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Measuring the administrative water allocation mechanism and agricultural amenities

Erez Yerushalmi

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Measuring the administrative water allocation mechanism and agricultural amenities

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May 25, 2012

Abstract

Many arid countries use an administrative water allocation mechanism. Quotas, price discrimination, and increasing block tariffs are set and enforced by prohibiting the resale of water. Critics of this mechanism argue that allocation is politicized, subjective and slow to respond, and therefore misallocates water compared to a market mechanism. However, an administrative mechanism also promotes social goals that are not valued economically. In this paper, both positive and negative impacts of the administrative allocation are explored, using a general equilibrium model and with Israel as a case study. The model concludes that from 1995 to 2006, potable water misallocation in Israel was relatively small, on average of 5.5 percent of the potable water supply. The value of agricultural amenities is imputed at approximately 2.3 times agricultural output. At the margin, introducing a water market in Israel is not recommended, *i.e.*, net-social welfare would fall.

- *Key Words*: Secondary water market, Administrative water allocation, Agricultural amenities, General Equilibrium.
- *JEL*: C68, Q15, Q25, Q28, O21

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1 Introduction

Most arid and semi-arid regions use an administrative water allocation mechanism, whereby the state monopolizes the water resource, and erects a regulatory body to administer it. The main tools used are quotas, price discrimination, and increasing block tariffs that are set and upheld by prohibiting the resale of water.[1]

Critics of this mechanism argue that allocation is subjective, politicized, and leads to inefficiencies (Dinar et al., 1997; Holden and Thobani, 1996). Much of the criticism centers on the agricultural sectors that have access to subsidized water, and farmers appear to have historical, senior rights, and are shielded by a strong lobby. Therefore, even when inefficiencies are detected, the political system finds it difficult to change antiquated allotments.[2] The result is inefficient use of water, whereby farmers grow low-value and surplus crops, while non-agricultural water users struggle to develop expensive new supplies (Colby, 1990; Plaut, 2000). In addition, a 'black' water market may form, which further indicates that water is misallocated (Lichtman, 2009).

These arguments are partly justified, but as discussed by Just et al. (1997), the goal behind an administrative allocation is to promote social objectives, such as water and food security, or equitable consumption across income groups or climate specific regions. Administrative mechanisms are also used to correct market-failures in situations of public goods, where an amenity provides non-marketed services, *e.g.*, agricultural landscape, tourism, heritage, etc. The multifunctionality of agriculture activities may produce benefits over and above the market value of agricultural production (Brunstad et al., 1999, 2005).

In this paper, I explore both positive and negative impacts of an administrative water allocation using Israel as a case study. The following questions are addressed: (1) Can the level of administrative misallocation be measured? (2) Who are the main inefficient water users, and how can allocation be improved? (3) What value do the amenities need to have in order to rationalize the current administrative allocation as efficient? (4) Finally, which is preferable, a market or an administrative mechanism?

To answer these questions, an applied general equilibrium model is developed and applied to Israel from 1995 to 2006. In the initial case, a regulator decides on a framework in which price discrimination, quotas, and increasing block tariffs are set, and water trade is prohibited. Water users decide on the amount of water to buy within this framework. Subsequently, in the counter-factual experiments, water trade is enabled within a *secondary* water market and prices adjust until markets clear. The model is furthermore extended

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[1] For discussion on various countries, see review by OECD (2010), and by Diakité et al. (2009), Ruijs (2008), Roseta-Palma and Monteiro (2008) and Hajispyrou et al. (2002).

[2] For a further discussion and summary for Israel, see extended Appendix A.

to account for the non-economic value of amenities; the agricultural sectors internalize the benefit of producing amenities that are demanded by the households.

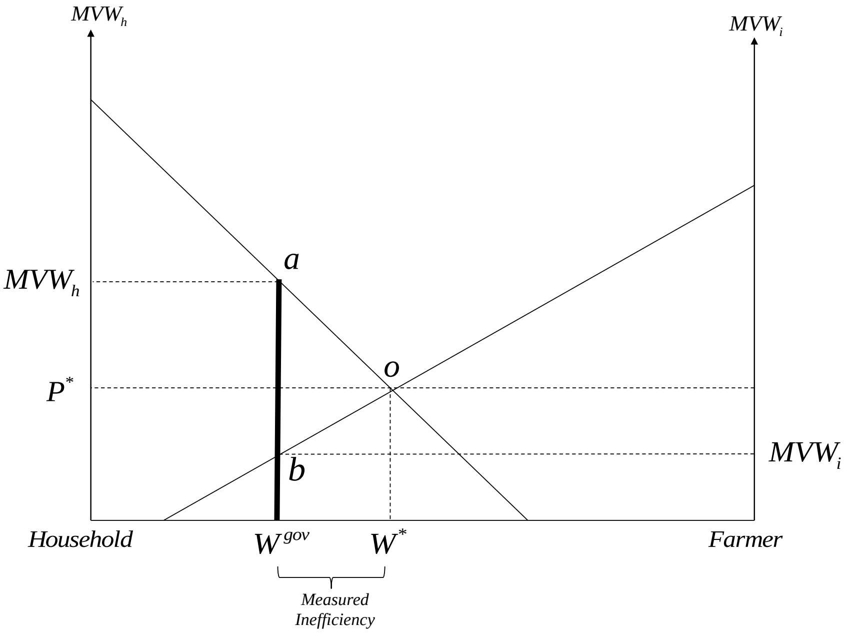
If we consider the market allocation to be efficient, the quantity of water traded would indicate the level of administrative misallocation. For example, a large secondary water market would indicate that the administrative mechanism is inefficient, and that a market mechanism would put water to better use. However, if the social value provided by the administrative mechanism is also included, it is then possible that the benefits from a water market could be smaller than the loss incurred to social value, *i.e.*, a net-social welfare loss.

At the parametrization stage of the model, under plausible assumptions, the approach was to select values that would naturally lead to the *largest* possible water misallocation. These results, therefore, are conservative, upper bound, estimates of the potential secondary water market for Israel. Nevertheless, the results find that the administrative misallocation is rather small and suggest that a market mechanism is not arguably better, at the margin. When the model is extended to include amenities, a water market is clearly undesirable. On the one hand, trade puts water to better use and raises *economic* welfare. But on the other hand, when trading away water quotas, agricultural output falls and reduces the positive externalities from the amenities. This lowers overall *social* welfare.

The paper makes the following contributions. First, it adds a new perspective into the discussion of water allocation efficiency in Israel. Contrary to most literature on Israel, the paper supports the continued use of an administrative water allocation mechanism. Second, it suggests a simple method, which can be used to evaluate and improve water allocation decisions also in other countries. Finally, the paper imputes the value of agricultural amenities in Israel, adding to the discussion by Fleischer and Tsur (2009); Kan et al. (2009) on the economic value of agricultural amenities. Thus, the paper relates to two areas of research. It has relevance for natural resource management that aims to improve the efficient use of a scarce resource, and it has implications for political and social policy.

The paper is structured as follows: Section two introduces a simplified theoretical model, and shows how inefficient water allocation arises from an administrative mechanism. Section three expands to a more realistic multi-sector applied general equilibrium model for the Israeli economy. Section four discusses the empirical results. Section five extends the model to impute the value of the agricultural amenities and overturns the results from the previous section. Finally, section six concludes.

Figure 1: Water Quotas With Two Agents



Note: Total water $\bar{W}$ is allocated by the government. Household is allocated water quantity W^{gov}, while farmers are allocated $\bar{W} - W^{gov}$. Area *aob* is the dead weight loss from inefficient water allocation. The potential secondary water market is the volume $|W^{gov} - W^*|$, a proxy for inefficiency.

2 The Water Model

Applied general equilibrium models have been developed to analyze different issues within water management (see Dixon, 1990; Berck et al., 1991; Seung et al., 2000; Diao et al., 2008). Diao and Roe (2003) specifically discuss administrative water allocation in Morocco, and find that reducing protectionist agricultural policy without correcting for distortions in irrigated agriculture pricing will lead to increased inefficient water use. Creating a water market, however, could compensate for the decline in farmers' profits and raise efficiency. Gómez et al. (2004) demonstrate that having a water market in the Balearic Islands, rather than an administrative mechanism, leads to economics gains that would allow for delays in investment in desalination plants. Becker (1995) focuses on the Israeli agricultural sector, and uses a linear programming model to analyze the effects of introducing a market mechanism on the shadow water prices for the various water basins, and also reports the economic gains from a water market.

The common theme in the above papers, is that a market mechanism leads to economic gains. However, they do not include the social consequences of introducing a water market. In this paper, social gains are an additional dimension to the administrative mechanism.

The usual benefits of a market are illustrated in Figure 1. Assume a closed economy with only two water users. The total water resource is quantity $\bar{W}$, and a social planner allocates W^{gov} to the household, and $\bar{W} - W^{gov}$ to the farmer. Furthermore, water trade is prohibited. However, this allocation is clearly not optimal, because the marginal values of water are not equalized, $MVW_h > MVW_i$.

When water trade is enabled, the household benefits from buying additional units of water, while the farmer benefits from selling some of his water rights. The discrepancy between the initial administrative allocation and the market allocation is the horizontal distance $|W^{gov} - W^*|$, measured in cubic meters of water. The quantity traded within this secondary water market is used as a proxy to indicate the level of inefficient allocation.[3]

2.1 A simplified trade model with water inputs

To describe the model used in this paper, consider a simplified closed economy. Firm $i \in N$ produces a single final good $Y_i \in y$, using a differentiable constant returns to scale production function $f_i\left(L_i, W_i\right)$ that uses labor and water inputs, respectively. Output prices and wages are $p_i, p_L \in p$, respectively.

One representative household $h \in H$ has a rational and locally non-satiated preference relation, with a continuous utility function $U\left(y\right)$. He consumes final goods Y_i, and water $W_h \in y$, and is endowed with a fixed supply of labor $\bar{L}$ and water $\bar{W}$.

The government, which is not explicitly modeled, holds the property rights of water, and assigns a different increasing block tariff (IBT) for each type of water user, *i.e.*, firms and households pay $p_{W,i}, p_{W,h} \in p$, respectively. However, unlike in the paper by Diao and Roe (2003), water users are *not* bound by the water quota allotted to them. They can, in general, obtain as much water as they desire by paying increasingly higher prices, within the IBT framework.

Given the above, $\forall i$, the firm's profit maximization problem is to choose labor and water demands, L_i and W_i, so as

$$\underset{L_i, W_i \geq 0}{\text{Max}}\, \pi_i\left(L_i, W_i\right) = p_i f_i\left(L_i, W_i\right) - p_L L_i - p_{W,i} W_i \tag{1}$$

The household's disposable income is $M = p_L \bar{L} + p_{W,h} \bar{W}_h + \sum_i^N p_{W,i} \bar{W}_i$, which includes income from wages and water charge fees, that are collected by the water authority and transferred to the household. $\bar{W}_i$ and $\bar{W}_h$ denote the administrative water allocation.[4]

The household's utility maximization problem is to choose consumption of goods and

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[3] See further discussion in Appendix A.4.

[4] Note that in the initial administrative allocation, $W_h = \bar{W}_h$, and could be netted out from both the household's income equation and utility maximization problem. However, they are intentionally there for clarity because when water trade is enabled, it is possible that $W_h \neq \bar{W}_h$.

water, Y_i and W_h, so as to

$$\underset{Y_i, W_h \geq 0}{\text{Max}}\; U\left(Y_i, \cdots, Y_N, W_h\right) \qquad \text{s.t. } M \geq \sum_i^N p_i Y_i + p_{W,h} W_h \tag{2}$$

Focusing on water, the first order conditions must be satisfied so that the marginal value of water (MVW) equals the real water price.

$$MVW_i = \frac{\partial f_i\left(\cdot\right)}{\partial W_i} \leq \frac{p_{W,i}}{p_i} \quad \perp \quad W_i \geq 0, \qquad \forall i \tag{3}$$

$$MVW_h = \frac{\partial U\left(\cdot\right)}{\partial W_h} \leq \frac{p_{W,h}}{p_U} \quad \perp \quad W_h \geq 0 \tag{4}$$

Following Mathiesen (1985); Rutherford (1995, 1999), we set up an Arrow–Debreu equilibrium as a mixed complementarity problem (MCP). Three types of weak inequality conditions must be satisfied: (i) zero profit, (ii) market clearance, and (iii) income balance, each associated with three non-negative variables, *i.e.*, $y^* \geq 0$, $p^* \geq 0$ and $M^* \geq 0$, respectively.

Using Shephard's lemma and defining the unit cost function as $c_i = C_i\left(p_L, p_{W,i}, Y_i = 1\right)$ and household's unit expenditure function as $e = E\left(p_i, p_{W,h}, U = 1\right)$, the demands for inputs by the producers, and demand for final goods and water by the household, are all summarized in the following weak inequalities, $\forall i$:

$$\text{Zero profit conditions:} \qquad 0 \leq c_i - p_i \quad \perp \quad Y_i \geq 0 \tag{5}$$

$$0 \leq e - p_U \quad \perp \quad U \geq 0 \tag{6}$$

$$\text{Market clearing conditions:} \qquad 0 \leq Y_i - \frac{\partial e}{\partial p_i} \cdot U \quad \perp \quad p_i \geq 0 \tag{7}$$

$$0 \leq \bar{W}_h - \frac{\partial e}{\partial p_{W,h}} \cdot U \quad \perp \quad p_{W,h} \geq 0 \tag{8}$$

$$0 \leq U - \frac{M}{p_U} \quad \perp \quad p_U \geq 0 \tag{9}$$

$$0 \leq \bar{L} - \sum_{i=1}^N \frac{\partial c_i}{\partial p_L} \cdot Y_i \quad \perp \quad p_L \geq 0 \tag{10}$$

$$0 \leq \bar{W}_i - \frac{\partial c_i}{\partial p_{W,i}} \cdot Y_i \quad \perp \quad p_{W,i} \geq 0 \tag{11}$$

$$\text{Income balance:} \qquad M = p_L \bar{L} + p_{W,h} \bar{W}_h + \sum_{i=1}^N p_{W,i} \bar{W}_i \quad \perp \quad M \geq 0 \tag{12}$$

where price vector p^* and activity levels y^* constitute a *competitive equilibrium.*

2.2 Secondary water market

As described through Figure 1 and Equations (3) and (4), assume that at the initial administrative allocation with restricted water trade, $\frac{p_{W,i}}{p_i} = MVW_i < MVW_h = \frac{p_{W,h}}{p_U}$, *i.e.*, the household has a higher marginal value of water than firm i. When water trade is allowed, the household would prefer to buy water from firm i (and the firm prefers to sell), up to a point where $MVW_i = MVW_h$.

More generally, water users can be *buyers* or *sellers*, and having $M = N + H$ water users[5] leads to M^2 trade configurations, with ψ_{mn} being the *relative* marginal value. If user $m \in M$ is a buyer, and user $n \in M$ is a seller, a possible trade channel is when $\frac{MVW_m}{MVW_n} = \psi_{mn} > 1$. Otherwise, it cannot be a possible trade channel.

$$\frac{MVW_m}{MVW_n} = \begin{cases} \psi_{mn} > 1 & \text{possible trade channel} \\ \psi_{mn} \leq 1 & \text{not possible} \end{cases} \tag{13}$$

These conditions, therefore, limit the number of configurations to only $T = \frac{M(M-1)}{2}$ possible trade channels, with $t \in T$ being a specific channel (Section 3.4 discusses how the marginal values of water are estimated with Table 3 a concrete example).

Thus, when water trade is enabled, the units of water, γ_t, that are transferred between seller n and buyer m are measured by

$$0 \leq \gamma_t \perp p_{W,n,t} - (1-\epsilon)\, p_{W,m,t} \geq 0, \qquad \forall t \tag{14}$$

with $p_{W,n,t}$ and $p_{W,m,t}$ being the water market prices for the seller and buyer, respectively. For computational purposes, $\epsilon \to 0$ is a small number to *'help'* the solver with slack activities, thus avoiding the problem of infinite solutions, *i.e.*, a degenerate model.[6]

There are various combinations (scenarios) of activating and deactivating water trade channels, *e.g.*, activating each channel separately, or all together. Therefore, each of the $t \in T$ channels has a binary action (designed by the scenario); active or not-active, $\{\mathcal{A}, \mathcal{NA}\} \in$ *Action*. There are $\{t_{\mathcal{A}}, t_{\mathcal{NA}}\} \in T$ channels, $\{i_{\mathcal{A}}, i_{\mathcal{NA}}\} \in N$ firms, and $\{h_{\mathcal{A}}, h_{\mathcal{NA}}\} \in H$ households, that are active or not-active, respectively.[7]

Finally, for a set of actions, the market clearing conditions (8) and (11) are replaced with

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[5] N firms and H households.

[6] This insures that when multiple t channels are opened (active), only *net transfers* of water is considered. For example, a case of infinite solutions is when a first user sells to the second, the second sells to the third, but the first also sells to the third. By adding ϵ, the solutions is limited to one (possible) case where, for example, the first sells to the second and to the third, while deactivating the second selling to the third.

[7] In other words, a water user will *not* trade because it is either a choice or it is *blocked.*

$$0 \leq \bar{W}_{\mathcal{A}} - \frac{\partial e_{\mathcal{A}}}{\partial p_{W,h_{\mathcal{A}}}} \cdot U_{\mathcal{A}} + \sum_{i_{\mathcal{A}}} \frac{\partial c_{i_{\mathcal{A}}}}{\partial p_{w,i_{\mathcal{A}}}} \cdot Y_{i_{\mathcal{A}}} \quad \perp \quad p_W = p_{W,h_{\mathcal{A}}} = p_{W,i_{\mathcal{A}}} \geq 0 \tag{15}$$

$$0 \leq \bar{W}_{i_{\mathcal{NA}}} - \frac{\partial c_{i_{\mathcal{NA}}}}{\partial p_{W,i_{\mathcal{NA}}}} \cdot Y_{i_{\mathcal{NA}}} \quad \perp \quad p_{W,i_{\mathcal{NA}}} \geq 0 \tag{16}$$

$$0 \leq \bar{W}_{h_{\mathcal{NA}}} - \frac{\partial e_{\mathcal{NA}}}{\partial p_{W,h_{\mathcal{NA}}}} \cdot U_{\mathcal{NA}} \quad \perp \quad p_{W,h_{\mathcal{NA}}} \geq 0 \tag{17}$$

Equation (15) states that the supply of traded water, $\bar{W}_{\mathcal{A}}$, will equal the demand for traded water, provided that water prices equalize within the secondary water market. Equations (16) and (17) reflect cases in which some water users are prohibited from trade, and have user-specific water prices and quotas.[8] Appendix B provides the full analytical model.

3 The applied general equilibrium model and the data

In order to adequately represent the actual empirical Israeli economy, the general equilibrium model that was discussed in the previous section is extended. The following will describe the main features of the applied model and of the data used.[9]

Table 1 presents key water figures for 2006. Roughly 68% of the total supply of water in Israel is potable water, of which there are four main users. Approximately 39% of potable water is consumed by agricultural sectors, 6% by manufacturing sectors, 16% by service sectors, and 39% by private households.[10]

The use of non-potable water, *i.e.*, salinized, contaminated, sewage effluents, flood, brackish water etc., has increased in the past two decades, due to growing pressures on the supply of water, and improvements in technology and infrastructure. Approximately 95% of it is used by the agricultural sector, and the rest by the manufacturing sectors.

The applied small open economy is aggregated into three main production sectors: agricultural, manufacturing and services, and one representative household. The government is not explicitly modeled, but its actions are manifested through the initial water allocation, i.e., quota and increasing block tariff (IBT) assignments to water users.

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[8] Here, there is only *one* representative household. Equation (17) is a case where the household is blocked from trading, and therefore $\frac{\partial e_{\mathcal{A}}}{\partial p_{W,h_{\mathcal{A}}}} \cdot U_{\mathcal{A}} = 0$ in Equation (15). Extending the analysis to multiple-households is a simple matter, *e.g.*, updating Equations (2) and (12), but requires further assumptions regarding water ownership in the applied model. Adding the government explicitly, would probably be required.

[9] Programmed and simulated in GAMS using Rutherford (1999)'s MPSGE.

[10] Water consumption by private households and service sectors is regarded as residential water consumption. Yearly data is reported by the *Israeli Water and Sewage Authority* by eleven sub-groups. Approximately 55% of total potable water is consumed by residential users of which 71% are private homes, and the rest are service sector, *i.e.,* commercial and public office buildings, swimming pools, gardens, etc.

Table 1: Key Water Figures in Israel (2006)

	Potable Water				Non-Potable Water		
User	**Mil. Cubic Meters**[a]	**% of Total**	**Expenditure (Current Mil. NIS)**[b]	**Marginal Value Water**[c]	**Mil. Cubic Meters**[a]	**% of Total**	**Expenditure (Current Mil. NIS)**[b]
Agriculture	519	39	768	1.48	589	95	474
Manufacturing	84	6	209	2.49	30	5	24
Services	213	16	833	5.15			
Household	524	39	1,889	4.85			
Total	**1,341**	**100%**			**619**	**100%**	
% Total Water	**68%**				**32%**		

Source: [a] The Water and Sewage Authority, Israel. [b] Own Calculation: water quantity times relevant price band. [c] From the water authority's 2006 price plan, with assumptions discussed in Section 3.4.

3.1 Production

Each of the three production sectors uses the following five inputs: labor, capital, intermediate goods, potable water, and non-potable water.[11] The production function is setup as a four-level nested constant elasticity of substitution (CES) structure, which simplifies the calibration procedure and captures the different substitution elasticities for pairs of inputs. Some of the main assumptions are the following.

First, the model is calibrated for a short-to-medium time horizon, which affects the assumptions that are made on factor mobility. Within a time frame of 3 to 4 years, land inputs are relatively rigid because of soil type, location, infrastructure, legislative constraints, and other reasons (Hertel, 2002). Here, because capital includes land, capital is also highly rigid, and is assigned as a sector specific input. This is especially true for the agricultural sectors.

Second, in order to capture the user specific characteristics of water, sector specific output-supply-price elasticities and water-demand-price elasticities are used to calibrate for the unknown substitution elasticities. These are summarized in Table 2, which are the mid-values from empirical papers. Agricultural sectors have a relatively inelastic supply price elasticity of 0.8, partly due to high land rigidity. Non-agricultural sectors have an elastic supply price elasticity of 3.0. Furthermore, both agricultural and manufacturing sectors have a water demand price elasticity of -0.7, while the residential water demand price elasticity is -0.1, i.e., service sectors and households.[12] As in many applied models, intermediate inputs

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[11] Service sectors have *zero* expenditure on non-potable water.

[12] Appendix C and D provide a detailed description of the empirical literature and assumptions behind these values, and explain the calibration method from the known elasticities and cost share to the unknown

Table 2: Output-supply-price and demand-price elasticities

	Output Supply Elasticity[a]	**Water Demand Elasticity**[a]	**Potable/Non-Potable Substitution**[b]
Agricultural	0.8	-0.7	1.1
Manufacturing	3.0	-0.7	1.1
Services	3.0	-0.1	
Household		-0.1	

Source: [a] Approximate mid-values reported in various papers. [b] Israel Water Authority

Note: The above values, together with the cost share from the social accounting matrix, calibrate sectors' and household's input substitution elasticities (see appendix).

are assumed to enter in fixed proportions (Leontief technology). Finally, the substitution elasticity between potable and non-potable water is assumed to be 1.1.[13]

Third, labor inputs freely migrate between the various sectors, and have a global wage level, p_L. Finally, in the benchmark, water inputs are allotted to users and are non-tradable, and water prices, $p_{W,i}$, are sector specific. As discussed in Section 2.2, when water-trade is allowed, water is reassigned as a global input, and trade occurs until the market clears. Water prices change sufficiently to drive water marginal values to equalize between users.

3.2 Household

The small open economy has one representative household that is endowed with labor, capital, and water resources, $\bar{L}$, $\bar{K}$, $\bar{W}$, respectively. Tax revenues are transferred to the household, including positive (negative) transfers of income to cover balance of payments, *bop*. Income is

$$M = P_{W,h}\bar{W}_h + \sum_{i=1}^{n}\left(P_L\bar{L}_i + P_{K,i}\bar{K}_i + P_{W,p,i}\bar{W}_{p,i} + P_{W,np,i}\bar{W}_{np,i} + \tau_i + bop_i\right) \tag{18}$$

and utility is derived by consuming potable water and final goods, using a two-level nest CES-Cobb Dougals function. Table 2 reports that the residential water demand price elasticity is -0.1, and with it I calibrate the unknown substitution elasticities between the demand for water and for other final goods.

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substitution elasticities within the production and utility functions.

[13] Water Authority assumes a substitution ranging from 1 to 1.2 between potable and non-potable water for agricultural use, depending on the water quality of non-potable water.

3.3 General assumptions in the model

Two assumptions are made in the model. First, in order to properly compare the welfare effects between the benchmark and the counter-factual scenarios, and because this is a static model, the balance of payments (BOP) is fixed to the year specific levels. Otherwise, it would not make sense to allow for policy experiments to increase the trade deficit and thus increase welfare, at the expense of foreign borrowing. Such a situation would be misleading because in a fully dynamic model, borrowing will have to be paid back at some point.[14]

Second, having increasing block tariffs usually means that higher block tariff users subsidize lower block tariff users. Here, however, the model is simplified by aggregating many different users to only four main groups, each with a uniform price. Thus, this assumption could be interpreted as if all users within a group have the same size and preferences, or as if they have already traded water internally between themselves. Dis-aggregating users into further sub-groups is possible, but would require a more detailed social accounting matrix.

3.4 Data and marginal value of water

The data is obtained from the *Use-Supply* tables published by the Central Bureau of Statistics (CBS) Israel for 1995, 2000, 2004, 2005 and 2006. It includes sectors output and inputs, household consumption and trade balance, as well as levels of taxes and subsidies. From these, social accounting matrices (SAM) were constructed and used to calibrate the model. Similar data for 2007 is not yet available. Labor inputs are obtained from CBS Israel's Compensation of Employees by Industry tables.

The water authority assigns increasing block tariff (IBT), whereby consumers pay progressively higher prices for each increasing quantity of water consumed.[15] Each main user, *i.e.*, agricultural, manufacturing, services, and households, has a different IBT structure.[16]

CBS Israel does not report the water sector separately from the electricity sector, and does not distinguish between potable and non-potable water. Therefore, the expenditure on water had to be estimated by other means, rather than directly from the Use-Supply tables. Residential water expenditure, *i.e.*, household and service sectors, were estimated by summing the total water quantity times the relevant tariff band for each type of residential user.[17] Agricultural water expenditure is obtained by multiplying the quantity of total

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[14] Practically, to fix the BOP to its benchmark level, household is endowed with a *fixed* amount of bop_i for each type of good $i \in N$.

[15] But not necessarily higher, *e.g.*, manufacturing has a lower price for water use above the 100% quota.

[16] Data obtained from the Water Authority and summarized in Appendix E.2.

[17] Detailed data on eleven residential sub-groups is reported by the Water Authority, *Residential Water Consumption* (a yearly publication in Hebrew).

potable water supply by tariff block A. Likewise for manufacturing, the quantity of water is multiplied by the main water tariff block. A similar method was used for non-potable water, which has only one price band.

Water users can obtain as much, or as little, water as they are willing to pay-for. This means that their marginal value of water (MVW) is equal, or somewhere below the next tariff block, of the last unit of water. Table 1 summarizes the total monetary expenditure on water, and the estimated marginal value for 2006. Recall that conservative values are preferred, which would increase water trade, *e.g.*, by lowering MVW for farmers and a increasing for households. The underlying assumptions for the marginal value of water are the following.

Agricultural water quotas were revised in 1989 with the following tariff blocks. Tariff A is charged up-to 50% of the quota, tariff B between 50-80%, and tariff C between 80%-100%. There are two further bands above 100% with lower prices.[18] Since 1989, extensive cuts in potable water quotas were made, and most of agricultural users pay tariff A, which is thus assigned as there marginal value for water.[19]

Manufacturing sectors have one main tariff up to 100% of the quota, and this is assigned as the marginal value of water.[20]

Different service sectors are assigned different tariffs. For example, hospitals and Mikves[21] fall under tariff A. Hotels fall under tariff B, while the rest of the service sectors fall under tariff C, *i.e.,* commerce, education, sport, public, etc. Public gardens are charged tariff D. In the model, tariff C is used as the marginal value of water for service sectors, because it captured 62% of the water used. Public gardens consumed around 25% of water in the service sector, but they do not account for GDP.

Finally, the household price scheme for 2006 included four tariff blocks. Tariff B captured around 61% of the total consumed water by households, and therefore chosen as the household's estimated marginal value of water.[22]

Table 3 is an applied example of the discussion in Section 2.2. It shows that having four main water users in Israel leads to sixteen water trade configurations. In order to obtain the *relative* marginal value of water (MVW) for a buyer/seller ψ_{mn}, as in Equation (13), divide the marginal values of water for each pair of users reported in Table 1. Values greater than

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[18] There are two further blocks. The first is up-to 10% above the quota, and the second is for above 10% above the quota. See Appendix E.2 for further detail.

[19] From a discussion with the Water Authority. Agricultural water consumption is not published, as it is done with residential consumption. Furthermore, the secondary water market would be smaller if tariff B would have been chosen. When in doubt, the larger, more conservative, secondary water market is preferred.

[20] There is also a lower water charge above 100% of the quota. See Table 11 for further details.

[21] Jewish Ritual Bath.

[22] In 1997, band B captured 70% of the total household water. Source: Israeli Water Authority, *Residential Water Consumption* (in Hebrew). In 2010, the price bands were changed. However, since the model's data covers until 2006, the effects of this new price band is left for future research.

Table 3: Water trade channels: relative MVW for 2006

		Buyer $m \in M$			
		Agricultural	Manufacturing	Services	Household
	Agricultural	1	**1.684**	**3.484**	**3.283**
Seller $n \in M$	Manufacturing	0.594	1	**2.069**	**1.949**
	Service	0.287	0.483	1	0.942
	Household	0.305	0.513	**1.061**	1

Note: These are the ratio of seller/buyer water marginal value. Divide values from the fifth column in Table 1 and numbers in bold are the possible water trade channels.

one indicate which water trade channels are possible, and who are the sellers and buyers. The six possible channels are marked in bold in Table 3. Service sectors, for example, value water by approximately 3.484 times that of agricultural sectors. Therefore, service sectors would be buyers from the agricultural sectors, but cannot be sellers.

4 Measuring the efficiency of an administrative water allocation

In this section of the applied model, water is initially allotted administratively to each of the four users, and water trade is forbidden. Then, in the counter-factual experiments, trade is allowed and water inputs are re-shuffled until all users have the same marginal value of water.

Compared to a market allocation, a certain degree of administrative misallocation is expected. The real question is, therefore, how large is the potential secondary water market likely to be? For example, a large misallocation could indicate a poor administrative mechanism, which would clearly be something to worry about. Such a result could indicate that a market mechanism may be superior.

If, however, the misallocation is rather small, then it is unclear which mechanism is better. The model, therefore, is extended to include the non-marketed economic value. Together, this section and the next contribute to a better assessment of the most preferable mechanism for Israel.

4.1 Results for 2006

The main results, which include the size of the secondary potable water market, the welfare gains, and their effect on the nominal water price are reported in Table 4.[23]

The most important result is the all-channel-trade scenario, in which the secondary

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[23] Detailed results and the GAMS/MPSGE model are available from the author upon request.

Table 4: Model Results (2006, % change)

				Welfare	**% Change in water prices**				
		Water*	**% of total**	**gains**	**Potable water**				**Non-potable**
	Channel (seller to buyer)	**MCM**	**potable**	**NIS mill.**	**Agri.**	**Indus.**	**Serv.**	**House**	**water**
1.	Agriculture to Manufacturing	32.7	2.4	21.5	8.0	-35.9			1.1
2.	Agriculture to Services	20.7	1.5	24.9	5.0		-69.8		1.2
3.	Agriculture to Household	44.5	3.3	51.0	11.5			-66.0	2.6
4.	Manufacturing to Services	9.5	0.7	5.7		17.5	-43.2		0.3
5.	Manufacturing to Household	15.5	1.2	8.2		31.9		-32.3	0.6
6.	Household to Services	0.7	0.1	0.1			-4.1	1.8	0.0
	All Channel Trade	**80.8**	**6.0**	**86.3**	**22.6**	**-27.2**	**-64.8**	**-62.7**	**4.4**
	(of which)								
	Manufacturing buys	22.5	1.7						
	Services buys	17.9	1.3						
	Household buys	40.3	3.0						
	Shadow Water Price (All Channel)					**1.81 NIS/CM**			

*Total Potable Supplied, in 2006, was 1340.5 Million Cubic Meters (MCM).

Note: Model's results for 2006 data. The second column is the quantity of water traded within each channel of the secondary water market. The third column is the percent of water traded of the total potable water supply in that year. The fourth column are the welfare gains in New Israeli Shekels (NIS) Million. The right hand section is percent change of nominal water price from the initial allocation.

potable water market is estimated at 80.8 million cubic meters (MCM). This is approximately 6.0% of the total potable water consumption in Israel in 2006. Agricultural sectors re-allocate potable water towards manufacturing sectors, that buy an additional 22.5 MCM of water, beyond their initial consumption within an administrative mechanism. Service sectors buy an additional 17.9 MCM, and households buy 40.3 MCM.

Because the water authority practices price discrimination, the secondary water market clears when nominal water prices rise (or fall) sufficiently to allow the marginal value of water to equalize for all users (reported in the right hand side of Table 4). In the all-trade scenario, agricultural water price rises by 22.6%, and falls for manufacturing, services, and households by 27.2%, 64.8%, and 62.7%, respectively. This would mean that in 2006, the market clearing nominal water price (shadow price) would have been NIS/MC 1.81.

Being a general equilibrium model, water trade also affects other variables in the economy such as production levels, sector specific return to capital, wage level and welfare. Table 5 reports the most important of them. These changes might seem small, but are a result of potable water inputs being only 2% of total input cost in the agricultural sectors, and less than 0.1% for manufacturing and service sectors. Household expenditure on potable water

Table 5: Other Key Results (2006, % Change)

	Agriculture			Manufacturing		
Channel	**Prod.**	**Price**	**Return on Capital**	**Prod.**	**Price**	**Return on Capital**
3. Agr sell to Hh	-0.2	0.4	0.13	-0.024	0.14	0.13
All Trade	**-0.4**	**0.7**	**0.13**	**-0.04**	**0.15**	**0.14**

	Services			Other Variables		
	Prod.	**Price**	**Return on Capital**	**Wage**	**Water Sector GDP**	**Price Non-Potable**
3. Agr sell to Hh	-0.01	0.13	0.13	0.13	1.4	2.6
All Trade	**0.02**	**0.10**	**0.13**	**0.27**	**2.3**	**4.4**

Note: Model output for 2006 - continued from Table 4. Values are percent change from the initial allocation.

is only 0.2% of disposable income.[24] Therefore, the household utility level (welfare) rises by only 0.01%. This is, however, equivalent to a 2.3% increase in economic value relative to the size of the water sector, and approximately New Israeli Shekels (NIS) 86.3 Million in 2006 prices (see fourth column in Table 4). The intuition behind these results is that by allowing for water trade, water inputs are put to better use, and the economy's production possibility frontier moves outwards.

To better understand the mechanism within a general equilibrium model, it is useful to focus, for example, on channel 3 in Table 4 and Table 5, where agricultural sectors sell *only* to households. In this channel, which has the largest impact on water trade, the size of the water transfer is around 44.5 MCM. Relative to the initial administrative prices, market water prices rise by 11.5% for the agricultural sectors, and fall by 66% for the household (see Table 4 channel 3).

As Table 5 reports, agricultural output falls by 0.2%, which raises agricultural prices by 0.4% and raises agricultural return on capital by 0.13%. As mentioned earlier, capital is a sector specific input, and will not have a direct effect on the rest of the economy. However, when water inputs are transferred to households, this raises demand for labor within the agricultural sectors, and leads to a wage increase across the whole economy. Indirectly, this raises the cost of production in the other two sectors, even though they are not involved in the water market. Production levels, therefore, fall in the manufacturing and service sectors, and output prices rise.

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[24] CBS Israel reports that household water consumption is approximately 1% of disposable income. This, however, includes all elements of water such as sewage cost, recycling, etc. In this model, these additional costs are attributed to capital inputs rather than water, because they are not directly related to water trade.

4.2 Sensitivity Analysis

Sensitivity analysis was performed on each sector using minimum and maximum parameters for the various output supply elasticities, and water demand elasticities (summarized in Table 6). These parameters are well above and below the accepted values that are reported and used in other studies. The results suggest that the model is well-behaved, and that the main results are robust.

Output supply price elasticity has a negligible effect on the size of the water market because, as mentioned previously, water accounts for a very small fraction of the input cost in production. Furthermore, capital is a sector specific input, which dampens the effect of parameter changes. Experimenting also with capital as a fully tradable input does not change the size of the secondary water market by any measure worth reporting.

A larger effect on the secondary water market comes from changing the water demand elasticities. Using unlikely, extreme, values for both agriculture and manufacturing sectors, the potential secondary water market reaches a range of 3.6% to 7.8% of the total potable water supplied. Yet, the outcomes are not far-off from the main result of 6%. Changing the water demand elasticities for residential users, *i.e.*, service sectors and households, by an unlikely order of magnitude of 10, changes the range to 4% to 18% of total potable water. Again, these are unlikely elasticities, but do not change the overall message described in the previous section.

Finally, stretching the water demand elasticities so that agricultural and manufacturing sectors are -1, and service sectors and household are -0.4, would increase the secondary water market to 198 MCM, which is 14.8% of total potable water supply.

The model is also tested with different marginal values of water. Because agricultural sectors are the main sellers of water, raising their water marginal value to the next price block, decreases the water market to 4.8% of total potable supply, and the nominal water shadow price rises to 2.05 NIS/CM. This outcome is not surprising, since the seller will sell less when his marginal value of water rises.[25]

Increasing the marginal value of water for the buyers, such as households and service sectors, either separately or jointly, will also not change the overall result but rather reallocate water differently between them. This is because at the top tariff blocks, both users have the same prices. Furthermore, the marginal value chosen for residential water users are already on the high-side, because the water price paid at the 'city gates' are lower than the actual price paid by final users. Thus, reducing their marginal value of water would have only reduced the secondary water markets.

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[25] Since manufacturing has one price block, no sensitivity test was conducted on its marginal value of water.

Table 6: Values used for Sensitivity Analysis, 2006

	Output Supply Elast.			**Water Demand Elast.**		
Sector	**Min**	**Model**	**Max**	**Min**	**Model**	**Max**
Agriculture	0.4	**0.8**	1.2	-0.1	**-0.7**	-2
Manufacturing	1	**3**	5	-0.1	**-0.7**	-2
Services	1	**3**	5	-0.01	**-0.1**	-1
Household				-0.01	**-0.1**	-1

Note: Max. and min. range for supply-price and demand-price elasticities. Bold numbers are the benchmark values.

In conclusion, besides confirming the validity of the model, the sensitivity analysis provides another important message. It shows that even when the deep parameters are somewhat imprecise, the size of the secondary water market is in the vicinity of 6% of the total potable water supplied (80 MCM in 2006). This is a rather small misallocation, and its significance will be discussed shortly. Furthermore, the results are mostly sensitive to the choice of the marginal values of water, which are harder to estimate. In this model, however, the idea was to capture the largest size of inefficiency possible, under plausible assumptions. Thus, increasing the marginal value of water for the agricultural sectors, the sellers, or lowering it for residential user, the buyers, would have only reduced the misallocation.

4.3 Comparing results for 1995 through 2006

The applied model is also calibrated for 1995 through 2006, for the years that CBS Israel had available data. Marginal values for water are re-assigned according to the relevant water prices chosen by the water authority at each year.[26] Using the year specific SAM, and the water demand-price elasticities and output-supply-price elasticities as reported in Table 2, the substitution elasticities are re-calibrated as discussed in Section 3.1. New water trade channels are set as in Section 3.4, *i.e.*, each year has its own values for Table 3.

The main results are summarized in the top section of Table 7, and conclude that the potential secondary potable-water market, for those years, would have been consistently around 5% to 6% of the total supplied potable water. The bottom section of Table 7 reports the changes to water price, relative to the initial administrative allocation, and the shadow water price.

At first, two results seem counter-intuitive, and are used to show how water authorities could use this kind of model to improve allocation efficiency. First, for 1995, the model

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[26] The water authority updated water prices according to a water index or due to administrative reform. The water index is based on the changes to the consumer price index, electricity prices and average wage levels. See extended Appendix E.2 for further details.

Table 7: Secondary Water Markets for 1995-2006

	Potable Water (Million Cubic Meters, MCM)			Non-Potable (MCM)	
Year	**Total**	**2nd Water Market**	**% of Total**	**Total**	**Nominal Price Change (%)**
1995	1574.7	**79.2**	**5.0**	406.5	3.5
2000	1481.4	**98.2**	**6.6**	442.3	4.6
2004	1359.0	**84.3**	**6.2**	595.3	5.0
2005	1344.1	**79.8**	**5.9**	617.3	4.1
2006	1340.5	**80.8**	**6.0**	618.5	4.4

	Nominal Change in Potable Water Price (%)				Shadow Water
Year	**Agriculture**	**Manufacturing**	**Services**	**Households**	**Price (NIS/CM)**
1995	13.4	-20.0	-76.1	-74.3	0.88
2000	20.8	-29.4	-73.6	-71.6	1.13
2004	22.5	-29.4	-66.4	-64.2	1.61
2005	21.2	-28.4	-63.8	-61.5	1.77
2006	22.6	-27.2	-64.8	-62.7	1.81

Note: Top section of Table 7, columns three and four, show the (potential) quantity of a secondary potable water market since 1995. Bottom section shows the percent change to potable water price from the initial allocation, and sixth column is the shadow price of potable water in nominal New Israeli Shekels (NIS) per cubic meter.

estimates that the potential secondary potable water market would have been the smallest, compared to the other years in the data (5.0% of total potable water). This is an indication of a high efficient allocation. Curiously, in that year, the supplied potable water was also the largest, 1575 MCM. Since agricultural sectors were portrayed as inefficient, “water guzzlers” in Israel, one would think that when the supply of potable water is large, there is more room for waste. The question is then, why was 1995 the most efficient year?

The reason is that in 1995, the infrastructure of non-potable water was at its infancy, and agricultural sectors were unable to substitute with lower quality water. Table 8 reports

Table 8: Potable water expenditure as % of total cost (net of tax)

	Agriculture	**Manufacturing**	**Services**	**Households**
1995	5.7	0.08	0.14	0.3
2000	2.5	0.031	0.12	0.2
2004	2.3	0.034	0.11	0.2
2005	2.2	0.034	0.11	0.2
2006	2.0	0.031	0.11	0.2

Note: from the social accounting matrix.

that the expenditure on potable water as a percent of total input cost, was twice as high in 1995 as compared to later years. Therefore, potable water were an essential input in those years.

The second counter-intuitive result is that the highest inefficient allocation (at 6.6% of total potable water supplied) was measured in the year 2000, in the midst of a water crisis in Israel. During the dry winters of 1998/9 through 2001/2, the water authority had cumulatively reduced agricultural potable water by approximately 40%, which were never returned in later years. Thus, by eliminating quotas, one should expect a more efficient allocation.

However, by 2000, new infrastructure and technologies that improved non-potable quality, enabled agricultural sectors to substitute potable water consumption with non-potable water, as illustrated in Figure 2. This meant that the expenditure on potable water dropped from 5.7% to a 2.5% of total cost on inputs (see Table 8), releasing excess potable water.

Furthermore, between 1995 and 2000, the water authority had reformed the water pricing scheme, disfavoring manufacturing sectors. While residential nominal water prices (households and service sectors) rose by approximately 16.5%, and for agricultural sectors by 20.7%, the manufacturing sectors had an increase of 45.7% in nominal water price.[27] The model captures the fact that manufacturing sectors would have liked to purchase more water from agricultural sectors, thus enlarging the potential secondary water market.

4.4 Policy implications

The policy implications, so far, are the following: First, water authorities across the world can use this method to estimate the level of allocation efficiency both within the current price-quota framework and for future proposed reforms. For example, the major reforms in Israel, between 1998 and 2001, though meant to deal with the serious water shortage of the time, were actually damaging and led to even more inefficient allocation. Furthermore, the latest pricing reforms in 2010, were not sufficiently evaluated.

Second, recalling that the results are meant as conservative, upper-bound, estimates of the secondary water market, I find that the administrative misallocation between 1995 to 2006 is on the average of 85 MCM. In other words, by *not* introducing a water market, Israel incurs an economic loss of around NIS 86 Million (in 2006 prices). This looks rather small, considering that it amounts to half the production of a desalination plant; It suggests that a market mechanism might not perform much better.

Finally, up until now, only the economic costs of an administrative mechanism were

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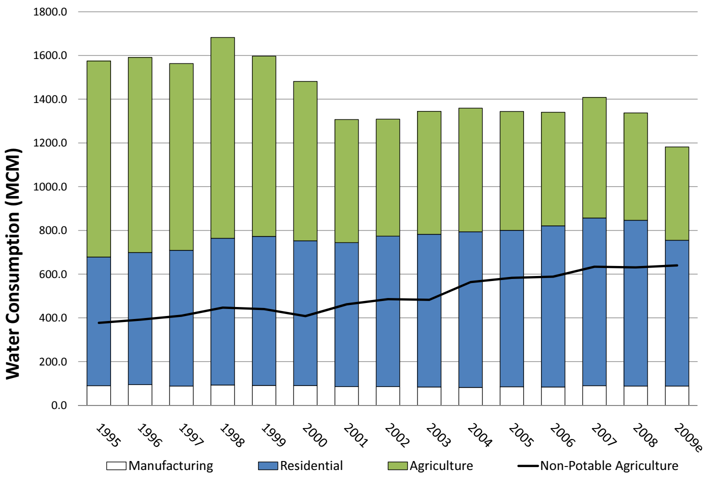
[27] Source: Water Authority water price data. This type of pricing change was due to an administrative reform, rather than a change to the water price index. See Table 11 in extended Appendix E.2.

Figure 2: Potable Water Consumption by Main Users (MCM)



Source: The Water and Sewage Authority, Israel.

Note: During the drought between winters 1998/9 through 2001/2, agricultural water quantities were reduced by 40%. This coincided with a rise in agricultural consumption of non-potable water. Water consumption by manufacturing sectors and residential users (per-capita) were fairly consistent. Roughly with population growth, residential water consumption rises by 2.3% per year (on average).

considered. By imputing some of the social value generated by the social planner, the next section compares the lost economic value from misallocation with the gains generated by maintaining the administrative mechanism.

5 Estimating the value of agricultural amenities

Typically, incomplete markets (or no markets at all, as in our case) are characterized by distortions and welfare losses. However, when amenities are involved, it is possible to rationalize this distortion as a corrective measure for sectors which create positive amenities that are not valued economically. For example, in addition to producing marketed goods, agricultural sectors also provide environmental amenities such as agricultural landscape, clean air, tourism, heritage preservation and other cultural elements that characterizes a country's self-narrative.[28]

The positive effects of agricultural amenities have been studied by various authors, *e.g.*, Drake (1992); Bowker and Didychuk (1994); Bergstrom et al. (1985); Brunstad et al. (1999); Fleischer and Tsur (2003, 2009); Kan et al. (2009) and others. These studies use micro-level

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[28] For example, the farming community in Israel is viewed as the "forefathers" of the Zionist movement who had built the state of Israel, and thus gives them an intrinsic cultural value.

Algorithm 1 Imputing the amenity value

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1. An arbitrary amenity value is chosen and taxed at 100% tax.
2. As in Section 4, compute size of water trade in a secondary water market.
3. Reduce tax on amenity to 0%, and re-compute size of the secondary water market.
4. Increase (decrease) amenity value and repeat (3) until the size of the secondary water
   market is null.
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data to impute the value of agricultural amenities in a partial equilibrium setting. This paper, however, uses the general equilibrium model developed in the previous sections to impute the value of agriculture amenity under a multifunctional agricultural sector, more resembling Peterson et al. (2002).

It is assumed that in addition to the privately traded commodities, agricultural sectors also provide an amenity, which they are not rewarded for producing. A regulator, however, recognizes this distortion and uses administrative water allocation to correct for it. The imputed value, in this extension, characterizes the amenity value which would rationalize the administrative water allocation as being efficient. Therefore, assuming the amenity value would have been accounted for in the first place, even with the possibility of water trade, water users would choose not to trade.

Algorithm 1 summarizes the method by which the amenity value is imputed. Using a fixed proportion transformation function,

$$Y_{agr} = \min\left\{\frac{Y^{c}_{agr}}{a}, \frac{Y^{nc}_{agr}}{b}\right\} \tag{19}$$

agricultural sectors are now assumed to jointly produce two types of goods; a privately traded commodity Y^{c}_{agr}, *e.g.*, apples, and a non-commodity Y^{nc}_{agr}, *i.e.* an amenity good such as landscape and heritage. Both goods are demanded by the representative household, but by initially setting a 100% tax rate on the non-commodity, and transferring the tax revenue directly to the households, the household pays for the commodity, but not for the non-commodity. In such a way, the household consume the amenity free of charge, *i.e.*, its price is zero. As long as the amenity tax rate is maintained at 100%, any arbitrary amenity value used in the data-set has no bearing on the water trade results, reported in Section 4.

Next, the amenity tax rate is reduced to 0%, and the size of secondary water market is re-computed. The model iteratively increases (decreases) the amenity value until a value is found that leads to *zero* water trade, even when trade is possible.

Table 9: Agriculture Amenity Value (2006)

	Channel	**Amenity Value**^{a} (2006 Million NIS)	**As % of Agriculture output**^{b}	**As % of total output**^{b}	**Amenity value lost from a water market**^{a} (2006 Million NIS)	***Net-social* welfare lost from a water market**^{a} (2006 Million NIS)
1.	Manufacturing buy	26,000	68	1.7	-28.7	-68.4
2.	Services buy	53,500	139	3.5	-61.8	-69.4
3.	Households buy	87,250	227	5.7	-165.6	-104.7
6.	**All Channel Trade**	**87,250**	**227**	**5.7**	**-321.5**	**-215.0**

*Source: ^{a} Model Result. ^{b} In 2006, agricultural economic output was NIS 38.5 Billion, and total country output was NIS 1,542.1 Billion. Source: Israel CBS and used in the SAM.

Note: The second column is the amenity value that rationalizes an efficient administrative allocation. The third and fourth columns are the size of the amenity value as a percent of the agricultural output and total output. The fifth column is the direct amenity value lost, and column six is the overall net-social welfare lost, from introducing a water market with the imputed amenity value included in a re-calibrated SAM. The difference between them are the welfare benefits from a water market.

Table 9 summarizes the imputed agricultural amenity value for the main channels, and for the all-trade channel scenario, for 2006. The conclusion is that it amounts to approximately NIS 87.3 billion. This is roughly 2.3 times the value of the agricultural economic output, and equivalent to 5.7% the total country's economic output. Similarly, it is equivalent to 70% of the total agricultural *social* output, *i.e.*, economic output plus amenity.

This is not to say that this value *is* the true value of the amenity, but rather that it indicates the amenity value which would rationalize the administrative allocation as being efficient given the preferences used. With a lack of information, the amenity enters a Cobb-Douglas utility consumption bundle with other goods. Hanemann (1991), in a related paper, discussed cases where public goods are readily substitutable for public goods, and others where they are not. At an aggregate level, it seems less realistic that the former is true for Israel. Therefore, reducing the substitution elasticity with other goods would only increase the imputed amenity level.

Furthermore and unsurprisingly, re-doing the analysis as in Section 4, but with a re-calibrated social accounting matrix (SAM) that accounts for the imputed amenity value from Table 9, all the main water market results are exactly the same as previously reported, *i.e.,* water quantities and prices, and changes to production are the same. Recall that production sectors do not internalize any benefits from producing an amenity. Therefore, it does not matter what the amenity value is.

However, what *is* different is the analysis of welfare. In this extension, the household utility function also includes a demand for amenities. When agricultural production falls, so does the amenity level proportionately. This, therefore, leads to a loss of amenity value worth NIS 321.5 million.[29] Yet, introducing a water market does improve the use of water inputs, raising welfare by NIS 106.5 million (similar to the result reported in Table 4).[30] Overall, this is a *net-social* welfare loss of NIS 215 million (see Table 9), which is translated as a 0.024% fall in utility level.

To gauge whether the value of the imputed agricultural amenity is plausible in an Israeli context, I compare with Kan et al. (2009) who use micro-level Israeli data to investigate the potential economic benefits of changing intra-agricultural land allocation among crops, while taking into account both profitability and amenity contribution. Their study is based on work by Fleischer and Tsur (2009), who estimate crop specific amenity-value function in an Israeli rural-urban land allocation setup. Kan et al. (2009) conclude that in Israel, the agricultural amenity value is roughly 33% of the total agricultural *social* output.[31]

Comparing their results to mine, the order of magnitude is rather similar, though my results are higher for the following reason. First, my analysis uses all agricultural sectors, while Kan et al. (2009) focus on *vegitative* agriculture only, which accounts for approximately 64% of total agricultural output. It would be possible to compare more closely my results with theirs by further dis-aggregating agricultural sectors.

Second, Kan et al. (2009) analyze only the northern regions because vegitative agriculture is predominately located in the wetter north of Israel, and not in the arid south. In my paper, however, agriculture is analyzed country-wide. Since both northern and southern farmers pay the same rates for water inputs, including southern farming in the analysis increases significantly the amenity value of agriculture as a whole.

Finally, it should be emphasized, again, that the agricultural amenity estimated here is not the amenity value *per se*, but rather the value which would rationalize the administrative water allocation as being efficient. This is different from Kan et al. (2009)'s approach who estimate the amenity value by comparing a profit maximizing function to its regional Pareto efficiency function. In my case, the amenity value consists of all elements of amenity, including cultural and heritage aspects. Though tough measures have been imposed on the Israeli public to conserve water, the administrative mechanism continues to operate in its present form. This suggests that the public has internalized the value of the amenity rather than overturning it.

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[29] As before in Table 5 of Section 4, agricultural production drops again by -0.37%. Due to the Leontief transformation, amenity drops by $-0.37\% \cdot 87,250 = -321.5$.

[30] Without considering amenities, Table 4 reported that a water market raises welfare by NIS 86.3 million.

[31] In Kan et al. (2009) Table 2, this is referred as total *net-social* benefits to remind the reader that total social benefits includes both the production profits and the amenity value, and I therefore do the same.

5.1 Policy implication

The main policy implication for the Israeli case is that if an environmental amenity of NIS 87.3 billion is present, introducing a water market will not necessarily increase welfare, but may actually reduce it. Some points to consider are the following.

First, we can *roughly* impute a lower bound amenity value, by combining Kan et al. (2009)'s results with this model, which would lead to a smaller amenity loss of around NIS 46.8 million.[32] Overall, the *net-social* welfare gains will be small, if the benefits from a water market are around NIS 80 to 100 million, as found in this paper. However, recalling that the aim has been to compute a conservative, upper-bound estimate, this means that the benefits from a water market could be even smaller.

Second, if the average yearly misallocated water is approximately 85 million cubic meters of water, this amounts to around half the production of a desalination plant.[33] Einav (2009) reports that the investment cost is somewhere in the range of half to one billion NIS. If the saved welfare loss is around NIS 215 million every 3 to 4 years, within a few years, a desalination plant therefore would be a better sustainable alternative to a water market.[34]

Finally, this paper has only focused on agricultural amenities and does not include amenities created by other sectors, *e.g.*, public and private gardens, world heritage sites, etc.[35] These are overlooked because the method implemented here cannot be used to compute them. Residential users have higher marginal values of water making them natural buyers of water. If it was possible to reward them for producing the amenity, as it was done with agricultural sectors, they would demand even more water. In this case, Algorithm 1 has no bound. Because the administrative allocation supposedly accounts for all amenities, the inframarginal social-welfare loss from introducing a water market could be even higher.

6 Conclusions

In Israel, parliamentary investigative committees and researchers from the natural and social sciences have concluded that for decades, the administrative water allocation mechanism has

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[32] An over-the-envelope calculation of the following: multiply the 2006 agricultural production level, NIS 38,497 million, by Kan et al. (2009)'s ratios of amenity to benefit, 33%. This very *rough* imputed amenity value will be NIS 12,704 million. Then, the fall in agricultural production, -0.37%, would lead to a loss of NIS 46.8 Mill in amenity value.

[33] Or in the vicinity of importing water from Turkey, under discussions between the two countries.

[34] Recall that 3 to 4 years is the short-to-medium run time-frame of the model.

[35] Recall that from Section 3.4, garden water consumption is around 25% of total residential. Furthermore, the amenity value of world heritage sites are unknown. For example, since 2000, the Jordan river has been dammed at the southern tip of the Sea of Galilee. The water trickling downstream is recycled water for touristic purposes. No water from the Jordan river is reaching the Dead Sea, which will eventually dry up. The irreversible environmental and historical implications are not measured here.

mismanaged water allocation. Underfunding of desalination plants, and over subsidizing of the agricultural sectors, had led to a severe hydrological deficit. Yet, the administrative allocation is crucial because it adds social benefits, which are difficult to evaluate economically.

By developing an applied general equilibrium model, this paper set out to evaluate these positive and negative aspects. The model compared the administrative mechanism with a simulated market mechanism, and concluded that between 1995 to 2006, a conservative, upper-bound, average of 85 million cubic meters of potable water were misallocated yearly, roughly 5% to 6% of the total annual supplied potable water. In monetary terms, this amounted to an economic loss of between NIS 80 to 100 million (in 2006 prices).

However, neglecting non-commodity considerations led to a partial understanding of the costs and benefits to welfare. An administrative mechanism also promotes social agendas, which are not considered within a market mechanism. For example, they protect agricultural amenities, which are non-commodities that farmers produce but are not rewarded for producing. In the extension of the model, the value of the agricultural amenity was imputed at around 2.3 times its commodity economic output. If a water market would be introduced, the social value lost could be around NIS 320 million. Overall, this is a *net*-social loss of NIS 215 million. These findings, therefore, supported the continued use of the water administrative mechanism in Israel.

Finally, because my conclusions apply to the short-to-medium run water situation, there are still limitations to the analysis . As Diao and Roe (2003) discuss, having a water market can eventually make water similar to any other traded commodity. It can motivate agents to search for better technology to increase water supply (*e.g.*, private and government collection of runoff water, desalinization of seawater, and recycling sewage water) for resale into the market for profit. The long-run potential gains from a market mechanism are not fully quantified in this short-to-medium run analysis, and further research is therefore necessary.

Extended appendix

A Water Policy in Israel

A.1 An overview of Israel's water policy

Menahem (1998), Becker and Lavee (2002) and others, have extensively discussed the historical development of water policy in Israel, which they divide into three sub-periods. In the first period, 1948-67, water sources and institutional frameworks were developed and the government pro-actively used administrative water allocation to supplement money transfers, promote settlement and food-security policies, and to subsidize agricultural and various manufacturing sectors.

In 1959, the Water Law was enacted as a legal framework for the control and protection of Israel's water resources. It states that all sources of water in Israel are public property and a person's land rights do not confer rights to any water sources running through or under his land. Every person is entitled to use water, as long as that use does not cause the salination or depletion of the water resource. For egalitarian reasons, all users far from the water source pay the same price as those close to it. Finally, the Water Law forbids the resale of water quotas, which disconnects market forces from the pricing and allocation of water.

The second period is considered to be 1967-90, in which agricultural expansion was prioritized over water resource conservation. Water management responded re-actively to seasonal rainfall variation, or to changes in the political environment. For example, during a drought, water quotas were sharply reduced, targeting first the agricultural sectors. Water quotas were returned to previous levels when rainfall was plentiful again.

Finally, the third period, from 1990 to present day, is characterized as a gradual paradigm shift, moving away from a reactive water management style, towards a more proactive approach. But changes have been slow, and over 40 years of excessive consumption, above the natural rate of replenishment, has led to severe hydrological deficits, which permanently threatens water quality.

A.2 A recent historical account of the hydrological situation and policy results

Between the winters of 1995/6 to 1998/9, rainfall was below the average of 1400 million cubic meters (MCM). In 1998, the Israeli government officially declared a "water crisis", which had continued on, and had peaked in winter 2001/2.

In 1997, the Arlozoroff Committee was formed to suggests policy reforms to deal with the “water crisis”. The conclusions, however, were not fully accepted, and included the following: economic incentives should be used to bring about a diversion of potable water away from agricultural sectors towards residential consumption. Farmers who, as a result, would suffer losses should be initially compensated. Agricultural water prices should be raised by 80% over several years, under the assumption that an 8% increase in price would result in a reduction of 4% to 5% of the quantity of agricultural water consumption. Finally, investment in desalination plants must begin immediately.

In 2001, as a result of the prolonged drought, the Israeli government re-evaluated the “water crisis”, and formed a Parliamentary Inquiry Committee to investigate its causes, and to suggest key reforms. The findings were presented in 2002. Some of the key conclusions were to establish an independent, professional water authority. Encourage and attract water professionals, such as water engineers, hydrologists, economists, and other water resource management professionals, to enter the water sector. Reduce bureaucracy and enhance the development of reclamation plants. Finally, invest in desalination plants and return natural resources to above the hydraulic ’Red Lines’ by 2005, and then continue with sustainable water management (Drayzin, 2002, Magen, 2002).

In 2008, the State Comptroller Committee received a report that analyzed how many of the 2002 Parliamentary Inquiry Committee’s conclusions were actually implemented. This report warned that the available water supply continued to be in deficit, and that only some of the lessons learned from the “2001 water crisis” were actually implemented, *e.g.*, the construction of desalination plants had been delayed by a around five years, because the plentiful rainfall of winter 2002/3 had allowed policy makers to divert attention to more urgent budgetary needs (Davidovich, 2008, Tal, 2008).

Since winter 2008/9 through winter 2010/11, another cluster of low yearly rainfall have lead the government to declare another “water crisis”. Once again, water allotments were reduced from agricultural sectors and several manufacturing sectors. Residential users were urged, through public awareness programs, to conserve water, and were limited and penalized from watering gardens. The water pricing framework was, once more, re-considered and revised.

A.3 Criticism of the administrative allocation in Israel

Plaut (2000) critically summarizes Israel’s administrative mechanism, and discusses why it is harmful, and produces waste and misallocation. He adds that the current system motivates farmers to use all the allotted yearly water, in order to justify and preserve their water allotments for the next year, even if it means dumping it.[36] This type of behavior resembles other settings, *e.g.*, government ministries and bodies, sub-divisions within large firms, etc, that use-up all resources before the budgetary-year ends. Furthermore, Lichtman (2009) reports illegal, shady, and inequitable water activities in Israel's farming sector, and estimates that a black water market operates at around 10 million cubic meters (MCM) yearly, *i.e.*, equivalent to a small desalination plant.

One can argue that this on-going "water crisis" is a result of mismanagement. Water supply and demand do not balance, and the administrative mechanism is unable to adjust water allocation efficiently and quickly. Introducing tradable water permits, however, would enable market forces to internalize the true value of the resource. Both sellers and buyers would gain from trade, regardless of whether the permits are auctioned or allocated free-of-charge (Becker, 1995; Holden and Thobani, 1996).

Alternative water allocation mechanisms have been discussed by many researchers in Israel and abroad. Dinar et al. (1997), Holden and Thobani (1996) and Livingston (1995) give a general review of the theoretical advantages and disadvantages of alternative mechanisms. Becker and Zeitouni (1998), Fishelson (1994), Moore (1994), Zeitouni et al. (1994) discuss alternative mechanisms within the Israeli context, and Bielsa and Duarte (2001), Calatrava and Garrido (2005), Garrido (2007), Pujol et al. (2006), Simon and Anderson (1990) discuss for other countries outside of Israel.

A.4 Inefficient administrative water allocation

Changing established allocation mechanisms is politically difficult, slow, and even too costly to justify a change. If the administrative allocation is not *too* inefficient, a better strategy might be to improve allocation within the current mechanism. Otherwise, if it is very inefficient, an alternative mechanisms might be better. Figure 3 illustrates why the political environment may make it difficult to change an established administrative allocation mechanism.[37]

Recall that *misallocation* is defined as the quantity of water (in cubic meters) that would be transferred from one user to the other, after water quotas and prices are set by the social planner. In other words, if the potential secondary water market is large, it could indicate that the initial administrative allocation is inefficient, and users prefer to re-shuffle water between them. Note, however, that non-economic value are not considered here, and that

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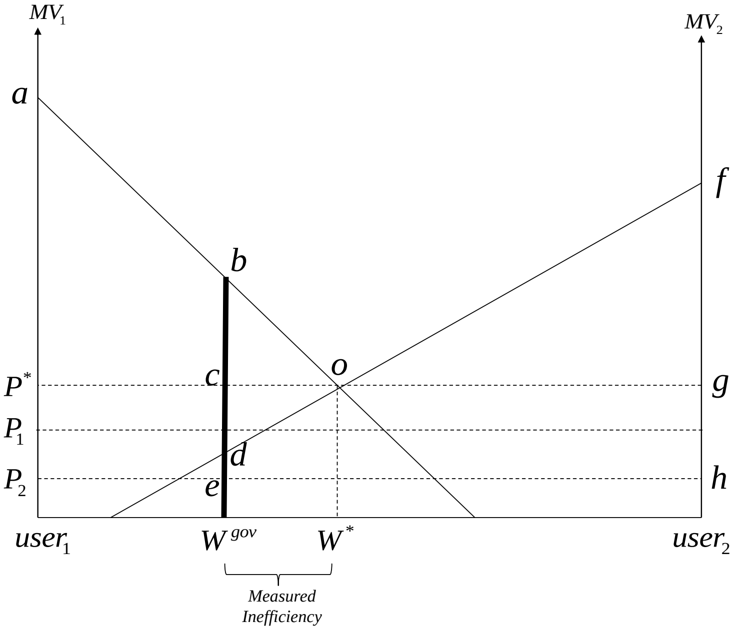
[36] Also, American environmentalists had criticized water policy in California's Central Valley for decades, arguing that it causes serious environmental damages. Farmers were sold water at prices far below its resource value, and they had simply dumped huge amounts of it on desert fields (Plaut, 2000). Recall, that also much of Israel is arid.

[37] Becker (1995) uses a similar example .

Figure 3: Water Quotas With Two Agents



Note: Total water $\bar{W}$ is allocated by the government. User 1 is allocated water quantity W^{gov}, while user 2 is allocated $\bar{W} - W^{gov}$. Area *bod* is the dead weight loss from inefficient water allocation. The potential secondary water market is the volume $|W^* - W^{gov}|$, a proxy for inefficiency.

the market mechanism is defined as the most optimal.

Assume a closed economy with only two water users. The total water resource is quantity $\bar{W}$, and the social planner allocates W^{gov} to user 1, and the rest $\bar{W} - W^{gov}$ to user 2. Furthermore, water trade is prohibited. However, this allocation is clearly not optimal, because the marginal values of water are not equalized between users. User 1 would benefit from buying some of user 2's water rights, while user 2 would also benefit from selling-off some of his water rights. Overall, the economy suffers a dead weight loss equal to area *bod.*

Furthermore, because the social planner also sets water prices, when it is set below the market price, two possibilities arise. At level P_1, user 1 has an excess demand for water, and user 2 has an excess supply. At level P_2, both users have excess demands.

In this model, *misallocation* is defined as the absolute horizontal distance $|W^* - W^{gov}|$ measured in cubic meters of water. Thus, inefficiency rises when the discrepancy between the initial allocation and the market allocation rises. Now assume that the water authority wants to reduce the inefficiency. To do so, it must raise the water price from P_2 to P^*, and adjust water quotas to point W^*. This would bring an overall benefit to the economy. However, without compensation, some users will be worse off, which will incentivize them to block this change, even at the cost of it being welfare improving.

For example, user 1's initial consumer surplus is area $abeP_2$, and user 2's consumer surplus is area $fdeh$. When price and quotas are re-adjusted to the optimal P^* and Y^*, user 1's consumer surplus changes to area aoP^*, which may (or may-not) be an improvement, depending on whether additional area boc is greater (or smaller) than the reduction in area P^*cep_2. On the other hand, user 2's consumer surplus is unambiguously reduced to area fog. Thus, efficiency is increased, but at the cost for some.

Furthermore, there are two additional considerations. First, user 2 will be willing to spend area *godeh* to block these changes. He will loss this area anyway, if the change occurs without compensation. Regarding user 1, this is again unclear, because his gain (or loss) from the re-adjustment is ambiguous. Second, assuming that the re-adjustment had occurred, since user 2 most likely would have invested area *godeh* to block the change, this could lead to an overall welfare loss. Again, user 1's case is ambiguous. The conclusion is that even though a regime shift could allocate water correctly, it might be unwarranted, because the total non-recoupable costs are greater than the economic gains from area *bod*.

Thus, an administrative allocation may become a method to re-distribute income. Various pressure groups struggle to maintain their historical allocations, which intensifies even further during severe water shortages and subsequent water quotas cuts (Plaut, 2000; and as reported in the media). In addition, since new mechanisms cannot be tested, politicians often prefer to hold-on to the mechanisms already in place, rather than risk an overhaul, only to discover later that it might be worse off.

A.5 A water market as one alternative to an administration mechanism

One alternative to an administrative mechanism could be a water market, which is relatively new in some regions such as Chile, Australia and the USA. In other regions, like Spain and India, water markets have been traditionally functioning for years.[38]

When initializing a new water market, there are four possible methods for allocating entitlements: (1) Random access; (2) Administrative rules based upon eligibility criteria; (3) Historical allotments; and (4) Auctions.

These methods have been used in different countries. Both auction and random access (also called lotteries) have been frequently used in allocating hunting permits for big game. However, they have also been used in water markets. Random access are more common in allocating permits among residents, while auctions are more common for allocating permits to nonresidents. The most widely used method for initializing a new water market has been the historical approach, which is also known as "first-come, first served" or "grandfathered".

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[38] See discussion and case studies by Bhatia et al. (1995); Holden and Thobani (1996); Dinar et al. (1997); Grafton et al. (2010).

Some of the reasons for its popularity are the following. As discussed in the section A.4, when users are initially (historically) allotted water and then allowed to trade, they are better-off. Therefore, they would be less likely to oppose a new water market, compared to other methods.

Furthermore, historical allotments recognizes the fact that previous water consumers had invested in resource extraction and infrastructure, and it would serve to protect those investments. Finally, empirical evidence suggests that using historical allocation leads to smaller financial burden on water users; Permit expenditure, which is the auction revenue collected by the government, is typically higher than the extraction costs, which are the real production costs for water. An auction method, therefore, could create opposition to change, while historical allocation would be accepted, and thus raises the chances for policy to be implemented (Lyon, 1982; Tietenberg, 2002).

Some general ideas for the institutional framework of a water market are the following. Water could be resold or rented by users, and water permits would be exchanged with minimal transaction costs. The new Water Authority would redefine its duties and would receive a status similar to a Central Bank, becoming a separate entity from the political arena. As water levels drop, salt water and other minerals infiltrate the aquifers and water basins, and deteriorate water quality; Consequently, the Water Authority could aim for a predetermined water quality level, by controlling for the available water supply after the rainy season, resembling the Central Bank that aims for a predetermined inflation target, by controlling the money supply.

If equal burden of risk is preferred, than allotments would be proportional. After the yearly supply of available water is determined, users would receive their proportional share, though actual quantities vary. The new Water Authority would monitor and enforce correct permit consumption, and impose a penalty on those who illegally extract excessive amounts of water.

Holders of water rights would also be owners of their waste-water. Entrepreneurs could collect waste-water and resale it back into the water market for profit. Other agents could invest in desalination plants or import water from other countries, and sell them in the water market for profit. Finally, the water market would develop a temporal forward market, in conjunction to spot contracts.

B A full description of the applied model

Following Section 2.1, the applied model is extended in the following way. The water model is a static general equilibrium model. For the specific Israeli case, production is aggregated into three main sectors: agricultural, manufacturing and service sectors. Each of them uses labor, capital, potable and non-potable water, and intermediate goods as inputs in production. There is one representative household, which derives utility by consuming water and final goods. Finally, government is not explicitly modeled, but its actions are manifested through the initial water allocation. Tax revenue from production is directly transferred to the representative household.

Water is initially allotted to each of the four users, and water trade is not possible. Then, when trade is allowed, water inputs are re-shuffled until all users have the same marginal water value.

Following Mathiesen (1985); Rutherford (1995, 1999), we set up an Arrow–Debreu equilibrium as a mixed complementarity problem (MCP). A complementarity constraint enforces that two variables are complementary to each other; i.e., that the following conditions hold for scalar variables x and y: $x \cdot y = 0, \quad x \geq 0, \quad y \geq 0$. This condition is compactly expressed as $0 \leq x \perp y \geq 0$. Intuitively, a complementarity constraint is a way to model a constraint that is combinatorial in nature since, for example, either x or y must be 0 (or both may be 0 as well).

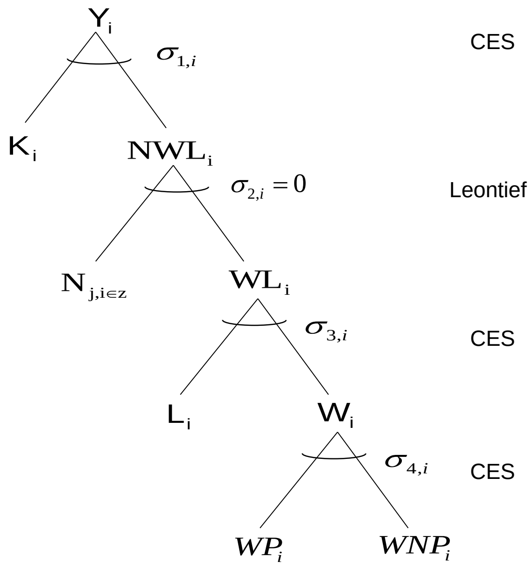
In a general equilibrium setting, three types of weak inequality conditions must be satisfied: (i) zero profit, (ii) market clearance, and (iii) income balance, each associated with three non-negative variables, *i.e.*, $y^* \geq 0$, $p^* \geq 0$ and $M^* \geq 0$, respectively.

B.1 Production Structure

Production has a four-level structure, which simplifies the calibration procedure and captures the different substitution elasticities for pairs of inputs. Section 3.4 and Appendix C.1 explain the assumptions and calibration method in further detail, while the following points should be noted. First, because capital incorporates land, it is assigned as a sector specific input. In the short-to-medium term, soil type, location, infrastructure, legislative constraints etc., make land rigid. It becomes convenient to place inputs which cannot migrate between sectors in the top level of production, and use the output supply elasticity, found in empirical papers, to calibrate for the substitution elasticity.

Second, in the initial allocation, water inputs are allotted to users and are non-tradable. They are, initially, sector specific with $p_{W,i}$ as there water prices. Placing water in the third level, enables me to calibrate substitution elasticities using water demand elasticities, which are readily available in empirical papers. However, when water-trade is allowed, it is reassigned as a global input. Trade continues until the market clears, and water prices change sufficiently to drive water marginal values to equalize between users.

Figure 4: The Production Function



Note: Production is a four level nested function. The lowest level combines potable and non-potable water into an aggregate water. The third level combines the aggregated water and labor inputs. In the second level, intermediate goods are combined with the water-labor aggregate. Finally, in the top level, capital is aggregated with the intermediate goods-water-labor aggregate.

Finally, labor inputs freely migrate between the various sectors, and have a global wage level, p_L.

Figure 4 illustrates production Y_i for $i \in z$ (discrete) final goods, and with j as i's alias. It has a four-level nested constant elasticity of substitution (CES) structure. In the lowest level, potable water, $W_{p,i}$, and non-potable water, $W_{np,i}$, are combined to form a water aggregator W_i. In the third level, water W_i and labor L_i inputs are combined to form an aggregator WL_i. In the second level, intermediate inputs $IN_{j,i\in z}$ are combined with the aggregator WL_i to form the aggregator NWL_i. Finally in the top level, capital K_i is combined with NWL_i to form the output Y_i.

Beginning with the **top level**, the implicit function theorem equates profit maximization with cost minimization, which takes the form:

$$\begin{aligned} \min_{K_i, NWL_i} \qquad & p_{K,i}K_i + p_{NWL,i}NWL_i \\ \text{s.t.} \quad Y_i = \; & A_{1,i}\left[\alpha_i K_i^{\rho_{1,i}} + (1-\alpha_i)\, NWL_i^{\rho_{1,i}}\right]^{\frac{1}{\rho_{1,i}}} \end{aligned}$$

$\sigma_{1,i}$ is the substitution elasticity within the CES production function. $p_{K,i}$ is the return on capital, $p_{NWL,i}$ is the price index for the aggregator. α_i defines the CES share parameters, and ρ_i is the CES exponent. Note that it is related to the substitution elasticity via $\sigma_i = \frac{1}{1-\rho_i}$ where $\sigma_i \geq 0$. Finally, $A_{i,1}$ is the level of technology.

Solving the minimization problem, and for simplification, reassigning the share parameters to incorporate the substitution elasticity using the relationship, $a_{K,i} = (\alpha_i)^{\sigma_{1,i}}$ and $a_{NWL,i} = (1-\alpha_i)^{\sigma_{1,i}}$, yields the following input demand equations:

$$0 \leq p_{K,i} \quad \perp \quad K_i \geq \frac{a_{K,i}}{A_{1,i}^{1-\sigma_{1,i}}} \left[\frac{(1-\tau_i)\, p_{Y,i}^{cons}}{p_{K,i}} \right]^{\sigma_{1,i}} Y_i$$

$$0 \leq p_{NWL,i} \quad \perp \quad NWL_i \geq \frac{a_{NWL,i}}{A_{1,i}^{1-\sigma_{1,i}}} \left[\frac{(1-\tau_i)\, p_{Y,i}^{cons}}{p_{NWL,i}} \right]^{\sigma_{1,i}} Y_i$$

with zero profit conditions denoting $p_{Y,i}$ and $p_{Y,i}^{cons}$ as the producer and consumer price indexes for sector i, respectively.

$$\begin{aligned} p_{Y,i}^{cons} &\leq \frac{1}{A_i\,(1-\tau_i)} \left[\alpha_{K,i} p_{K,i}^{1-\sigma_{1,i}} + \alpha_{NWL,i} p_{NWL,i}^{1-\sigma_{1,i}} \right]^{\frac{1}{1-\sigma_{1,i}}} \perp Y_i \geq 0 \\ p_{Y,i} &= (1-\tau_i)\, p_{Y,i}^{cons} \end{aligned}$$

At the **second level**, we assume the aggregate NWL_i has a fixed proportions share of intermediate goods IN_{ji}, and a water-labor sub-aggregate WL_i. The following is the optimization problem:

$$\begin{aligned} \min_{WL_i, N_{ji}} \qquad & p_{WL,i} WL_i + \sum_{j=1}^{z} p_{Y,ij} IN_{ji} \\ \text{s.t.} \quad NWL_i = \quad & \min \left[\frac{WL_i}{a_{WL,i}}, \frac{IN_{ji}}{a_{IN,ji}}, \ \ldots\ , \frac{IN_{zi}}{a_{IN,zi}} \right] \end{aligned}$$

Solving this minimization problem yields the following demand equations and price index

$$\begin{aligned} 0 \leq p_{WL,i} &\quad \perp \quad WL_i \geq a_{WL,i} NWL_i \\ 0 \leq p_{Y,i} &\quad \perp \quad IN_{ji} \geq a_{IN,ji} NWL_i \end{aligned}$$

with price index

$$p_{NWL,i} \leq a_{NWL,i} p_{WL,i} + \sum_{j=1}^{n} a_{IN,ji} p_{Y,i} \quad \perp \quad NWL_i \geq 0$$

At the **third level**, a water aggregator W_i and labor L_i inputs are aggregated into WL_i, where $\sigma_{3,i}$ is the substitution elasticity. The optimization problem is to

$$\begin{array}{rrl} \min\limits_{W_i,L_i} & & p_{W,i}W_i + p_L L_i \\ \text{s.t.} & WL_i = & A_{3,i}\left[\alpha_{WL,i}W_i^{\rho_{3,i}} + \left(1-\alpha_{WL,i}\right)L_i^{\rho_{3,i}}\right]^{\frac{1}{\rho_{3,i}}} \end{array}$$

and the solution yields the following equations:

$$\begin{aligned} 0 \leq p_{W,i} \quad \perp \quad W_i &\geq \frac{a_{W,i}}{A_{3,i}^{1-\sigma_{3,i}}}\left[\frac{p_{WL,i}}{p_{W,i}}\right]^{\sigma_{3,i}} WL_i \\ 0 \leq p_L \quad \perp \quad L_i &\geq \frac{a_{L,i}}{A_{3,i}^{1-\sigma_{3,i}}}\left[\frac{p_{WL,i}}{p_L}\right]^{\sigma_{3,i}} WL_i \end{aligned}$$

with price index

$$p_{WL,i} \leq \frac{1}{A_{3,i}}\left[\alpha_{W,i}p_{W,i}^{1-\sigma_{3,i}} + \alpha_{L,i}p_L^{1-\sigma_{3,i}}\right]^{\frac{1}{1-\sigma_{3,i}}} \perp WL_i \geq 0$$

Note that labor can migrate freely between all production sectors, and therefore has an economy-wide wage rate.

At the **fourth level**, potable water, $W_{p,i}$ and non-potable water $W_{p,i}$ inputs are aggregated into W_i, where $\sigma_{4,i}$ is the substitution elasticity. The optimization problem is:

$$\begin{array}{rrl} \min\limits_{W_{p,i},W_{np,i}} & & p_{W,,p,i}W_{p,i} + p_{W,np,i}W_{np,i} \\ \text{s.t.} & W_i = & A_{4,i}\left[\alpha_{W,p,i}W_i^{\rho_{4,i}} + \left(1-\alpha_{W,p,i}\right)L_i^{\rho_{4,i}}\right]^{\frac{1}{\rho_{4,i}}} \end{array}$$

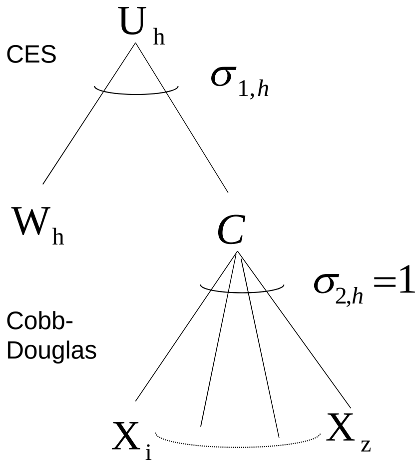
and the solution yields the following equations:

$$\begin{aligned} 0 \leq p_{W,p,i} \quad \perp \quad W_{p,i} &\geq \frac{a_{W,p,i}}{A_{4,i}^{1-\sigma_{4,i}}}\left[\frac{p_{W,i}}{p_{W,p,i}}\right]^{\sigma_{4,i}} W_i \\ 0 \leq p_{W,np} \quad \perp \quad W_{np,i} &\geq \frac{a_{W,np,i}}{A_{4,i}^{1-\sigma_{4,i}}}\left[\frac{p_{W,i}}{p_{W,np}}\right]^{\sigma_{3,i}} W_i \end{aligned}$$

$$p_{W,i} \leq \frac{1}{A_{4,i}}\left[\alpha_{W,p,i}p_{W,p,i}^{1-\sigma_{4,i}} + \alpha_{W,np,i}p_{W,np,i}^{1-\sigma_{4,i}}\right]^{\frac{1}{1-\sigma_{4,i}}} \perp W_i \geq 0$$

Note that non-potable water can migrate freely between all production sectors, and therefore has an economy-wide price. At the margin, this will increase the possible secondary water market for potable water.

Figure 5: Household Utility



Note: Utility is a two level nested function. The lowest level combines all final goods into an aggregate. In the top level, water input is combined with the final goods aggregate.

B.2 Household Utility Structure

The small open economy has one representative household, $h \in H$, that is endowed with labor, capital, and water resources. She receives tax revenue, and transfers positive (negative) value of income to cover balance of payments. Thus, the disposable household income is:

$$M = P_{W,h}W_h + \sum_{i=1}^{z}\left(P_L L_i + P_{K,i}K_i + P_{W,p,i}W_{p,i} + P_{W,np,i}W_{np,i} + p_{Y,i}^{cons}\tau_i + bop_i\right)$$

Extending this model for multiple households is a simple matter, but would then require assumptions regarding water ownership. In such a case, the above income equation would need to be revised. However, it would seem better to add a government agent that owns the water endowments.

Figure 5 illustrates the household's utility function, as a two level maximization problem. The lowest level combines all final goods into an aggregator, while the top level combines water inputs with the aggregator.

The **top level** maximization problem is of the following form:

$$\begin{aligned} \max_{W_h, C} \quad U = & \quad H\left[\beta W_h^{\rho_{1,h}} + (1-\beta)\, C^{\rho_{1,h}}\right]^{\frac{1}{\rho_{1,h}}} \\ \text{s.t.} \quad M \geq & \quad p_{W,h} W_h + p_C C \end{aligned}$$

W_h is household water consumption, with $p_{W,h}$ its consumer water price. C is an aggregated quantity of final goods consumed, with p_C its consumer price index. H is a shift parameter, and $\sigma_{1,h} = \frac{1}{1-\rho_{1,h}}$ is the substitution elasticity. Note that we can re-parametrize $b_W = \beta^{\sigma_{1,h}}$ and $b_C = (1-\beta)^{\sigma_{1,h}}$.

Solving the maximization problem yields the following demands and unit utility cost:

$$\begin{aligned} 0 \leq p_{W,h} \quad \perp \quad W_h \geq b_W \left[\frac{P^U}{p_{W,h}}\right]^{\sigma_{1,h}} M \\ 0 \leq p_C \quad \perp \quad C \geq b_C \left[\frac{P^U}{p_C}\right]^{\sigma_{1,h}} M \end{aligned}$$

$$P^U \leq \left[\beta_W \left(p_{W,h}\right)^{1-\sigma_{1,h}} + \beta_C \left(p_C\right)^{1-\sigma_{1,h}}\right]^{\frac{1}{1-\sigma_{1,h}}} \perp U \geq 0$$

In the **second-level**, the aggregated goods consumed is assumed to have a Cobb-Douglas structure with the following maximization problem,

$$\begin{aligned} \max_{X_i} C \quad &= \quad \Phi \cdot \Pi_{i=1}^{z} \left\{X_i^{\gamma_i}\right\} \\ \text{s.t. } I \quad &\geq \quad \sum_{i=1}^{z} p_{Y,i}^{cons} X_i \end{aligned} \tag{20}$$

and note that $\sum_{i=1}^{z} \gamma_i = 1$, $I = M - p_{W,h} W_h$ and Φ is a shift parameter.

Solving the maximization problem yields the demand for each final good, X_i,

$$0 \leq p_{Y,i}^{cons} \quad \perp \quad X_i \geq \frac{\gamma_i I}{p_{Y,i}^{cons}}$$

and $p_{Y,i}^{cons}$ as its consumer unit price

$$p_C \leq \Phi \cdot \Pi_{i=1}^{z} \left\{\left(p_{Y,i}^{cons}\right)^{\gamma_i}\right\} \perp C \geq 0$$

B.3 Closure Rules for Balance of Payments

Economies are dynamic and can run trade imbalances at any period by buying or selling assets. However, since this is a static model, I fix the balance of payments (BOP) in all counter-factual scenarios to the initial value. If not, it would be difficult to interpret welfare effects. For example, if a policy experiment leads to an increase in the trade deficit, welfare will increase due to foreign borrowing. This is misleading because at some point, borrowing will have to be paid back. Thus, household is assigned an endogenous endowment bop_i, which fixes the trade surplus (deficit) for each good to its initial value.

B.4 Market clearing conditions and secondary water market

As discussed in Section 3.1 and Appendix C, it is assumed that in the short-to-medium run, capital K_i, is a rigid input, with a sector specific return on capital. Labor, L_i, and non-potable water, $W_{np,i}$, are fully flexible across all sectors with a uniform wage rate and non-potable water price. The market clearing conditions are

$$\begin{aligned} L^s &= \sum_{i=1}^{z} L_i \\ W^d_{np} &= \sum_{i=1}^{z} W_{np,i} \\ K^s_i &= K^d_i \end{aligned}$$

All goods in the economy are fully consumed, either as household final goods, as intermediate inputs for production, or as exports

$$Y_i = X_i + N_{ji} + NX_i$$

Secondary potable water market

Having $i \in N$ firms (with j alias for i) and $h \in H$ households water users, let $M = N + H$ be the total number of water users. As discussed in Section 2.2, and depicted in Figure 3, each user is allocated a different *potable water* quota with a different water price. As long as water trade is prohibited, the market clearing condition for potable water is

$$\begin{gathered} W^s_i = W^d_i \\ W^s_h = W^d_h \\ p_{W,i} \neq p_{W,j} \neq p_{W,h} \end{gathered} \tag{21}$$

and because water users choose the amount of water to consume, the water price of the last unit is also the marginal water value. Each user has, therefore, a different marginal value of water (MVW)

$$MVW_i \neq MVW_j \neq MVW_h$$

When a secondary water market is introduced, water inputs are transferred to those users valuing them most. The market clears once a uniform *real* water price is reached. Water users can be *buyers* or *sellers*, and having M water users leads to M^2 trade configurations, with ψ_{mn} being the *relative* marginal value. If user $m \in M$ is a buyer, and user $n \in M$ is a seller, a possible trade channel is when $\frac{MVW_m}{MVW_n} = \psi_{mn} > 1$. Otherwise, it cannot be a possible trade channel.

$$\frac{MVW_m}{MVW_n} = \begin{cases} \psi_{mn} > 1 & \text{possible trade channel} \\ \psi_{mn} \leq 1 & \text{not possible} \end{cases}$$

These conditions, therefore, limit the number of configurations to only $T = \frac{M(M-1)}{2}$ possible trade channels, with $t \in T$ being a specific channel. (see Table 3 for a concrete example).

Thus, when water trade is enabled, the units of water, γ_t, that are transferred between seller n and buyer m are obtained by

$$0 \leq \gamma_t \perp p_{W,n,t} - (1-\epsilon)\, p_{W,m,t} \geq 0, \qquad \forall t \tag{22}$$

with $p_{W,n,t}$ and $p_{W,m,t}$ being the water market prices for the seller and buyer, respectively. For computational purposes, $\epsilon \rightarrow 0$ is a small number to *'help'* the solver with slack activities, thus avoiding the problem of infinite solutions (a degenerate model). This insures that when multiple t channels are opened (active), only *net transfers* of water is considered. For example, a case of infinite solutions is when a first user sells to the second, the second sells to the third, but the first also sells to the third. By adding ϵ, the solutions is limited to one (possible) case where, for example, the first sells to the second and to the third, while deactivating the second selling to the third.

There are various combinations (scenarios) of activating and deactivating water trade channels, *e.g.*, activating each channel separately, or all together. Therefore, each of the $t \in T$ channels has a binary action (designed by the scenario); active or not-active, $\{\mathcal{A}, \mathcal{NA}\} \in$ *Action*. There are $\{t_{\mathcal{A}}, t_{\mathcal{NA}}\} \in T$ channels, $\{i_{\mathcal{A}}, i_{\mathcal{NA}}\} \in N$ firms, and $\{h_{\mathcal{A}}, h_{\mathcal{NA}}\} \in H$ households, that are active or not-active, respectively. In other words, a water user will *not* trade because: it is either a choice, or it is *blocked.*

Thus, when Equation (22) is enabled, $\forall t_{\mathcal{A}}$, water units, $\gamma_{t_{\mathcal{A}}} > 0$, are exchanged between users up to a point where $p_{W,n,t} = (1-\epsilon)\, p_{W,m,t}$. If however, the seller's unit water price is higher than the buyer's, $p_{W,n,t_{\mathcal{A}}} > (1-\epsilon)\, p_{W,m,t_{\mathcal{A}}}$ (a strict inequality), the activity goes slack, $\gamma_{t_{\mathcal{A}}} = 0$, *i.e.*, there is no trade.

Enabling water trade for various water trade channels and actions, $\forall i$ and $\forall h$, the market clearance condition of Equation (21) is updated by the following

$$
\begin{gathered}
W^s_{h_{\mathcal{A}}} + \textstyle\sum_{i_{\mathcal{A}}} W^s_{i_{\mathcal{A}}} = W^d_{h_{\mathcal{A}}} + \textstyle\sum_{i_{\mathcal{A}}} W^d_{i_{\mathcal{A}}} \\
p_{W,i_{\mathcal{A}}} = p_{W,j_{\mathcal{A}}} = p_{W,h_{\mathcal{A}}} \\
W^s_{i_{\mathcal{NA}}} = W^d_{i_{\mathcal{NA}}} \\
W^s_{h_{\mathcal{NA}}} = W^d_{h_{\mathcal{NA}}} \\
p_{W,i_{\mathcal{NA}}} \neq p_{W,j_{\mathcal{NA}}} \neq p_{W,h_{\mathcal{NA}}}
\end{gathered}
\tag{23}
$$

B.5 agricultural amenity

The representative agricultural producer, $agr \in z$, is now assumed to jointly produce two types of goods; a privately traded commodity, Y^c_{agr}, *e.g.*, apples, and a non-commodity, Y^{nc}_{agr}, *i.e.* an amenity good such as landscape and heritage. Note that to clarify notation, when the amenity is added, the agricultural output and consumer price, previously defined as $Y_{agr}, p^{cons}_{Y,agr}$, are split into two variables: $Y^c_{agr}, p^c_{Y,agr}$ and $Y^{nc}_{agr}, p^{nc}_{Y,agr}$. For all other goods, nothing has changed.

The household utility function is re-defined to include the demand for both goods, *i.e.*, agricultural commodity and non-commodity. However, by initially setting the non-commodity tax rate to $\tau^{nc} = 100\%$, and transferring the tax revenue directly to the households, the household pays for the commodity, but not for the non-commodity. Therefore, the household consumes any level of amenity available, *i.e.*, its price is zero. As long as the tax rate on the amenity is maintained at 100%, any arbitrary amenity value used in the benchmark data-set, has no bearing on the water trade results. It does, though, affect the level of utility.

The level of amenity is imputed by reducing the tax rate to $\tau^{nc} = 0$, which allows agricultural firms to internalize the amenity they produce. The model, then, searches for an imputed amenity level that would lead to *zero* water trade, even when trade is possible (see Section 5).

Assuming a fixed proportion transformation function, the agricultural sector's new profit-maximization problem, which now includes both a commodity good and a non-commodity, is:

$$\begin{aligned}\underset{Y_{agr},Y^c_{agr},Y^{nc}_{agr}}{\text{maximize}}\ \pi_{agr} &= (1-\tau_{agr})\, p^c_{Y,agr} Y^c_{agr} + (1-\tau^{nc})\, p^{nc}_{agr} Y^{nc}_{agr} - p_{Y,agr} Y_{agr} \\ \text{s.t. } Y_{agr} &\geq \min\left\{\frac{Y^c_{agr}}{a}, \frac{Y^{nc}_{agr}}{b}\right\}\end{aligned}$$

with τ_{agr} and $p_{Y,agr}$ defined previously, as the agricultural production tax rate and the producer price, respectively.

Solving the maximization problem leads to the following supply functions for commodity and non-commodity goods:

$$\begin{aligned} 0 \leq p^c_{agr} \quad &\perp \quad Y^c_{agr} \geq aY_{agr} \\ 0 \leq p^{nc}_{agr} \quad &\perp \quad Y^{nc}_{agr} \geq bY_{agr} \end{aligned}$$

The zero profit conditions gives the unit cost of production of the output.

$$p_{Y,agr} \leq a \cdot (1-\tau_{agr})\, p^c_{agr} + b \cdot (1-\tau^{nc})\, p^{nc}_{agr} \perp Y_{agr} \geq 0$$

Finally, with lack of better information, the non-commodity (the amenity) enters a Cobb-Douglas utility function with other commodity goods in Equation 20, *i.e.*, *amenity* $\in z$. The significance is that the substitution elasticity between the non-commodity and commodity goods is 1. It is possible, with better information, to calibrate the substitution elasticity by using, for example, the demand price elasticity of an amenity. Hanemann (1991), in a related paper, discussed cases where public goods are readily substitutable for public goods, and others where they are not. However, this is difficult to find because an amenity, being a non-commodity, has no market price.

For the moment, it seems more likely that the substitution elasticity would probably be less than 1, at an aggregate level. As discussed in the paper, this would mean that the amenity value could be even larger, thus supporting even further, the main conclusions of the paper.

C Estimating the substitution elasticities in production

Well documented water demand elasticities and output supply elasticities are used to capture the specific characteristics of the water sector. This calibrates the substitution elasticity between factors in the production function and utility function. Table 10 summarizes the

Table 10: Calibrating the Substitution Elasticities, SAM 2006

	Output Supply Elasticity[a]	**Water Demand Elasticity**[a]	**Potable/Non-Potable Elasticity**[b]	**Cost Shares (2006, %)**[c]				**Calibrated Substitution Elasticity**		
	η_i	$\epsilon_{W,i}$	$\sigma_{4,i}$	$\theta_{K,i}$	$\theta_{W,1,i}$	$\theta_{W,2,i}$	$\theta_{W,3,i}$	$\sigma_{1,i}$	$\sigma_{2,i}$	$\sigma_{3,i}$
Agricultural	0.8	-0.7	1.1	46.5	3.3	6.2	19.0	0.70	0	0.84
Manufacturing	3.0	-0.7	1.1	56.0	0.03	0.1	0.4	3.81	0	0.7
Services	3.0	-0.1		19.0	0.1	0.1	0.3	0.70	0	0.1
		$\epsilon_{W,h}$			$\theta_{W,h}$			$\sigma_{1,h}$		
Household		-0.1			0.21			0.1		

Source: [a] Approximate mid-values reported in various papers. [b] Israel Water Authority. [c] Cost shares are from the Social accounting Matrix. Source: Central Bureau of Statistics Israel and own calculation.

Note: Calibrating substitution elasticities is done by combining the supply and demand elasticities with the cost shares.

values used.

The time frame of the general equilibrium model affects the assumptions we make on factor mobility, and the interpretation of the results. Hertel (2002) regards a time frame of 3 to 4 years as the medium-run, which is a sufficient for adjustment to take place. In the short-run, agricultural production has limited buffer stock, which makes it especially vulnerable to supply shocks and leads to wide fluctuations in commodity prices. In the long-run, the importance of stock diminishes and production has time to adjust.

Land supply rigidity depends on many factors, such as the availability of suitable land, the potential to convert land from one type of crop to another, or to another sector, *i.e.*, manufacturing or services. Furthermore, the existence of legislative or policy constraints can impede the transfer of land and make it immobile. Therefore, a lower land supply elasticity reflects higher immobility. For example, in the center of Israel, former farmlands are standing idle and ex-farmers are waiting for authorization to convert land into lucrative housing developments or office space. This stands in contract to manufacturing and service sectors, which have lower barriers. Thus, for the reasons above and because land is incorporated into capital, I assign capital a sector specific input.

The first section of Table 10 summarizes the sector specific elasticities, which will be used to calibrate the substitution elasticities. Agricultural sectors have a relatively inelastic supply price elasticity of 0.8, which is partly due to land's rigidity. Non-agricultural sectors have an elastic supply price elasticity of 3.0.

To calibrate the substitution elasticities σ_i, consider the four level production structure which was discussed in Section B.1 and Figure 4. In the first level, a perfectly elastic aggregator NWL_i is combined with an immobile capital. Rutherford (2002, p.20) explains how to calibrate the substitution elasticity, $\sigma_{1,i}$, when one of the inputs are immobile by

$$\sigma_{1,i} = \frac{\eta_i \theta_{K,i}}{1 - \theta_{K,i}} \tag{24}$$

where $\theta_{K,i}$ is the benchmark value of the cost share of capital, the fixed input, obtained from the social accounting matrix (SAM). η_i is the supply price elasticity obtained from empirical studies.

Many empirical studies have estimated η_{agr} at around 0.8. See Askari and Cummings (1977), Peterson (1988), Rao (1989) for a good review of the findings. For manufacturing and services, a great deal of literature focus on supply price elasticities of single sectors, *i.e.*, transport, housing, energy etc., but to my knowledge, there are no estimates for aggregated levels.[39] Since these sectors are generally elastic, I use a supply price elasticity of $\eta = 3$ for both manufacturing and service sectors.

In the second level, it is common practice to aggregate intermediate inputs and sub-aggregates in fixed-proportions, $\sigma_{2,i} = 0$.

Finally, in the third level, water and labor inputs are combined, and Appendix C.1 shows how I calibrate the substitution elasticity $\sigma_{3,i}$ by

$$\sigma_{3,i} = \frac{\epsilon_{W,i} + \sigma_{2,i}\theta_{W,3,i} - (\sigma_{2,i} - \sigma_{1,i})\,\theta_{W,2,i} - \sigma_{1,i}\theta_{W,1,i}}{(\theta_{W,3,i} - 1)} \tag{25}$$

where $\sigma_{1,i}$ and $\sigma_{2,i}$ are the substitution elasticities from the upper levels. $\theta_{W,1,i}$, $\theta_{W,2,i}$, $\theta_{W,3,i}$ are the water cost-shares relative to each nest, for the various sectors i, which are obtained from the SAM. $\epsilon_{W,i}$ is the water demand price elasticity reported in many empirical studies. For agricultural sectors, Bernardo et al. (1987), Booker and Young (1994), Moore and Hedges (1963), Nieswiadomy (1985), Scheierling et al. (2004) find values for $\epsilon_{W,i}$ ranging from -0.14 to -1. For the Israeli agriculture sector, -0.7 is an accepted figure. Eckstein (2001) estimates Israel's agricultural demand price elasticities to be between -0.5 to -0.8, while Becker and Lavee (2002) state it is close to -1.

For manufacturing sectors, Williams and Suh (1986) and Wang and Lall (2002) estimate their water demand price elasticities to be between -0.7 to -1, while I use -0.7. Finally, because the service sectors are mainly office buildings within residential areas, we calibrate them according to surveys for residential water demand price elasticities, similar to households. Fishelson (1994) estimates Israel's residential water demand at -0.1, while Hansen (1996), Arbués et al. (2003), Dalhuisen et al. (2003) and others report that residential water demand

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[39] For example, literature that report for single sectors are: Blackley (1999); Green et al. (2005); Malpezzi and Maclennan (2001) report elastic values for the housing market, as high as 20. Dahl and Duggan (1996) reports a supply price elasticity of 1.27 in the U.S. energy market.

price elasticities are low, ranging between -0.1 and -0.3. I use use -0.1. Sensitivity analysis is reported in section 4.2.

C.1 Calibrating 3rd level substitution elasticity

In order to calibrate σ_3, I follow Rutherford (2002). Assume a three-level nested production function similar to Section B.1, but use a general CES case rather than the Leontief structure in the second nest, and with the fourth nest aggregated into the third. If we construct the cost function from a calibrated benchmark in which input prices and total cost are unity, we can scale the benchmark values of the sub-aggregate cost as unity and express the demand for water as:

$$W = [p_W]^{-\sigma_3} p_{WL}^{\sigma_3-\sigma_2} p_{NWL}^{\sigma_2-\sigma_1} [p_Y]^{\sigma_1} \bar{W}$$

The derivative of the the demand for water with respect to the input price of water, at the initial allocation point where all prices are unity is:

$$\frac{\partial W}{\partial p_W} \mid_{p=1} = \left[-\sigma_3 + (\sigma_3 - \sigma_2) \frac{\partial p_{WL}}{\partial p_W} + (\sigma_2 - \sigma_1) \frac{\partial p_{NWL}}{\partial p_W} + \sigma_1 \frac{\partial p_Y}{\partial p_W} \right] \bar{W}$$

By Shephard's Lemma the derivative of the unit cost function with respect to input prices will give the share of inputs at the benchmark calibration, where $\bar{X}$ indicates values at the benchmark.

$$\frac{\partial p_{WL}}{\partial p_W} = \frac{p_W \bar{W}}{p_W \bar{W} + p_L \bar{L}} = \theta_{W,3}$$

$$\frac{\partial p_{NWL}}{\partial p_W} = \frac{p_W \bar{W}}{p_W \bar{W} + p_L \bar{L} + p_N \bar{N}} = \theta_{W,2}$$

$$\frac{\partial p_Y}{\partial p_W} = \frac{p_W \bar{W}}{p_W \bar{W} + p_L \bar{L} + p_N \bar{N} + p_K \bar{K}} = \frac{p_W \bar{W}}{p_Y \bar{Y}} = \theta_{W,1}$$

thus,

$$\frac{\partial W}{\partial p_W} \mid_{p=1} = \left[-\sigma_3 + (\sigma_3 - \sigma_2) \theta_{W,3} + (\sigma_2 - \sigma_1) \theta_{W,2} + \sigma_1 \theta_{W,1} \right] \bar{W}$$

The elasticity of demand is defined as $\epsilon_W \mid_{p=1} = \frac{\partial W}{\partial p_W} \frac{p_W}{W}$ and therefore

$$\epsilon_W \mid_{p=1} = \left[-\sigma_3 + (\sigma_3 - \sigma_2) \theta_{W,3} + (\sigma_2 - \sigma_1) \theta_{W,2} + \sigma_1 \theta_{W,1} \right]$$

Finally, solving for for σ_3 yields:

$$\sigma_3 = \frac{\epsilon_W + \sigma_2\theta_{W,3} - (\sigma_2 - \sigma_1)\,\theta_{W,2} - \sigma_1\theta_{W,1}}{(\theta_{W,3} - 1)}$$

D Estimating the substitution elasticities in utility

Appendix B.2 discusses the household's utility structure. Using water demand price elasticities, $\epsilon_{w,h}$, I calibrate the household's substitution elasticity, $\sigma_{1,h}$, with the following equation:

$$\sigma_{1,h} = \frac{\epsilon_{w,h}}{\theta_{w,h} - 1} \tag{26}$$

The cost share of water, $\theta_{w,h}$, is obtained from the SAM. Household water demand price elasticity, $\epsilon_{w,h}$, is estimated at –0.1, as I did for service sectors. Interestingly, because the water cost share is nearly zero, the substitution elasticity equals minus the demand elasticity of water (see right hand side of Table 10). Finally, in the second level, final goods are aggregated using a Cobb-Douglas function with $\sigma_{2,h} = 1$, which is standard practice in many applied general equilibrium models.

D.1 Calibrating Household's 1st Level Substitution Elasticity

Similar to Section C.1, I calibrate the household's substitution elasticity using water demand price elasticities. At the calibrated benchmark, in which input prices and total expenditure are unity, we can scale the benchmark values of the sub-aggregate expenditure as unity and express the demand for household water as:

$$W_h = \bar{W}_h p_{W,h}^{-\sigma_{1,h}} p_U^{\sigma_{1,h}}$$

where p_U is defined as the expenditure function for a unit utility.

Differentiate the above with respect to household water expenditure, obtain:

$$\frac{\partial W_h}{\partial p_{W,h}} = \bar{W}_h \left[-\sigma_{1,h} p_{W,h}^{-\sigma_{1,h}-1} + \sigma_{1,h} p_U^{\sigma_{1,h}-1} \frac{\partial p_U}{\partial p_{W,h}} \right] \tag{27}$$

Again by Shephard's Lemma, the derivative of the unit expenditure function with respect to input prices will give the share of inputs at the benchmark calibration.

$$\frac{\partial p_U}{\partial p_{W,h}} = \frac{p_{W,h}\bar{W}_h}{p_{W,h}\bar{W}_h + p_C\bar{C}} = \theta_{W,h}$$

Recalling that all prices are unity at benchmark, rearrange 27 as:

$$\frac{\partial W_h}{\partial p_{W,h}}|_{p=1} = \bar{W_h}\left[-\sigma_{1,h} + \sigma_{1,h}\theta_{W,h}\right]$$

Finally, defining the own-price elasticity of household water demand as $\epsilon_{W,h}$ and solving for $\sigma_{1,h}$, obtain:

$$\sigma_{1,h} = \frac{\epsilon_{W,h}}{\theta_{W,h} - 1} \tag{28}$$

E Data Collection and Building the SAM

This section will briefly summarize the data collection process and assumptions made in the calibration of the model.

E.1 Social accounting Matrix

Careful attention was placed on the construction of the social accounting matrix (SAM), which are based on *Use* and *Supply* tables published by the Israeli central bureau of statistics (CBS). It must be mentioned that the Use and Supply tables for years 2000, 2004, 2005, 2006 were reported in purchaser prices and aggregates matched. However, data for 1995 were not directly comparable, because Use data was reported in current output prices, while Supply data was reported in purchaser's prices. As a result, aggregates do not match, and additional assumptions had to be made in order to balance the SAM. Double checking the weights of inputs in production with later years, I believe that the 1995 SAM is good enough for comparison with the other years.

Water expenditure for each sector is estimated via other means, and not directly through the Use-Supply tables. This is because CBS does not report water separately from the electricity sector for two reason. First, due to national security reasons, they do not reveal sources and dependents. Second, electricity consumption is the largest input into water production, and it is natural for CBS to aggregate them together. As Plaut (2000) reports, electricity is approximately 28% of Mekorot's input costs, which amounts to approximately 6% of Israel's total electricity consumption.[40]

The water authority publishes potable and non-potable water consumption for agricultural and manufacturing use, and residential use, *i.e.*, services and household. Residential use is reported, for eleven sub-groups: housing, education, sport, public gardens, public buildings, health, hotels, commerce and trade, security and transport, construction, and service. Data for 2000, 2004, 2005, 2006 and for 1995, the weights from 1996 were used.

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[40] This high energy requirement is due to having water pumped from the sea of Galilee, an elevation of about 210 meters below sea level to an elevation of 152 meter above sea level into the national water carrier, from which gravity continues to transports the rest towards the center of Israel.

Thus, water expenditure in households and service sector is the sum water quantity times the relevant tariff band, as reported by the Water Authority. Agricultural water expenditure is obtained by multiplying the quantity of total potable water supply by the first price block. Likewise for manufacturing, the quantity of water is multiplied by the main water tariff block. Finally, Labor inputs are obtained from CBS' Compensation of Employees by Industry tables.

E.2 Water Consumption by User and Water Prices

Water price data was received from the water authority from Jan 1996 until December 2009. Prices update according to changes in the water-index, which is based on changes to the consumer price index, electricity prices and average wage levels, or as an administrative decision with governmental approval. In order to obtain a yearly water price, I simply average prices if they were changed more than once during the year. Water prices are calculated by the cost of extraction, and additional cost that are supposed to capture distribution and environmental sustainability.

Water Authority uses a complex increasing block tariff (IBT) for each type of consumer. As Table 11 illustrates, agricultural sectors pay a different price from the residential users, with a different IBT structure. Within residential users, different price are also charged. The water authority has changed its pricing structure in 2010, aiming to have similar water pricing for all users (See Water-Authority (2010)).

Table 11: Water Price by User (Yearly Average)[a]

Year	**Quantity**	**1996**	**2000**	**2004**	**2005**	**2006**	**2009**
Household	First 8 CM	2.32	2.69	3.19	3.31	3.52	4.17
	Next 7 CM	3.42	3.99	4.49	4.61	4.85	5.75
	Any additional CM	4.97	5.78	6.28	6.40	6.69	7.93
Hospitals and Mikve		3.68	4.28	2.26	2.38	3.43	2.77
Hotels		1.27	1.69	2.19	2.30	2.48	4.23
Public Buildings, Stores, Business, etc.		3.68	4.28	4.78	4.90	5.15	6.04
Public Gardens		4.97	5.78	6.28	6.40	6.69	7.68
Manufacturing (Potable)	In allocation limits	1.10	1.60	2.28	2.48	2.49	3.19
Excess	Up to 10% over allocation	0.36	0.36	0.36	0.36	0.36	0.36
Excess	Above 10% over allocation	0.96	0.96	0.96	0.96	0.96	0.96
Agriculture (Potable)	Quantity A	0.78	0.94	1.31	1.46	1.48	1.63
	Quantity B	0.89	1.08	1.54	1.69	1.70	1.87
	Quantity C	1.11	1.38	1.98	2.13	2.15	2.36
Excess	Up to 10% over allocation	0.36	0.36	0.36	0.36	0.36	0.36
Excess	Above 10% over allocation	0.96	0.96	0.96	0.96	0.96	0.96
Recycled (Shafdan)		0.52	0.62	0.79	0.79	0.80	0.86
Effluents		0.38	0.45	0.51	0.51	0.52	0.64

Source: Israeli Water Authority

[a] In 2010, the price bands were changed. However, since the model's data covers until 2006, I do not investigate the effects of this new price band.

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