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How Much it Costs to Cover Costs: An Economy-Wide Model for Water Pricing

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Abstract

This study offers a high-resolution model of an economy-wide water supply. The model is sufficiently detailed to represent all main water sources; the principal segments of the con- veyance system; urban, industrial and agricultural demand regions; and various water types, including fresh, saline, and recycled water. The model characterizes the optimal-spatial water allocation and establishes a comprehensive system of pumping levies and user fees that supports the optimal allocation. In addition, it enables simulating government pricing policies and assessing the welfare consequences of deviation from the optimal ones. The model is calibrated for Israeli 2010 data, and its usefulness is demonstrated by an evaluation of the economy-wide cost function and an assessment of the welfare cost of the recent Israeli Balanced Budget Water Economy legislation. Finally, the implications for international water trading between Israel and its neighbours are derived.

Keywords: natural resources; water economy, model, pricing.

JEL classification: Q15, Q25, Q27, Q28

1 Introduction

Recent years have seen population and income growth, leading to increased water demand and exacerbation of worldwide water scarcity. To meet these challenges, international organizations, e.g., Molle (2009), OECD (2010), are promoting the reinforcement of the traditional arsenal of quantity instruments for water allocation, such as quotas or riparian rights, with market-based policies, such as user charges and fees. Two main arguments are raised by those organizations to justify the above policy reforms: 1) Pricing constitutes essential incentives for efficient water use, and

2) Fees are necessary for cost recovery and the funding of the water system's operation and maintenance, and for funding investment in infrastructure.

The economic theory underlying the setting of efficient prices is well known, and calls for marginal cost pricing. However, the application of marginal cost pricing on an economy-wide scale is rather complex. First, it requires detailed spatial data regarding the physical structure of the pumping and conveyance system, and elaborated information regarding the associated costs. Second, the marginal cost in each demand region is a function of the combination of sources from which water is supplied to that particular region. Yet the mix of sources itself depends on many varying factors, such as hydrological conditions, precipitation, and government policies. Third, efficient prices ought to reflect not just actual cost, but also the scarcity rents of the limited water resources and the shadow prices of engineering and hydrological capacity constraints. The shadow prices, in turn, hinge not only on the supply factors, but also on the consumed quantities and hence on factors affecting the demand. Thus, economy-wide water pricing is an entangled task that requires a high-resolution, computerized model of the water economy (e.g., Jenkins et al. 2004; Rosenberg, Howitt, and Lund 2008). In this paper, we describe the development of such a detailed hydroeconomic model and illustrate its applicability by the formulation of an economy- wide pricing system for water in Israel. The model is developed based on the MYWAS platform, a multi-year extended version of the original one-year steady-state WAS (Water Allocation System) model (Fisher et al., 2005).

Israel is located at the border of the desert, it is subject to a semi-arid climate, and the annual availability of natural water is less than 160 cubic meters per capita, defined by the FAO as a region with severe water scarcity. To cope with those conditions, the Israeli government has established over the years an extensive and costly water system (Kislev 2011). The total annual costs of this system are estimated at more than 10 billion NIS, or 20% of the national expenditures on health or defense, and more than 1% of the national GDP. The complex physical system is accompanied by comprehensive and elaborate regulations (Kislev 2011). On January 1st, 2010 the Water Act in Israel was amended by a "balanced budget" decree for the water economy. That is, from the beginning of 2010 on, the cost of operating the water system must be recovered by the user payments. A subsidy to any sub sector of the population necessitates a price rise for other groups in order to balance the budget.

A second objective of the paper is to assess the welfare implications of this legislation, and more generally, to examine the potential for possible contradiction between the two roles of the pricing system, which are suggested by international organizations: I. the provision of efficient incentives, and II. cost recovery. To this end, we conceptualize a notion of an economy-wide cost function for the water sector, and use it to assess the marginal and average cost curves and quantify the magnitude of scale economies in the Israeli water economy.

The third and final objective of the paper has to do with conflict resolution and international trade in the context of water. As illustrated by a citation from Genesis 26:20 - "And the herdsmen of Gerar strove with Isaac's herdsmen, saying: The water is ours". Throughout the entire history of Canaan and the entire Jordan basin, water has been a source of conflicts and wars. The use of models such as MYWAS to calculate scarcity rents and shadow values can facilitate cooperation by capping the values of the scarce resources and demonstrating that the gains from collaboration can be considerable. Of particular interest in the Israeli-Palestinian context is the value of the various cells of the mountain aquifer, a source of ongoing dispute between the two entities (Fisher and Huber-Lee 2011). We use the updated MYWAS model to continue the work of Fisher and Huber-Lee (2011) to appraise the value of these aquifers and to calculate the shadow prices of water in the various geographical regions as the basis for potential trade with the Palestinian Authority and Jordan.

The increasing scarcity of water resources in many parts of the world, and the consequent need for efficient management of the limited resource, has led in recent decades to impressive development of hydro-economic models (e.g., Rosegrant (2000), Harou et al. 2009; Booker et al. 2012). Hydro-economic models differ substantially in their approach, e.g., optimization vs. simulation; and the objective function, e.g., cost minimization vs. welfare maximization. Modeling efforts in this area can be further differentiated by the scale of the application, time range, and level of resolution of the model. Similarly to the Californian Calvin model, which is described in Draper et al. (2003) and Jenkins et al. (2004), MYWAS is an economy-wide high resolution model. However, the Calvin model does not account for wastewater reclamation and the use of the recycled water for irrigation, while in the Israeli case, treated waste water is an important resource that accounts for 25% of the entire country's water supply and close to 50% of the irrigation water.

Several hydro-economic models have been developed for Israel. MYWAS is a multi-year extension of the single-year WAS model, which was developed for Israel, Jordan, and the Palestinian Authority during the mid-1990s (Fisher et al. 2002, 2005, 2011). Since the "production" of water by means of desalination of seawater and treatment of wastewater have become a major source of water in Israel – more than 50% of the aggregate water supply – the current version of the model elaborates considerably on those activities. The economic effect of the increased use of marginal water in Israel was recently studied via a CGE model of the Israeli water economy (Luckmann et al. 2011, 2014). The advantage of CGE models over sectoral models such as MYWAS lies in their capacity to endogenize the prices of other goods in the economy, and in exploring the (income) distributional effects of the changes in the water sector. However, due to data limitations, CGE models are not detailed enough to enable the spatial resolution necessary for establishing an efficient and cost recovering price system.

The development of a high-resolution spatial model of the water economy is our objective. We report the development of a non-linear mathematical programming model, which characterizes optimal water allocation and infrastructure investments across space, while taking into account a range of economic data and physical factors and constraints. The model is calibrated based on Israeli data from 2010. In the following section, we describe the development of the model, its topology, and calibration. Section 3 compares the optimal water allocation to the actual 2010 allocation, which was designed to recover cost and evaluate the welfare implications of the recent "balanced budget" legalization in Israel. In section 4, we characterize the efficient prices for the water economy and discuss the possibility of decentralization. In section 5, we introduce the concept of an economy-wide cost function and employ it to assess the scale economies in the Israeli water economy. In section 6, we use the model results to derive a few implications concerning the potential of water trade with Jordan and resolution of the dispute over the mountain aquifer with the Palestinian authority. Section 7 concludes.

2 The Model: MYWAS

The computerized model is developed on a GAMS platform and is connected to WEAP (Water

Evaluation and Planning), an interface module that facilitates simulations (Fisher and Huber-Lee 2011). The development process includes the design of the model's topology, formulating the physical constraints, as well as the calibration based on economic data and estimates from recent literature. The model incorporates the demand functions of households, industry, and agricultural users. In the agricultural sector, we distinguish between fresh, saline, and treated wastewater. In addition, we incorporate detailed infrastructure information and costs structure.

2.1 Topology

The topology specifies the water sources (aquifers, natural surface water, desalination plants, and wastewater treatment plants); the regions of demand for agricultural and non-agricultural (urban and industrial) water uses, and the connections between the sources and the demand zones. The model elaborates on all principal water sources in Israel, which total 46. These include 16 aquifers, 19 wastewater treatment plants, 3 reservoirs, 4 seawater desalination plants, and 4 desalination plants for saline water. Data on the various sources appears in Tables 1-3 below.

The conveyance system includes 183 pipelines for fresh water and 58 pipelines for marginal water. Schematic depictions of the fresh water system are shown in Figure 1; Figure 2 (Appendix) depicts the topology of the fresh and brackish water systems for irrigation, and Figure 3 (Appendix) shows a schema of the wastewater system. In addition, for each water source and the main junctions along the national water carrier, Tables A1-A8 in the Appendix describe the linkages to the demand regions. The model topology was developed with engineers from Tahal, Inc., Israel's largest engi- neering firm and the designer of most large water projects in Israel. In addition to the topology, Tahal provided the cost and hydrological data. The company ensures the reliability and accuracy of the data and guarantees that the model topology and data are consistent with the official information of the state of Israel and the Israeli Water Authority.

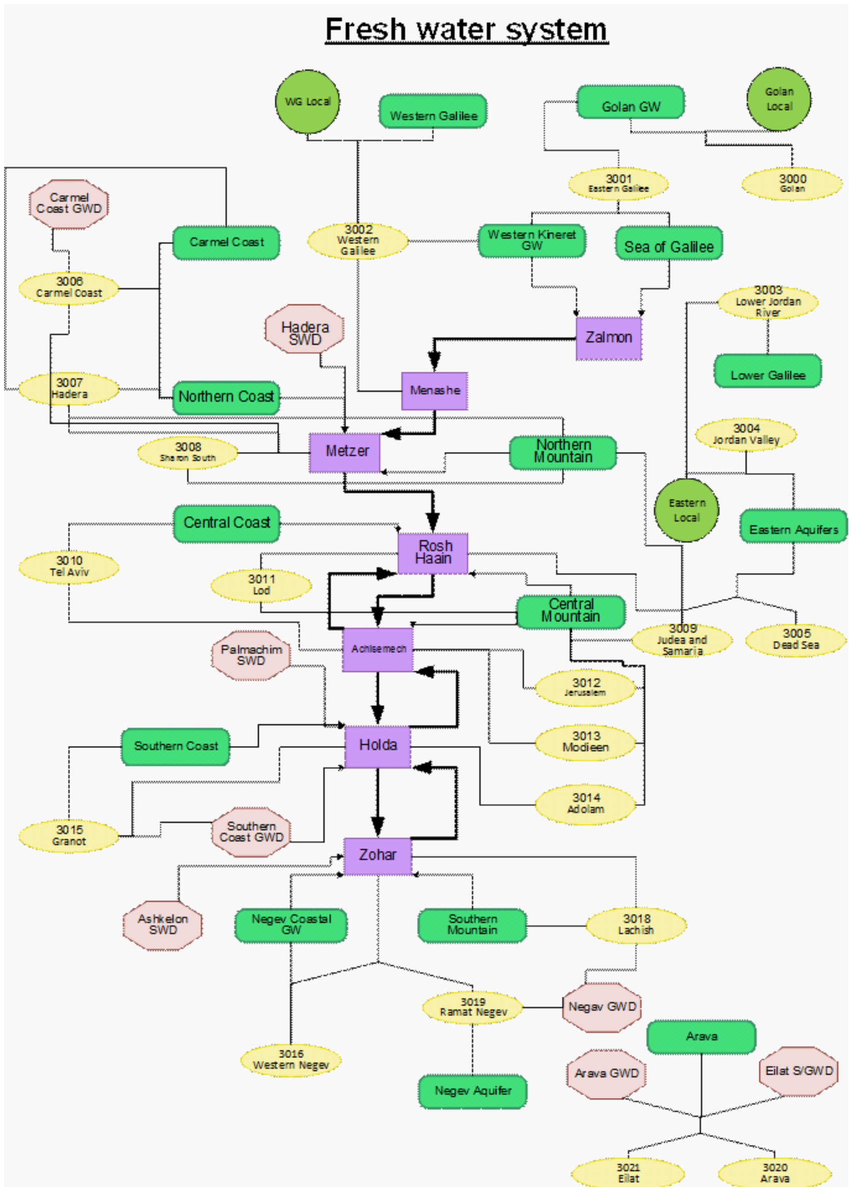
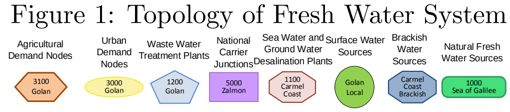


Figure 1: Topology of Fresh Water System



2.2 Supply and Cost

The supplied quantities from each water source are endogenously determined by the model to maximize the economic surplus, given the hydrological and

Table 1: Natural Potable Water Sources

Name	Storage Capacity (MCM/Y)	Extraction in 2010 (MCM/Y)	Optimal Extraction (MCM/Y)	Annual Recharge (MCM/Y)	Extraction Capacity (MCM/Y)	Average Cost of Extraction ($/CM)	Shadow Price ($/CM)
Sea of Galilee	692	165	247	247	500	0.096	0.29
Golan	107	10	17	59	17	0.18	0.18
Western Sea of Galilee	128	56	49	49	82	0.0775	0.39
Western Galilee	215	90	105	105	116	0.048	0.43
Lower Galilee	41	13	23	23	24	0.06	0.39
Eastern Aquifers	495	41	90	283	90	0.0654	0.36
Northern Mountain	442	85	87	87	135	0.0334	0.39
Carmel Coast	51	18	22	32	22	0.0254	0.40
Northern Coastal	585	85	76	76	127	0.025	0.40
Central Coastal	251	29	27	27	45	0.027	0.42
Central Mountain	654	146	161	161	214	0.12	0.32
Southern Coastal	614	193	66	66	252	0.0275	0.40
Negev Coastal	250	22	17	17	60	0.032	0.45
Southern Mountain	98	38	20	20	43	0.15	0.45
Ramat HaNegev	83	2	3	12	3	0.04	0.46
Arava	67	13	17	17	23	0.0385	0.36
Total/Average	**4773**	**1006**	**1051**	**1280**	**1753**	**0.07**	**0.36**

engineering constraints, which are reported in Tables 1-3. For each natural potable water source, Table 1 provides details on the hydrological storage capacity, the annual extraction in 2010, average annual recharge, and maximal annual pumping capacity.

Similarly, the first column in Table 2 exhibits, for the various desalination plants, the annual desalination capacity.

Finally, Table 3 shows the annual treating capacity. The raw, untreated water for each treatment facility is supplied by the linked regions of urban demand. As per Israeli data (Water Authority 2015), we assume that 66% of the consumed water in each urban region is recycled and supplied to all linked treatment facilities.

The model presumes linear cost structure, i.e., the pumping, desalination, and treatment costs are constant per cubic meter, yet vary across sources. Tables 1-3 report the marginal cost of extraction from the various sources. Similarly,

Table 2: Desalination Plants

Plant	Capacity (MCM)	Observed 2010 (MCM)	Optimal 2010 (MCM)	Shadow Value ($/CM)	Cost ($/CM)
Hadera	142	127	44	0	0.4
Palmachim	47	47	47	0.01	0.4
Ashkelon	120	120	100	0	0.4
Eilat	26	26	2	0	0.4
Total/Average	**335**	**320**	**193**	**0.01**	**0.4**

Table 3: Wastewater Treatment Facilities

Facility Name	**Capacity (MCM)**	**Observed 2010 (MCM)**	**Optimal 2010 (MCM)**	**Shadow Value ($/CM)**	**Cost ($/CM)**
Golan	3	3	3	0.30	0.26
Tzfat	11	10	11	0.31	0.27
Kineret	8	8	8	0.38	0.27
Western Galilee	29	26	29	0.31	0.29
Beit Shean	3	3	3	0.37	0.31
Kishon	60	57	60	0.25	0.29
Jordan Valley	9	8	9	0.34	0.24
Judea & Samaria	5	5	5	0.34	0.27
Yarkon	12	12	12	0.33	0.32
Nesher	19	18	19	0.30	0.31
Shfela	42	41	42	0.30	0.32
North Coast	22	19	22	0.32	0.30
Central Coast	46	45	46	0.33	0.29
Shafdan	128	126	128	0.25	0.32
South Coast	6	6	6	0.32	0.29
Negev Coast	31	24	31	0.38	0.31
Negev	31	29	31	0.38	0.30
Dead Sea	1	1	1	0.31	0.30
Arava	8	8	8	0.31	0.31
Total/Average	**471**	**450**	**471**	**0.30**	**0.30**

while the cost of conveying a cubic meter of water is constant and does not vary with the quantity, it differs from one segment of the supply system to another. This data are shown in Table A1-A8. Note that despite the linearity assumption, the model yields an increasing marginal cost curve. The reason therefor is that as the water supply increases, the model activates increasingly costly sources.

2.3 Demand Calibration

The model presumes constant elasticity Urban demand functions, i.e., $d^i = R^i p^{-\eta}$, where d^i marks the quantity of water consumed in the urban demand region i, R^i is a calibration constant, p is the price of residential water, and η is the demand elasticity. Following the recent estimates of urban demand functions in Israel by Bar-shira, Kislev, and Cohen (2007), we let the demand elasticity equal -0.1. Using 2010 data on urban water consumption and residential water prices, we calibrated a constant elasticity urban demand function for each of the urban-demand zones specified in the topology. The industrial demand functions were calibrated in a similar manner, assuming that the industrial demand elasticity equals -0.33. This number was adopted from Fisher et. al. (2005).

For each agricultural-demand zone, we calibrate a demand function that incorporates the various water qualities supplied to the region. The function represents the value of marginal product of freshwater, where non-fresh water (treated wastewater and brackish water) quantities are multi- plied by conversion factors, applied to convert to units of "freshwater equivalents". The conversion factors are identical to those, which are administrated by the Water Authority and the Agriculture and Rural Development Ministry to convert freshwater quotas to quotas of non-freshwater sources. To this end, let the agricultural production in region i y^i, be given by the function:

$$y^i = A^i(d^f + \alpha d^r + \beta d^b)^\delta$$

where A^i and δ are calibration/estimation constants, d^f, d^r, and d^b stand for fresh, reclaimed, and brackish water respectively, and α and β are fresh water equivalent conversion factors. The quantity $d^f + \alpha d^r + \beta d^b$ is referred to as "effective water". The value marginal product of fresh water is then $B^i(w^f + \alpha w^r + \beta w^b)^{\alpha-1}$, where $B^i = \delta P^i A^i$, and P^i is a price index of the agricultural output in region i. Based on Bar-shira, Finkelshtain and Simhon (2006) the parameter $\alpha = -0.5$ and given the administrative conversion ratios $\alpha = 0.83$, $\beta = 0.5$, The parameter B^i is calibrated based on the equality of the VMP to the price of fresh water, $B^i(w^f + \alpha w^r + \beta w^b)^{\delta-1} = p^f$. Note that the last equation implies a constant elasticity demand function for effective water.

3 Efficient Allocation

Under the optimal scenario and a (single year) static analysis, MYWAS characterizes the optimal spatial water allocation, which maximizes the aggregate annual economic surplus in the water economy. That is, the model maximizes the sum of consumers' and producers' surplus in the agricultural, urban, and industrial sectors; minus the variable costs of pumping, recycling, desalination, and conveyance. The infrastructure, hydrological and engineering constraints, cost structure, and the demand functions are taken as given.

In addition to the search for the optimal allocation, the "optimal mode" is useful for simulating the effects of changes in the exogenous factors – such as the hydrological conditions, cost and technology parameters, and demand factors – on the optimal allocation. However, the feature of the model that is most important for the analysis in this paper is its capacity to report the scarcity rents for each water source, the shadow prices for all the engineering constraints, and the shadow prices for water of each type and at any location. This feature provides the foundations for an efficient pricing system: a system of pumping levies and user charges that creates the correct incentives for the various stakeholders in the water economy, and thus supports the optimal allocation. The shadow prices are also useful for identifying bottlenecks in the pumping and delivery system and elements of the infrastructure system that could be profitably expanded. Finally, the shadow prices allow valuing the scarce water resource, which may foster trade and resolution of water disputes.

3.1 Theory

Consider a small, open economy with natural sources of fresh and brackish water, urban demand regions with freshwater demand for residential and industrial use, agricultural regions that demand irrigation water of various qualities, and an infrastructure system incorporating desalination plants, wastewater treatment facilities, pumping stations and pipelines. In this section, we introduce a formal description of a single-year version of MYWAS. For a multi-year, discrete-time dynamic optimization, model see Reznik et al. (2015b).

We use the following notations: Let A, U denote the sets of agricultural and urban demand regions; and let F, S, D, T denote the sets of natural freshwater sources, natural saline water, desalination facilities, and wastewater treatment plants, respectively. The union of all water sources is marked by $W = F \cup S \cup D \cup T$. Fresh water from various sources may be mixed in junctions of the national carrier that delivers water from the north to the south. The set of junctions is denoted by J.

The demanded quantity in each of the n demand regions is marked d^i, $i \in U, A$, and the reclaimed waste water supplied by this region to a treatment facility $j \in T$ is d^i_j. The quantities supplied from a water source or a junction $i \in W \cup J$ to a demand region or a junction j are denoted by s^i_j, $i \in W, J$ $j \in U, A, J$. Consumer surplus is marked $CS^i(d^i)$. Note, that water consumers may be residents of an urban zone, with neighboring industrialists and farmers in an agricultural region. For each water source $i \in W$, we incorporate an engineering constraint k^i describing the maximal extraction capacity from this source, from a technical perspective. In the case of natural sources, it represents the pumping capacity. For desalination plants it is the annual desalination capacity and for treatment facilities it stands for the annual treatment potential. Similarly, k^i_j stands for the maximal conveyance capacity from a water source or a junction i to a demand region or a junction j. For natural fresh and saline sources an additional constraint, $v^i \; i \in F \cup S$, is included to represent the annual recharge to the aquifer. Similarly, the annual treatment of water in a given treatment facility is limited by the supply of urban waste water to the treatment facility $v^i \; i \in T$.

The cost of delivering a cubic meter of water from source or a junction i to a demand region or a junction j is denoted as $t^i_j, \; i \in W \cup J, \; j \in U, A, J$. In the case of urban demand regions this includes the cost of collecting and treating the wastewater. The cost of extracting a cubic meter of water from source $i \in W$ is denoted c^i. For aquifers it is the cost of pumping the water. For desalination plants, it is the cost of desalination. In the case of waste water, c^i represents the cost of pumping the treated water for the purpose of conveyance to an agricultural demand zone. As written above, the cost of the treatment itself is charged to the urban consumers who produce the wastewater.

In addition, we need to introduce notations for several technological parameters. For agricultural demand zones, we assume that the effective consumed quantity is a weighted sum of the water of varying qualities.Thus, non-potable water (treated wastewater and brackish water) are multiplied by conversion factors for transforming a unit of non-fresh water to a "fresh water equivalent." The conversion factors for brackish and treated wastewater are denoted byα and β respectively. Finally, the rate of reclamation of waste water in urban zones is marked μ.

The model MYWAS solves for the following optimal plan for water allocation:

$$\max_{d^i, s^i_j} \left[\sum_{i \in A \cup U} CS^i(d^i) - \sum_{i \in W \cup J} \sum_{j \in A \cup U \cup J} (c^i + t^i_j) s^i_j \right] \quad (1)$$

$$\begin{aligned}
S.T. \qquad (1)\ \forall j &\in A,\ d^j \leq \sum_{i \in FUDUJ} s^i_j + \alpha \sum_{i \in S} s^i_j + \beta \sum_{i \in T} s^i_j, \\
(2)\ \forall j &\in U,\ d^j \leq \sum_{j \in FUDUJ} s^i_j, \\
(3)\ \forall i &\in W, \quad \sum_{j \in A \cup U} s^i_j \leq \min(k^i, v^i), \\
(4)\ \forall i &\in W \cup J,\ \forall j \in U \cup A \cup J, \quad s^i_j \leq k^i_j \\
(5)\ \forall j &\in T,\ v^i = \sum_{i \in U} d^i_j, \\
(6)\ \forall i &\in U,\ \sum_{j \in T} d^i_j = \mu d^i.
\end{aligned}$$

Thus, the model maximizes the aggregate economic surplus, net of the extraction and conveyance costs and subject to the following constraints. Constraints (1) & (2) ensure that the quantity of water consumed in each demand region do not exceed the quantities delivered to this region from all sources. Constraint (3) guarantees that the annual quantity of water extracted from a given source does not exceed the minimum of two quantities; 1) the quantity of water available for extraction, 2) the pumping quantity which is limited by the technical pumping capacity. The set of constraints (4) ensures that the quantity of water, which is supplied from source or junction i to demand region or junction j, does not exceed the capacity of the pipe that links the two. Finally, constraints (5) and (6) provide that annual quantity of water treated in a specific facility j, $j \in T$ is bounded by the total supply of wastewater from linked urban demand regions; and the supply of wastewater from a specific urban region to all linked treatment facilities is limited by the product of the wastewater reclamation rate μ, and the quantity demanded in this specific urban zone.

3.2 Optimal Extraction

The second and third columns of Table 1 present the optimal extraction quantities and compares them to the observed 2010 levels. On Aggregate, the optimal extraction of fresh water is only 4.5% larger than the total observed supply from those sources. However, for some specific sources, the deviation between the optimal and observed quantities is significant. Notable cases are the Sea of Galilee, where the model suggests that the optimal pumping should have been 50% larger than the observed level, and the southern coastal aquifer, where the model's optimal pumping is only 35% of the observed extraction. The explanation for the gap in the case of the Sea of Galilee might be that in 2010, the water table of the lake was very low due to consecutive severe droughts. Considering the risk that further deficit pumping would have driven the water levels below the "red lines", causing irreversible damage to the Sea of Galilee, the decision makers at the Israeli Water Authority (IWA) decided to reduce the extraction and raise the reliance on desalination and pumping from the coastal aquifer. However, the water table was also very low in the coastal aquifer, but the IWA officials decided to extract from this aquifer twice the quantity of the annual recharge. The explanation for this discrepancy may be related to the fact that the water table in the Sea of Galilee is visible to the public and often raises a public debate, while the water level in the coastal aquifer is unobservable.

For each desalination plant, Table 2 describes the actual supply in 2010, optimal quantity for 2010, shadow price of the capacity constraint, and the variable cost of desalination, each per cubic meter. As can be seen from the table, the optimal quantities are equal to or less than the desalinated quantities in 2010. The optimal aggregated desalination is 60% of the observed quantity, and only 57% of the annual desalination capacity. Since the capacity constraints are not binding, the dual picture is that the shadow values equal zero or very close to it. These results suggest that from an economic perspective, the construction of desalination facilities in Israel, which began in 2005, should have been delayed.

The situation is reversed in the context of effluent treatment plants. The optimal quantities of wastewater treatment (Table 3) are greater than or equal to the observed quantities, and the optimal aggregate quantity is 5% larger than the observed quantity. More importantly, in all cases, the model treats water up to the capacity constraint. This implies that further investment in the expansion of wastewater facilities is profitable from a social welfare standpoint.

3.3 Consumption

Table 4 reports the efficient water allocation to each of the 18 agricultural demand regions. The first column presents the actual 2010 allocation, which was induced by a system of administrative prices and quotas, combining quantity and price controls. The second column shows the optimal spatial allocation for 2010, and the third column shows the allocation of water, which would be supported by the 2010 prices, with no effective quotas for fresh water. The aggregate optimal allocation differs only by 7% from the actual allotment, and the maximal deviation of the region-specific water consumption from its counterpart optimal use equals 12%. Two main conclusions emerge from those results: Firstly, despite political pressure (e.g., Finkelshtain and Kislev 1997, Finkelshtain, Kan and Kislev 2015) and partial information, the administrative pricing and quota system yields water allotment to agriculture that is close to the level that maximizes welfare. Secondly, from the results in column 4 and Table 6, regarding the price regime (with no fresh water quotas) it follows that a price-only regime for fresh water could have lead to an allocation that is superior to the mixed control regime. Thus, one could conclude that the quota system is redundant and the pricing system is welfare dominant. This result is in agreement with that of Finkelshtain, Kan and Kislev (2015).

Table 4: Allocation to Agriculture

	Quantity, Million Cubic Meters			$ per Cubic Meter
Region	Observed	Optimal	2010 Prices	Shadow Value
Golan	30	30	26	.46
Kineret	49	44	48	.55
Acco	41	37	42	.56
Haifa	12	11	11	.51
Hadera	48	46	49	.51
Jerusalem	30	28	27	.52
Sharon	57	53	55	.51
Rehovot	32	30	32	.52
Ashkelon	83	80	85	.49
Ramat Negev	159	140	155	.58
Arava	37	36	37	.48
Tzfat	80	79	82	.47
Jeezrael Valley	154	141	141	.54
JS Settlements	10	10	8	.50
Tel Aviv	3	3	3	.51
Petah Tikva	31	30	31	.51
Ramle	16	15	16	.53
Jordan Valley	33	31	32	.50
Total/Average	**907**	**843**	**881**	**.51**

The situations in the two sub-sectors of the urban regions – residential and industrial – differ markedly. Table 5 reports the water allocation to urban residential consumers in each of the 21 demand regions. The optimal allocation to the residential sector is larger than the actual allocation in all 21 regions. The aggregate optimal allotment to the residential sector is larger by 71 millions m3 (almost 10%), than the actual consumption level in 2010, entailing annual welfare loss of close to $100 millions. In the industrial sector, for which we do not report the detailed results, the 2010 consumption is merely identical to the optimal allocation, with the difference less than 1%.

4 Efficient Pricing and Decentralization

As per the first clause in the Israeli Water Act of 1959, all water sources are publicly owned and to be managed by the state for the needs of the people. By law, regions where the demand exceeds the supply are declared scarcity regions, and the state regulates water use in those regions by means of pumping licenses and quotas. Over the years, centralized water allocation has been undergoing a gradual reform, where quantitative regulations such as quotas and licenses, are replaced by administrative prices and levies. An important question that has become relevant is how to administrate efficient prices that support optimal allocation. This is the subject of the current section, where based on the model results, we describe a system of efficient prices that facilitates partial decentralization, in the sense that given these prices, the optimal allocation is preserved, while households, industrialists, and farmers are free to choose how much water to consume. Moreover, the water supplier, which is obligated to provide the demanded quantities, can apply the extraction and conveyance plan of its choice.[1]

4.1 Demand

We begin with the agricultural sector, Israel's main water consumer. At the optimal allocation, the value of marginal product of the water in each agriculture demand region equals the marginal cost of supplying the water to this region. The marginal cost includes the scarcity rents and shadow prices of any binding constraint. Those values are reported by the model for every demand region and sector, and are referred to as the regional shadow prices of the water. The equality of the marginal cost to the value of marginal product implies that determining the prices for irrigation water at the levels of the shadow values could implement the optimal water allocation in the agricultural sector.

The shadow prices for irrigation water in the various agricultural regions are reported in the last column of Table 4. The average shadow price equals 51¢, which is close to the marginal cost of desalinating and conveying the water, estimated at 50¢. The proximity between the two is additional evidence of the

[1] For simplicity, in this analysis we describ e a single water supplier. In Israel, 60% of the water is supplied by Mekorót, a state-owned firm, and the rest by private suppliers.

Table 5: Allocation to Urban Regions

Region	Quantity, Million Cubic Meters Observed	Optimal	$ per Cubic Meter Shadow Value
Sharon South	87	95	1.26
Golan	5	5	1.94
Eastern Galilee	78	88	1.05
Western Galilee	126	137	1.40
Carmel Coast	8	8	1.15
Hadera	25	28	1.15
Granót	70	78	1.16
Jordan Valley	7	8	0.72
Jerusalem	63	68	1.54
Lachìsh	46	50	1.30
Western Negev	28	31	1.20
Ramát haNegev	4	4	1.50
Arava	3	4	0.97
Gilboa-Haród	7	7	1.64
Judea and Samaria	15	16	1.48
Tel-Aviv	114	122	1.59
Lod Valley	37	41	1.25
Modieen	15	16	1.38
Adolam	1	1	1.39
Dead Sea	6	7	1.29
Eilat	8	8	1.59
Total/Average	**752**	**823**	**1.33**

closeness of the actual agricultural water supply to the optimal allocation of water to this sector. Moreover, in 2010, farmers were billed according to a tier pricing system. The rate for the highest tier was 55¢, which is close to the efficient price, and provides an additional explanation for the near-optimal allocation to agriculture in 2010. Note that the interregional differences in the efficient prices are relatively small, the largest deviation from the average being 7¢ (last column of Table 4). Taking into account that the price elasticity equals -0.5, this implies that a uniform price at the level of the average of the shadow prices, rather than differential prices that equal the regional specific shadow prices, would have led to a rather small deviation of the quantities from the optimal supply. By triangle calculations, we find that the associated welfare loss is very moderate, about $15 million per year.

A similar principle of decentralization applies in the case of residential demand. The shadow values of the water in the various urban demand regions equal the inverse demand function, evaluated at the optimal consumption level. Therefore, billing households for water as per those shadow values, which are reported in Table 5, would lead to optimal consumption in the residential sector. The shadow prices average $1.3. As can be seen in the table, the shadow prices vary considerably across locales, with the coefficient of variation equal to 0.2. This means that the uniformity of water prices for households, introduced in 2010, is inefficient. Moreover, the marginal (highest tier) water price for residential consumers in 2010 was $3.2, that is, the actual price is more than twice the average optimal shadow price, which introduces further welfare loss. However, due to the low demand elasticity, the difference between the optimal quantity and the observed one is relatively small.

Note that the shadow price for the urban sector is 1.6 times the shadow price for agriculture. The reasons for this difference are that the farm sector uses water of poorer quality, and that post consumption, the water supplied to households requires collection and treatment of the wastewater. Similarly, water to industry is a production input, and post production must be treated, a costly process. This explains the rather high shadow price that (evaluated at the optimal allocation) averages $1.33 per cubic meter. The price for industrial use in 2010 was $1.3 per cubic meter, which is close to the optimal shadow price, so that we can conclude that as far as it concerns the industrial sector, the actual 2010 prices support the optimal allocation.

4.2 Supply

While administering the prices for water at the level of the above shadow values ensures optimal consumption levels, can extraction and supply be decentralized? The answer is affirmative. Suppose that the concession for water supply is given to a regulated monopoly. As per regulations, the monopoly is obligated to supply the quantities demanded, and prices are capped at the above shadow prices. Suppose further that the monopoly is free to choose from where and how much water to extract, yet is subject to an aquifer levy that equals the shadow prices of water at source. Finally, the monopoly is given the right to use the existing infrastructure, yet bears the variable cost of supply. Since the monopoly's revenue is predetermined, striving to maximize its profits, it will minimize the supply cost. The resulting plan of extraction and supply that minimizes the cost will be identical to the one that solves Problem (1).

The shadow prices for the various possible sources of fresh water, for the case of the optimal allocation, are reported in Table 1. Recall that the water extraction from a specific aquifer may be limited by the annual recharge to the aquifer, or by the engineering constraint that restricts pumping capacity. In the first case, the number reported in Table 1 is the scarcity rent. In the second case, it is the shadow price associated with the engineering constraint. The shadow prices range from 18¢/CM in the Golan Heights to 46¢/CM on the Negev. Of special interest are the shadow prices in the central coastal region, which average 41¢/CM, just over the marginal cost of desalination, yet considerably lower than the full cost (including capital cost) of desalination, which costs 60-80¢/CM. This fact strengthens the assertion that the development of desalination facilities in Israel happened too early and the scope of construction was too large. However, taking into account that the capital already invested therein is sunk cost, the operation of the existing desalination plants at a marginal cost of less than 41¢/CM is profitable.

5 Economy-Wide Cost Function and Balanced Budget

This section is devoted to the evaluation of the economy-wide cost function and assessment of scale economies in the Israeli water economy. We then discuss the implications for social welfare of the recent "balanced budget" amendment to the Israeli Water Act, in the presence of scale economies. We begin with a concept of an economy-wide cost function.

5.1 Definition

One can view the water economy as a multiproduct firm: It supplies water of various qualities to diverse locales, in our notations the vector $d^1, \cdots, d^n,\ i \in U, A$. Therefore, to define an economy-wide cost function, we borrow the concept of ray average cost, from the literature on multiproduct firms (e.g., Baumol 1977) and vary the quantities $d^1, \cdots, d^n,\ i \in U, A$ along a ray. That is, starting from the optimal allocation of water, $\bar{d}^1 \cdots, \bar{d}^n,\ i \in U, A$, we change all demanded quantities proportionally and calculate the variation in the minimal cost of supplying those quantities. The quantities of water of the various qualities are transposed to "freshwater equivalents" by using the conversion factors from above, and are summed over all demand regions. We denote this sum by $Q = \sum_{i \in FUD} \gamma\ \bar{d}^i$ ',Q is the total quantity of "effective water" consumed in the economy, and $\gamma > 0$ is the proportion factor. The literature on multiproduct firms proceeds by defining the cost function as C (γ), thus, viewing the cost as a function of γ. But using the above aggregation and noting that $Q = \sum\limits_{i \in FUD} \gamma \ \bar{d}^i \Longleftrightarrow \gamma = \frac{Q}{\sum\limits_{i \in FUD} \bar{d}^i}$ we can equialvlently view

the cost as a function of Q, which seems more natural. That is, the economy wide cost function, $C(Q)$ is defined by:

$$C(Q) = \min_{s_j^i} \left[\sum_{i \in W \cup J} \sum_{j \in A \cup U \cup J} (c^i + t_j^i) s_j^i \right] \tag{2}$$

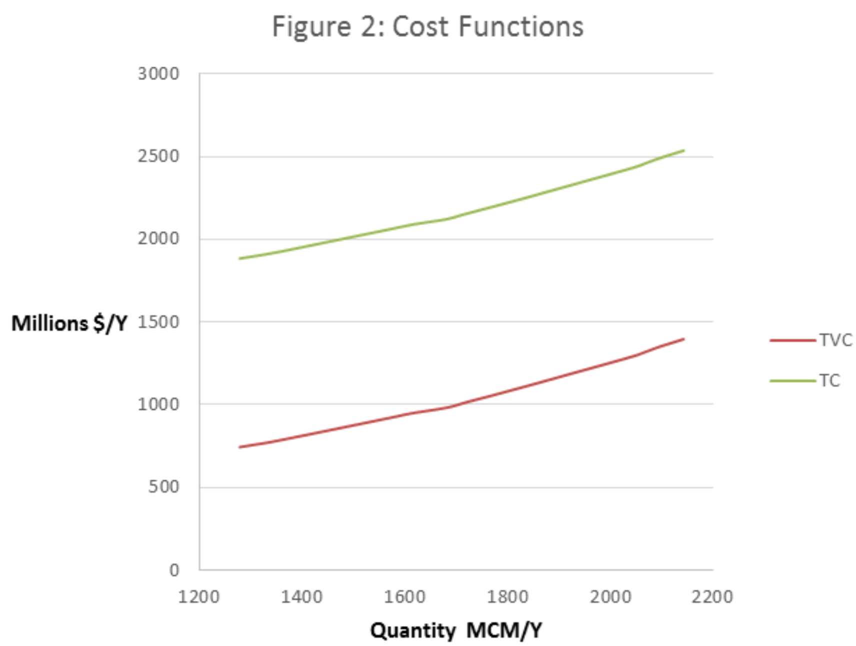
$$\begin{aligned}
S.T. \qquad (1)\ \forall j &\in A,\ \gamma \bar{d}^j \leq \sum_{i \in FUDUJ} s_j^i + \alpha \sum_{i \in S} s_j^i + \beta \sum_{i \in T} s_j^i, \\
(2)\ \forall j &\in U,\ \gamma \bar{d}^j \leq \sum_{j \in FUDUJ} s_j^i, \\
(3)\ \forall i &\in W, \quad \sum_{j \in A \cup U} s_j^i \ \leq \min(k^i, v^i), \\
(4)\ \forall i &\in W \cup J,\ \forall j \in U \cup A \cup J, \quad s_j^i \leq k_j^i \\
(5)\ \forall j &\in T,\ v^i = \sum_{i \in U} \gamma \bar{d}_j^i, \\
(6)\ \forall i &\in U,\ \sum_{j \in T} \bar{d}_j^i = \mu d^i, \\
(7) \forall i &\in U, A,\ Q = \sum_{i \in FUD} \gamma \ \bar{d}^i \Longleftrightarrow \gamma = \frac{Q}{\sum\limits_{i \in FUD} \bar{d}^i}.
\end{aligned} \tag{3}$$

The function $C(Q)$ describes the minimal cost of supplying an aggregate quantity, Q, where the ratio of supply to various locales is preserved at the level of the optimal allocation. Constraint (7), which is added to the 6 constraints of Problem (1), guarantees that the proportion by which the regional quantities are increased is sufficiently large to ensure aggregate water supply at a level Q. Note, that although Program (2) is linear, the cost function defined by (2) is convex in Q and the marginal cost is increasing, the reason being that increase in Q requires putting into use increasingly costly water sources.

5.2 Empirical Evaluation of the Cost Function

We use MYWAS to search for minimum cost allocations as defined by Equation (2) and calculate the associated cost. The proportion factor, γ varies in the range $[0.675, 1.1]$ by step size of 0.025. The aggregate supply of "effective water" is confined to $[1198, 1998]$ million cubic meters. Total cost of supply varies in the range of $\$[1,884, 2,536]$ millions. The cost calculated by the model for the 2010 supply level is \$2,304 million, which is close to the estimate of the CBS for the year 2006, updated to 2010 prices: \$2,200 million[2].

[2] The CBS estimate is based on 2006 supply, the most recent estimate available.



To calculate the marginal and average costs, we fit a cubic line to the total cost data. The fitted cost function is presented in Figure 2,

the derived marginal and avergae cost curves are shown in Figure 3.

The results suggest that the cubic term is significant, but small 1×10^{-4} ¢/CM. The marginal cost, MC, is increasing in the range of $[59, 217]$¢/CM, and the average cost, AC, is U-shaped in the range of $[261, 147]$¢/CM. The efficient scale of production is about 3,250 million CM/Y, or 71% larger than Israel's actual water supply. While these are aggregate values that do not directly correspond to the marginal or average cost in any particular demand region, the calculations suggest that for the relevant production scale, the average cost is decreasing and larger (of course) than the marginal cost, an indication that the Israeli water economy operates in an output region, which is characterized by scale economies. Increasing supply with the existing infrastructure, could decrease the cost per cubic meter.

A quantitative index of scale economies, calculated at the optimal allocation quantities, yields: $\frac{AC(Q)}{MC(Q)} = \frac{1.25}{0.91} = 1.4$ suggests that at optimal allocation, scale economies are considerably large.

Indeed, we use the model to calculate the cost of supply at optimal allocation and the revenue that would have resulted from the consumers' prices and aquifer levies that support optimal allocation, and find a deficit at the magnitude of $754 million, or about a third of the total cost. This implies that the two main arguments, used by international organizations to promote market-based

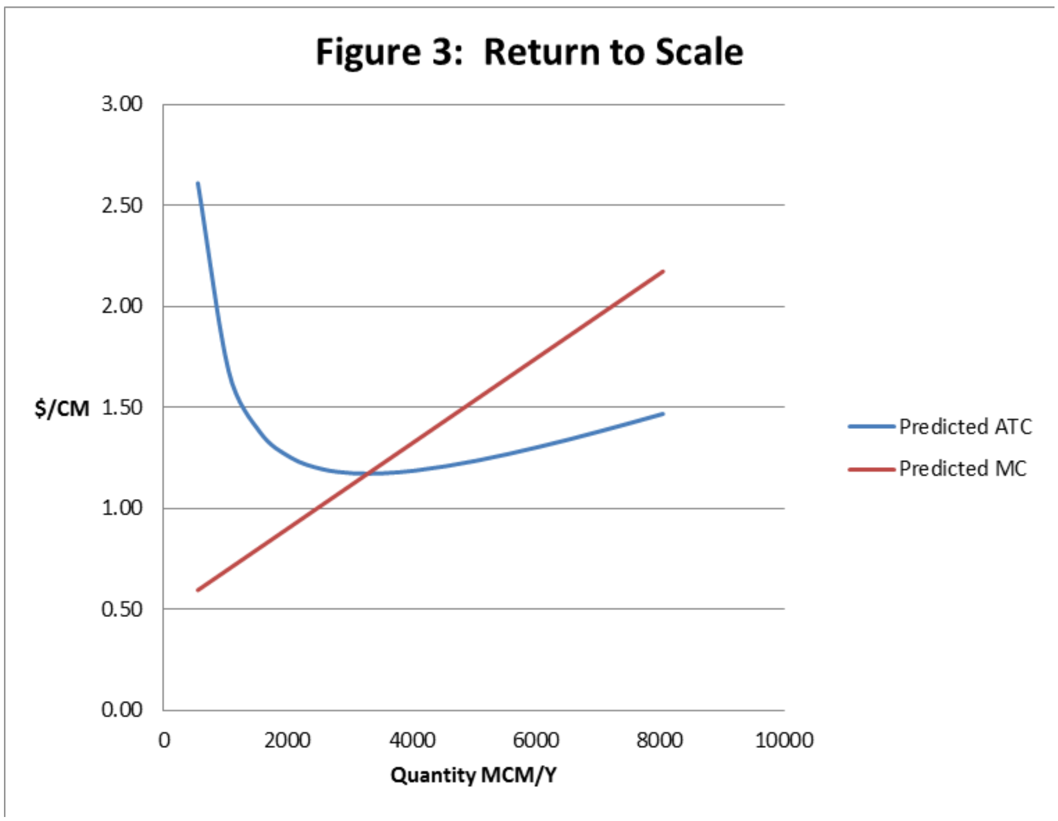


Figure 3: Return to Scale
3.00
2.50
2.00
$/CM 1.50
1.00
0.50
0.00
0
2000
4000
6000
8000
10000
Quantity MCM/Y
Predicted ATC
Predicted MC

policies, efficiency, and cost recovery, are at odds. While efficiency requires marginal cost pricing, in the case of scale economies, those prices do not cover the cost. On the other hand, average cost pricing, which has been in force in the Israeli water economy from 2010 on, recovers cost, but leads to inefficiency and sub-allocation of water. The next subsection presents the welfare implications.

5.3 The Balanced Budget Amendment

As per this amendment, starting January 2010, water tariffs in all sectors of the economy should fully cover the cost of supply. Following this reform, the average tariff for households was immediately raised by as much as 35-40%. In the agriculture sector, the prices are gradually increasing as per an agreement between the farmers' organization and the government, according to which the price should eventually reflect average cost. During 2009-2011, agricultural prices were increased at a cumulative rate of 25%. Currently, relying on the cost recovery principle, the IWA is proposing a sharp increase of almost 40% in the price of irrigation water.

The implications for social welfare can be deduced by assessing the welfare loss that resulted from alternative price regimes, designed by the IWA to recover costs. In Table 6, we compare the aggregate allocations and welfare levels of three scenarios. 1) In the first, we simulate the allocation under the price structure that existed in 2010. In agriculture, the block-rate regime included three tiers that average to $0.48 /CM. The prices for regular and SHaFDaN[3]-treated water were $0.2 and $0.24 /CM respectively. The uniform price for industry was $0.8 /CM, and two price tiers for urban consumers averages to $2.4 /CM. 2) The second simulation refers to 2014-5 prices: In agriculture, a $0.65 /CM uniform price was in force for fresh water. The prices for regular and SHaFDaN treated wastewater were $0.27 /CM and $0.28 /CM respectively. The prices for brackish water, industrial, and residential use did not change from the 2010 levels. 3) The third and final simulation addresses the IWA proposed prices for the coming year, 2015-6. For fresh water consumption in agriculture, a flat rate of $0.83 /CM. For regular treated waste and brackish water, the prices do not change. The price of SHaFDaN water is slightly raised to $0.29 /CM. Finally, the prices for residential use show a slight change: The basic tier is $2.1 /CM, and the regular one is $ 3.4 /CM. The simulated 2010 allocation and the actual 2010 allocation were compared to the optimal 2010 allocation. The simulated allocations under the 2014/5 and proposed 2015/6 prices were compared to the optimal 2015 allocation.

The main conclusion that emerges from the table is that the cost of covering costs is more than $100 million annually, or more than 10% of the water economy's share of the GDP (Kislev 2011). There are two main reasons for this welfare loss: Firstly, the tariffs that were designed to raise revenue are higher than the marginal cost, including the scarcity rents. This implies that the consumed quantities in the agricultural and residential sectors are lower than the

[3] SHaFDaN [Hebrew acronym for shfachèi dán, or "Dan wastewater", "Dan" being another name for Greater Tel Aviv] treatment facility, where the water is treated at a tertiary level.

Table 6: Balanced Budget and Welfare Levels

Scenario	Urban MCM	Ind. MCM	Ag Fresh MCM	Ag Rec. MCM	Ag Brk. MCM	Ag Total EW MCM	Total MCM	SW Desal. MCM	GW Desal. MCM	Welfare loss $\$10^6$/yr
Observed 2010	752	129	493	390	179	907	1943	320	45	112
2010 prices	752	129	501	390	113	881	1885	262	35	99
2014 prices	756	129	341	407	146	752	1780	110	11	134
IWA proposed prices	764	129	264	407	146	675	1710	80	11	138

optimal quantities. Water that could be extracted at lower cost than the benefits to consumers is left in the aquifers and in the Mediterranean. This absurdity was especially visible last year, where the IWA shut down more than 100 MCM capacity of the desalination plants, since at the current prices, the quantities demanded were lower than the potential production. Of course, the sunk cost investment in those plants was levied on the water consumers' shoulders. The second reason for the welfrare loss is related to the scale economies that characterize the water sector: Raising prices leads to reduced quantities, and since the average cost function is decreasing, this increases the cost of production per cubic meter. Both factors contribute to welfare loss.

A possible solution to the conflict between efficiency and a balanced budget is implementation of a more sophisticated pricing system. An immediate example is a two-part tariff, where the per-CM price equals the marginal cost, with the constant set to cover the cost. For urban users, the constant may be a function of household size, while in agriculture it may be a function of the farm's size or its historical water quota. In both cases, the constant payment can be thought of as a club membership fee, which each user pays to become eligible for water. The second part of the tariff is a function of the demanded quantity.

6 Trade and Conflict Resolution

Water is a matter of historical dispute between Israel and its neighbors. In this section, we apply the model's results to a discussion of two related issues: 1) the Israeli-Palestinian conflict regarding the mountain aquifer and 2) a possible water trade between Israel and Jordan. The analysis in this section, which uses the model's estimates of scarcity rents for monetization of the water in the aquifers, is very close to Fisher and Huber-Lee (2011), we use an updated data and topology.

6.1 The Israeli-Palestinian Water Dispute

A quantitative review of the dispute's history, starting from the 1967 war onward, is presented in Kislev (2006, 2008), who distinguishes between two main periods: The first, 1967-1995, was characterized by considerable investment on the part of the Israeli government to develop and expand the Palestinian supply system. In the second period, 1995 onward, the development and the allocation of water resources is governed mainly by the so called interim agreement. Table 7 presents the mountain aquifer water distribution between Israel and the Palestinians as per this agreement, the provisions of which state that the Palestinians consume 118 million cubic meters, or 18% of the aquifer's water. In Table 4, the shadow price of the aquifer's water is 37¢ per cubic meter. This caps the annual value of the aquifer's water to about $222 million, and the Palestinians' share at about $40 million. This would also be the cost for Israel to double the supply of water from the aquifer to the Palestinian Authority, and make up for the water loss with increasing desalination. Note that this was about the cost of a single day of warfare in the recent Protective Edge operation, not including, of course, the loss of life and suffering.

Table 7: Mountain Aquifer Water Distribution

Aquifer	Palestinians	Israel	Total
Eastern	54	40	94
Western	22	340	362
Northern	42	103	145
Total	118	483	601

Interestingly, Fisher and Huber-Lee (2011) used the 1993 WAS model to predict the shadow prices of water in Palestinian locales in the proximity of the mountain aquifer. The predicted values for the year 2010 are 2-3 times the scarcity rent for Israel from the very same water. Thus, there is no doubt that there is a wide room for mutual economic gain from water trade between Israel and the Palestinian Authority. A possible transaction would include diversion of a larger share of the water from the mountain aquifer to the Palestinians in exchange for a fee that covers the desalination of the diverted water, payment for which could have been financed at least partially by international aid.

6.2 Israeli-Jordanian Water Trade

The Israeli-Jordanian peace treaty of 1994 sets the allocation of 50 million cubic meters of water by Israel to Jordan, and calls for future cooperation in the development of additional water sources. In recent years, a concrete water trade plan is under discussion by officials in both countries, calling for Israel to enlarge its water supply to Jordan from natural sources in the north of Israel in exchange for water supply from Jordan to Israel in the Southern Arava region.

Would such a transaction be mutually beneficial? Recall the results in Table 1: The scarcity rents for potable sources in northern Israel are in the range of 29 ¢/cm (Sea of Galilee) to 36¢ /cm (Eastern aquifer), while in the Arava, the value is 36 ¢/cm, so that Israel would break even from such a deal. However, to supply the water in the south, Jordan will have to desalinate Red Sea water, which will cost more than 50¢/cm. Using Fisher and Huber-Lee's (2011) predictions of shadow values for agricultural use in the northwestern agricultural regions of Jordan, which are about 15¢/cm, such an exchange is not profitable for Jordan. However, the shadow price for water in Amman exceeds $3 per cubic meter. Obviously, economic efficiency calls for diversion of water from the northwestern agricultural regions of Jordan to Amman. But given that such diversion is not feasible for political reasons, water exchange may be mutually beneficial.

7 Concluding Remarks

Recently, during the writing of this paper, the public debate over the IWA proposal to raise, once more, the prices for agriculture, is broadening and involves officials from the Finance Ministry, the IWA, and the Agriculture Ministry, all of whom share a common database and employ top experts. So the natural question is: Why can't they agree on an efficient policy? Obviously, part of the explanation lies in the area of political economics, and the influence of farmers' organizations and other interest groups, such as Mekorót employees.

However, in the last several months what as appears to be a sincere demand is being made by stakeholders for quantitative assessments of the effect of policy changes. It seems that policy makers are missing objective assessments of the economic consequences of their decisions. Could this explain the continuing disagreement between various branches of the government? In other areas of the economy, such as antitrust policy, governments worldwide are increasingly adopting empirical economic methods and analysis as the basis for enacting policies. Isn't it time for a similar development regarding water?

This paper demonstrated that a high-resolution model of the water economy is useful to characterize efficient water allocation, simulations of exogenous and policy changes, and assessment of shadow prices as the basis of efficient water pricing and monetization of the value of this scarce resource. We hope that this paper and other similar studies that discuss the recent developments in the area of computerized models of the water economy will promote the implementation of such models beyond academia.

References

[1] Bar-Shira, Ziv, Israel Finkelshtain, and Avi Simhon. 2006. "The Econometrics of Block Rate Pricing in Agriculture." *Am. J. Agr. Econ.* 88 (November): 986-999.

[2] Bar-shira, Z., Kislev, Y. and Cohen, N. 2007. "The Demand for Water in the Municipalities." Economic Quarterly 54: 179-203.

[3] Baumol J., William. 1977. "On the Proper Cost Tests for Natural Monopoly in a Multiproduct Industry." AER, Vol. 67, No. 5 (December), pp. 809-822.

[4] Booker, James F., Richard E. Howitt, Ari M. Michelsen, and Robert A. Young. 2012. "Economics and the Modeling of Water Resource and Policies." Natural Resource Modeling 25(1):168–218.

[5] Draper, Andrew J., Marion W. Jenkins, Kenneth W. Kirby, Jay R. Lund, and Richard E. Howitt. 2003. "Economic-Engineering Optimization for California Water Management." journal of water resources planning and management (June):155–64.

[6] Finkelshtain, Israel and Yoav Kislev. 1997. "Prices vs. Quantities: The Political Perspective." *J. Pol. Econ.* 105 (February): 83-100.

[7] Finkelshtain, I., I. Kan, and Y. Kislev. 2015. "A Two-Pronged Control of Natural Resources: Prices and Quantities with Lobbying." Edmond J. Safra, Harvard University Working Papers, No. 60. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2592687

[8] Fisher, F.M., S. Arlosoroff, Z. Eckstein, M. Haddadin, S. Hamati. A. Huber-Lee, A. Jarrar, A. Jayyousi, U. Shamir. H. Wesseling 2002. "Optimal water management and conflict resolution: The Middle East Water Project." Water Resource Research. Vol. 38 No. 11, (November): 1-17.

[9] Fisher, F.M., A.T. Huber-Lee, I. Amir, S. Arlosoroff, Z. Eckstein, M. Haddadin, S. Hamati, A. M. Jarrar, A. F. Jayyousi, U. Shamir. H Wesseling. 2005, Liquid Assets, Published by Resources for the Future, Washington DC.

[10] Fisher, F.M. and A.T. Huber-Lee. 2011. "The value of water: Optimizing models for sustainable management, infrastructure planning, and conflict resolution." Desalination and Water Treatment 31: 1-23.

[11] Harou, Julien J., M. Pulido-Velazquez, D. E. Rosenberg, J. Medellín-Azuara, J. R. Lund, and R. E. Howitt. 2009. "Hydro-Economic Models: Concepts, Design, Applications, and Future Prospects." Journal of Hydrology 375(3-4):627–43.

[12] Israeli Water Authority (IWA). 2015. Environmental Surveys and Studies, Science Division, INPA. "Waste Water Collection, Treatment and Reuse for Agriculture Irrigation- National Survey 2012." [Hebrew].

[13] Jenkins, Marion W., J. R. Lund, R. E. Howitt, A. J. Draper, S. M. Msangi, S. K. Tanaka, R. S. Ritzema, and G. F. Marques. 2004. "Optimization of California's Water Supply System: Results and Insights." Journal of Water Resources Planning and Management (August):271–80.

[14] Kislev, Y., 2006. "The Water Economy of Israel" in: Water in the Middle East: Cooperation and Technological Solutions in the Jordan Valley, K. David Hambright, F. Jamil Ragep, and Joseph Ginat (eds.). Norman, OK: Univ. of Oklahoma Press.

[15] Kislev Y., 2008. "Water in the Palestinian localities." Water engineering (Hebrew).

[16] Kislev, Y., 2011. The Water Economy of Israel. Taub Center for Social Policy Studies in Israel. Policy Paper No. 2011.15.

[17] Luckmann, J., H. Grethe, S. McDonald, A. Orlov, and K. Siddig. 2014. "An Integrated Economic Model Of multiple Types and Uses of Water." Water Resources Research 5(50):3875–92.

[18] Luckmann, J., K. Siddig, D. Flaig, and H. Grethe. 2011. A General Equilibrium Approach to Model Water Scarcity in Israel.

[19] Molle, Francois. 2009. "Water Scarcity, Prices, and Quotas: A Review of Evidence on Irrigation Volumetric Pricing." *Irrig. Drain. Syst.* 23 (February): 43-58.

[20] OECD. 2010, European Environment Agency, OECD/EEA "Database on Instruments Used for Environmental Policy and Natural Resources Management."

[21] Reznik, A., E. Feinerman, I Finkelshtain, F. M. Fisher, A. T. Huber-Lee, B. Joyce, and I. Kan. 2015. "Economic Implications of Agricultural Treated Wastewater Reuse in Israel: A Statewide Long-Term Perspective", Manuscript.

[22] Rosegrant, M. W., C. Ringler, D.C. McKinney, X. Cai, A. Keller and G. Donoso. 2000. "Integrated Economic-Hydrologic Water Modeling at the Basin Scale: The Maipo River Basin." Agricultural Economics 24(1):33–46.

[23] Rosenberg, D. E., R. E. Howitt, and J. R. Lund. 2008. "Water Management with Water Conservation, Infrastructure Expansions, and Source Variability in Jordan." Water Resources Research 44.

8 Appendix

Table A1: Transmission Links of Potable Sources to Urban Demand Zones

Source Name	Destination Name	Transfer & Distribution Cost ($/CM)	Sewage Removal Cost ($/CM)
Golan GW	Eastern Galilee	0.432	0.68
	Golan	0.308	0.642
Sea of Galilee	Eastern Galilee	0.42	0.68
Western Kinneret GW	Eastern Galilee	0.372	0.68
	Western Galilee	0.354	0.646
WG Aquifer	Western Galilee	0.344	0.646
Lower Galilee GW	Lower Jordan	0.31	0.66
Eastern Aquifers	Dead Sea	0.306	0.661
	Jordan Valley	0.306	0.66
	Judea and Samaria	0.303	0.67
Northern Mountain Aquifer	Hadera	0.3	0.61
	Judea and Samaria	0.303	0.67
	Sharon South	0.297	0.642
Central Mountain Aquifer	Adolam	0.456	0.66
	Jerusalem	0.58	0.8
	Judea and Samaria	0.303	0.67
	Lod Lowland	0.28	0.634
	Modieen	0.35	0.51
Southern Mountain Aquifer	Lachish	0.294	0.583
Carmel Aquifer	Carmel Coast	0.306	0.66
	Hadera	0.3	0.61
Northern Coastal Aquifer	Carmel Coast	0.306	0.66
	Hadera	0.3	0.61
	Judea and Samaria	0.303	0.67
	Sharon South	0.307	0.642
Central Coastal Aquifer	Tel Aviv	0.31	0.797
Southern Coastal Aquifer	Granot	0.28	0.6
Negev Coastal Aquifer	Western Negev	0.315	0.585
Negev Aquifer	Ramat Negev	0.33	0.73

Table A2: Transmission Links of Dessalination Plants to Urban Demand Nodes

Source Name	Destination Name	Transfer & Distribution Cost ($/CM)	Sewage Removal Cost ($/CM)
Eilat SWD	Arava	0.336	0.66
	Eilat	0.336	0.66
Jordan Valley	Lower Jordan	0.36	0.66
	Jordan Valley	0.356	0.66
Western Galilee	Western Galilee	0.394	0.646
Carmel Coast	Carmel Coast	0.246	0.66
South Coast	Granot	0.28	0.6
Negev	Lachish	0.314	0.583
	Ramat Negev	0.3	0.73
Arava	Arava	0.346	0.66
	Eilat	0.346	0.66

Table A3: Transmission Links Between National Career Junctions and Urban Demand Nodes

Source Name	Destination Name	Transfer Cost ($/CM)	Sewage Removal Cost ($/CM)
Menashe	Western Galilee	0.384	0.646
Metzer	Carmel Coast	0.356	0.66
	Hadera	0.32	0.61
	Sharon South	0.287	0.642
Rosh Haain	Judea and Samaria	0.49	0.67
	Lod Lowland	0.27	0.634
Achisemech	Jerusalem	0.48	0.8
	Judea and Samaria	0.623	0.67
	Lod Lowland	0.29	0.634
	Modieen	28.08	0.51
	Tel Aviv	0.295	0.797
Holda	Adolam	0.596	0.66
	Granot	0.27	0.6
	Jerusalem	0.69	0.8
	Judea and Samaria	0.633	0.67
	Modieen	0.36	0.51
Zohar	Judea and Samaria	0.603	0.67
	Lachish	0.434	0.583
	Ramat Negev	0.3	0.73
	Western Negev	0.335	0.585

Table A4: Transmission Links of Potable Water Sources to Agricultural Demand Zones

Source Name	Destination Name	Transfer Cost ($/CM)
Golan GW	Golan	0.01
Sea of Galilee	Kineret	0.01
	Tzfat	0.01
Western Kinneret GW	Kineret	0.01
	Tzfat	0.01
WG Aquifer	Acco	0.01
Lower Galilee GW	Jeezrael Valley	0.01
Eastern Aquifers	Jordan Valley	0.01
	JS Settlements	0.01
Northern Mountain Aquifer	Hadera	0.01
	Petah Tikva	0.02
	Sharon	0.02
Central Mountain Aquifer	Jerusalem	0.01
	Ramle	0.01
	Rehovot	0.01
Southern Mountain Aquifer	Ashkelon	0.01
	Ramat Negev	0.01
Carmel Aquifer	Hadera	0.01
	Haifa	0.01
Northern Coastal Aquifer	Hadera	0.02
Central Coastal Aquifer	Petah Tikva	0.02
	Tel Aviv	0.02
Southern Coastal Aquifer	Ashkelon	0.01
	Rehovot	0.04
Negev Coastal Aquifer	Ashkelon	0.01
Negev Aqufer	Ramat Negev	0.01
Arava GW	Arava	0.01

Table A5: Transmission Links of Wastewater Sources to Agricultural Demand Zones

Source Name	Destination Name	Transfer Cost ($/CM)
Golan	Golan	0.01
Tzfat	Tzfat	0.01
Kineret	Kineret	0.01
Beit Shean	Jeezrael Valley	0.01
Jordan Valley	Jordan Valley	0.01
Western Galilee	Acco	0.09
	Haifa	0.09
Kishon	Haifa	0.13
	Jeezrael Valley	0.13
North Coast	Hadera	0.03
	Sharon	0.03
Central Coast	Petah Tikva	0.02
	Sharon	0.02
	Tel Aviv	0.02
Yarkon	Petah Tikva	0.02
Shafdan	Ashkelon	0.09
	Ramat Negev	0.16
Shfela	Ashkelon	0.06
	Jerusalem	0.06
	Rehovot	0.06
Nesher	Jerusalem	0.06
	Ramle	0.06
Judea & Samaria	JS Settlements	0.01
South Coast	Ashkelon	0.04
	Rehovot	0.04
Negev Coast	Ashkelon	0.02
	Ramat Negev	0.03
	Rehovot	0.02
Negev	Ramat Negev	0.03
Dead Sea	Arava	0.02
Arava	Arava	0.02

Table A6: Transmission Links of Saline Water Sources to Agricultural Demand Zones

Source Name	Destination Name	Transfer Cost ($/CM)
Jordan Valley	Jeezrael Valley	0.01
	Jordan Valley	0.01
Western Galilee	Acco	0.01
Carmel Coast	Hadera	0.01
South Coast	Ashkelon	0.01
	Rehovot	0.04
Arava GW	Arava	0.01
Negev GW	Ramat Negev	0.01

Table A7: Transmission Links of Treated Saline Water Sources to Agricultural Demand Zones

Source Name	Destination Name	Transfer Cost ($/CM)
Jordan Valley	Jeezrael Valley	0.06
	Jordan Valley	0.06
Western Galilee	Acco	0.06

Table A8: Transmission Links Between National Career Junctions and Agricul-rural Demand Nodes

Source Name	Destination Name	Transfer Cost ($/CM)
Menashe	Acco	0.05
	Haifa	0.05
	Jeezrael Valley	0.05
Metzer	Hadera	0.03
	Haifa	0.06
	Jeezrael Valley	0.03
	Sharon	0.01
Rosh Haain	Petah Tikva	-
	Sharon	-
Achisemech	Jerusalem	0.13
	Ramle	0.02
	Tel Aviv	0.005
Holda	Jerusalem	0.34
	Rehovot	0.01
Zohar	Ashkelon	0.06
	Ramat Negev	0.05

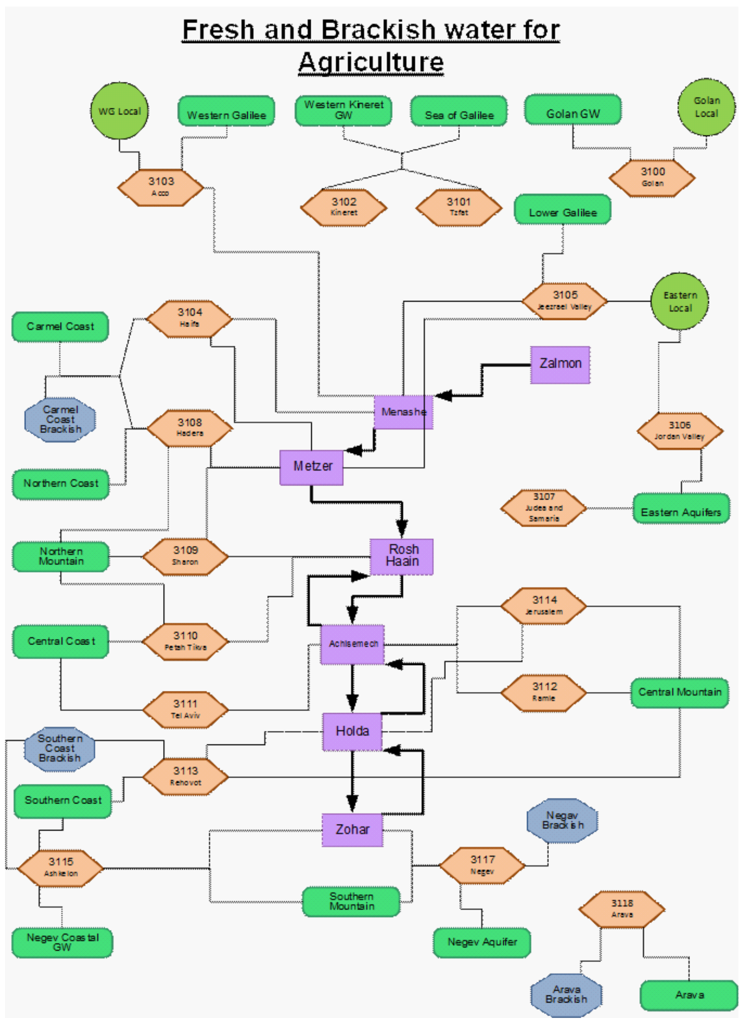


Figure 2: Fresh and Brackish Supply to Agriculture

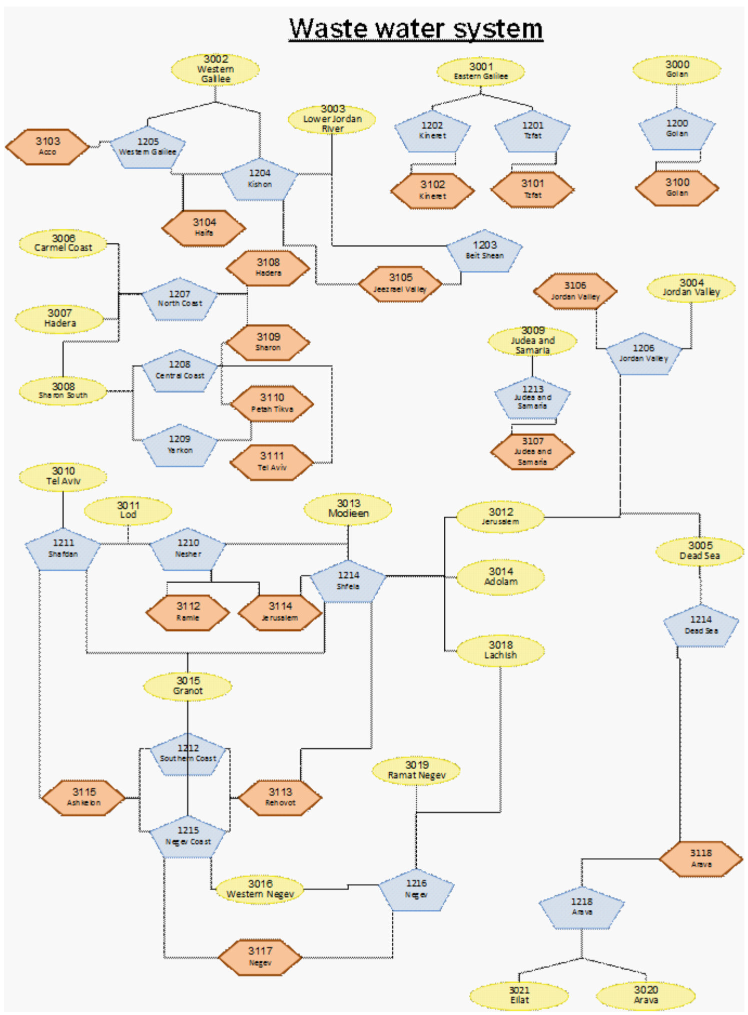


Figure 3: Waste Water Supply to Agriculture

Map 1: Recycling Facilities