slightly (below 0.3%).

Table 2: Changes in water prices

		average water price [USD/m³]			change compared to base [%]	
water quality	sector	base	lib	marg	lib	marg
potable water	agriculture	0.24	0.66	0.98	172.3	303.8
	industry	0.48			37.6	104.0
	municipalities	0.97			-32.0	0.9
reclaimed wastewater	agriculture	0.21	0.18	0.17	-16.6	-17.4
brackish water	agriculture	0.23	0.10	0.10	-57.1	-57.6

Source: model results.

Due to the increased prices, consumption of potable water is reduced in most cases, whereby the decrease of consumption is negatively correlated to the increase in prices. Only municipalities consume about 21% more potable water in the lib-scenario as they experience a price drop. However, overall potable water consumption drops in both scenarios by 14.6% and 32.5% for lib and marg scenarios, respectively. On the other hand the usage of marginal water is increased as it becomes cheaper due to both scenarios (Table 3).

However, despite of a stronger price drop for marginal water and a much higher reduction of potable water use in the marg-scenario, the increase of marginal water use is higher in the lib-scenario, such that total water consumption remains almost constant in this simulation. This can only be explained when the effect of the price changes on the whole economy is considered. In the lib-scenario the economy is growing, the gross domestic product (GDP) rises by 0.74%, whereas in the marg-scenario the economy experiences a general downturn and the GDP falls slightly by 0.07%.

Despite the highest reduction of potable water use by the agricultural sector, the reduction in its total water use is relatively small (-11% and -20% for the lib and marg scenarios, respectively). This is explained by potable water in this sector being partially substituted by marginal water. The changes in water use by the agricultural sector are shown in Figure 7. The consumption of potable water by all agricultural activities would decline due to both scenarios by up to 66% and 78%, respectively. On the other hand, the use of brackish water would increase by up to 90% in the lib-scenario. The use of reclaimed wastewater rises by up to 17%. This smaller increase is due to the more moderate price drop this water commodity experiences in both scenarios compared to brackish water (compare Table 2).

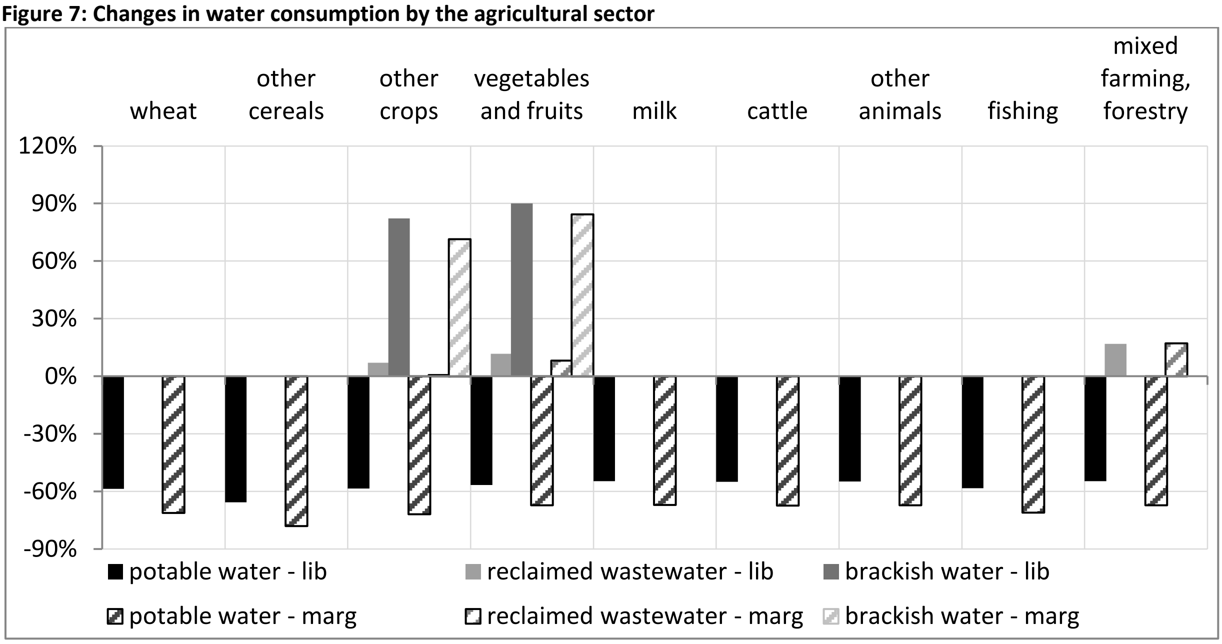
Table 3: Changes in water demand and supply

		water quantity [million m³]			change compared to base [%]	
sector	water quality	base	lib	marg	lib	marg
agriculture	potable	565	239	166	-57.7	-70.6
	reclaimed	379	419	404	10.6	6.5
	brackish	185	348	335	88.2	81.2
	sum	*1129*	*1006*	*905*	*-10.9*	*-19.8*
manufacturing	potable	113	88	63	-22.3	-44.0
municipalities	potable	712	861	709	20.9	-0.4
total		**1954**	**1955**	**1678**	**0.0**	**-14.2**
thereof	natural fresh water	1199	1025	810	-14.5	-32.5
	desalinated	191	162	129	-14.8	-32.4

Source: model results.

When looking at the changes of agricultural output, it becomes clear that especially activities with high shares of water as intermediate input are negatively affected (compare Figure 6). Accordingly, the highest losses (-17% in the marg-scenario) occur in the production of “other cereals”. Although “vegetables and fruits” production is also very water intensive (13% of production costs), the reduction in output is much lower (-3% in the marg-scenario), as in this activity potable water is substituted by marginal water to a large extend. The animal keeping activities are even less affected because water plays only a minor role in their production costs with the only exemption being fishing, where the share of potable water in the production costs is 9% and it cannot be substituted.

Figure 7: Changes in water consumption by the agricultural sector

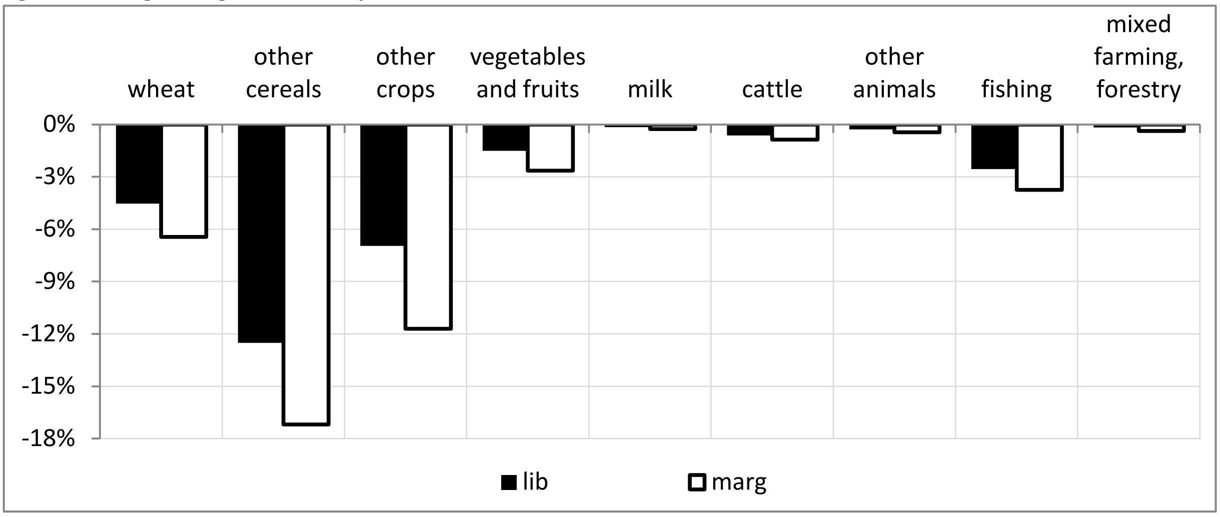


Source: model results.

The overall welfare effects of the two simulations are rather small, as the share of the water sector in Israeli economy is relatively small (about 0.7% of total domestic production in the base situation) and water consumption makes up to less than 1% of expenditure of all household groups. Generally the lib-scenario increases welfare slightly for almost all household groups due to the drop in water prices charged to municipalities, whereby the equivalent variation measured as a share of household income in the base scenario is below 0.2% for all household groups. Only the two poorest quintiles of non-jewish households experience a very small loss of welfare (below -0.05%). This is due to the fact that this population group derives a relatively high share of income from employment in the agricultural sector, in which wages drop, due to the reduced production of this sector (compare Figure 8). In the marg-scenario households are mostly affected negatively (the richest quintiles of each household group slightly gain, due to falling prices for services and increasing income from enterprises), however the magnitude remains below 0.3% and can be even decreased, if the generated government savings due to the abolished subsidy are transferred to households.

The outcome for the government is generally positive. In the lib-scenario this is mainly due to the overall economic growth, which results in higher government income (+0.7%) mainly from increased sales and income tax revenues. In the marg-scenario the government income rises by 0.3%. This is mainly due to the now positive revenue from the water sector, as prices for potable water are higher than average supply costs and the water subsidy is abolished.

Figure 8: Changes in agricultural outputs



Source: model results.

5. Conclusions and Discussion

The functioning of the water sector in Israel being not sustainable is widely understood in the current political debate. This analysis shows that the currently applied pricing structure in the Israeli water sector actually harms the economy and results in an annual GDP loss of 0.7% which is close to one Million US Dollar. Therefore, if the water sector would be completely liberalized, such that water fees cover average supply costs, government income would rise. The resulting government surplus could in turn be used for transfer payments to mitigate the losses which especially occur in the agricultural sector. For example the investment in water saving irrigation or the access to the reclaimed water network could be financially supported. Alternatively, the money could be used to invest in additional desalination plants that reduce the pressure on the natural aquifers. However, the necessity to develop further fresh water sources shrinks in both scenarios simulated in this study, as the demand for potable water falls. Alternatively, resources could be spend on the improvement of the quality of reclaimed wastewater, such that it could be used with less restrictions in the agricultural sector and maybe also in some industrial activities such as cooling of processes. This would take further pressure away from the freshwater resources.

The general equilibrium approach applied in this study considers the linkages between economic actors. Therefore, this analysis shows that the lib-scenario allows to save a considerable quantity of natural fresh water and at the same time the economic effect for households, the government and the economy as a whole is a positive one. In other words, water could be saved without harming the economy and the economic activities which are harmed could be compensated by the gains of other sectors through governmental transfers.

The marg-scenario allows reducing the demand for natural fresh water to en even lower level; such that the aquifers would not be overexploited even at the low replenishment rates of the recent drought years (see Introduction). In the longer term it would allow the Israeli economy to be completely independent from the natural fresh water resource, as the water fee covers the costs of desalination including the capital costs for the investment in new desalination plants.

As long as also the natural fresh water resource will be used, the government income will raise due to the difference in supply costs and water fees. An additional simulation shows that, if this money would be spend on transfers to households, their losses due to the raised water fees could be almost completely compensated.

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