A Two-Pronged Control of Natural Resources: Prices and Quantities with Lobbying

by

Iddo Kan

Department of Agricultural Economics and Management, The Hebrew University of Jerusalem; Israel; kan@agri.huji.ac.il (corresponding author);

Israel Finkelshtain

Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, finkelsh@agri.huji.ac.il;

Yoav Kislev

Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, kislev@agri.huji.ac.il.

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ABSTRACT

This study offers a political-economic model of an industry regulated by an integrated system of both direct and market-based policies. The model is incorporated into a normative theoretical analysis and serves as a basis for structural econometric estimations. Exploiting disaggregated data on agriculture and irrigation in Israel in the mid-1980s, when water was regulated by both quotas and prices, the model's political and technological parameters are structurally estimated and used to assess the relative efficiencies of quotas, prices, and an integrated regulation regime.

I. Introduction

Recent decades have seen population and income growth and alongside them, over-utilization of natural resources and aggravated environmental problems in many parts of the world. These developments — often augmented by awareness of the need to cover costs — are increasingly leading policymakers to reinforce the traditional arsenal of quantity instruments with market-based policies such as user and polluter charges (OECD 2010). As a result, the prevailing regulations in many countries are mixtures of direct and market-based instruments. Examples include the 1990 Clean Air Act in the U.S. that involves polluting standards and charges (EPA 2001) and the regulation of environmental externalities in many countries by means of both quotas and user taxes (EPA 2004). An additional important case is irrigation water—70% of freshwater used around the world—that in many locales is managed by a combination of charges and quotas; examples can be found in Australia, California, China, Iran, Israel, Peru, and Spain (Molle 2009).

Government intervention, whatever its nature, most often encounters political lobbying and pressure and, beginning with the seminal work of Buchanan and Tullock (1975) on taxes and quotas, there has been a long succession of studies of environmental and resource regulation under political lobbying. More recently, Fredriksson (1997) compared taxes with subsidies in pollution control; Finkelshtain and Kislev (1997) examined the relative robustness to political influence of quantity versus price regulations; Finkelshtain and Kislev (2004) analyzed alternative subsidy and tax regimes facing politically powerful interest groups; Yu (2005) studied environmental protection and direct and indirect political influence; and Roelfsema (2007) investigated strategic delegation of environmental policymaking. However, to the best of our knowledge, political equilibrium under a mixed policy regime of direct and indirect controls is an as-yet unexplored topic. This is the subject of the present study, wherein we offer a political-economic model of an industry regulated by an integrated system of both direct and market-based policies.

Political influence has also been studied empirically. A noticeable earlier effort was the pioneering work of Zusman and Amiad (1977) who analyzed agricultural support policies. More recent estimates of structural political parameters have been based on application of the *Protection for Sale* theory of Grossman and Helpman (1994) to trade policies. A common feature of the estimations in the trade context was that policymakers were found valuing social welfare highly relative to political contributions. This finding is puzzling, particularly in light of reports on extensive investments in lobbying. Many extensions of the model were suggested in attempts to reconcile the apparent contradiction of broad support for lobbying and political contributions on the one hand, and irresponsive governments on the other. However, as Gawande and Magee (2010) demonstrated, despite these efforts, the puzzle has not been solved.

In their own attempt to solve the puzzle, Gawande and Magee distinguish between cooperative lobbying, wherein all firms take part in the political activity; and non-cooperative lobbying, wherein some firms lobby and contribute politically while others are free-riders. Inter-industrial differences in protection may be explained by variations in the level of free-riding. In this paper, we study water regulation in Israel and show that free-riding in lobbying may play an important role in explaining the differences in effectiveness of firms' specific controls (quotas) in contrast to uniform regulation (economy-wide tax or price). Accounting for these differences, we found that policymakers in Israel valued highly the interests of the agricultural lobby.

When an industry is regulated by a system of two integrated controls, the intensities of lobbying associated with any of the economic instruments are mutually interdependent. For instance, lobbying for higher quotas will not be observed where both taxes and quotas are comparatively high and the quotas are not effectively constraining. In another situation, with a combination of a low tax and small quotas, the tax will be irrelevant. Borrowing from the terminology of information economics, we term these specific cases, respectively, *pooling price* and *pooling quota* equilibrium. When both controls are effective, a *separating equilibrium* emerges wherein the population is divided into two interest groups, each bounded by a different instrument and acting accordingly in the political arena. In the proposed terminology, the situation in Israeli agriculture forms a separating equilibrium.

The political process we are studying is embedded in a predetermined "constitution," wherein the control regime may be quotas, a price, or an integrated regime. By its choice of the control regime, and the initial quotas, the government determines which type of equilibrium will emerge in the economy. Thus, an interesting policy question is: Which of the above equilibria is more efficient? This question is examined empirically in the paper via simulations of the various equilibria, based on estimated technological and political parameters. An important finding of the paper, at least for the conditions prevailing in Israel, is that pooling price equilibrium, inducing more free-riding than the alternative regimes, is welfare dominating.

The next section of the paper presents a political-economic model of a mixed regime in a sector with heterogeneous producers. We then develop the necessary conditions for the existence of the three cases: pooling price, pooling quota, and separating equilibrium. These conditions are employed in Section III to construct a structural empirical model used to estimate the technological and political parameters of the model. Section IV presents simulations of alternative equilibria, and Section V is a concluding comment.

II. Theory

Consider an agricultural sector in a small, open economy. Water suppliers allocate water to farmers using both prices and quotas as dictated by a government regulator. The quotas are individual and non-transferable.[1] Technologies and markets are ever changing; the regulation instruments are therefore examined periodically and modified as needed. This modification and the resetting of prices and the quotas is the subject of the political process modeled below.

Farming conditions are heterogeneous and farmers vary in their abilities. Let γ, with the distribution function $z(\gamma)$, represent the farming unit's technological level, and for convenience, treat this variable as continuous. The profit per farm is given by $\pi(w,\gamma) - pw$, where w is the farm's water use and p is an administratively determined agricultural water price. The function $\pi(w,\gamma)$ subsumes the prices of all variable outputs and inputs, excluding p, and is assumed continuous, increasing, twice differentiable, and strictly concave in w. The derivative of $\pi(w,\gamma)$ with respect to water consumption, $\pi_w(w,\gamma)$, is the water's value of marginal product (VMP), which we assume is increasing in γ. The inverse of this function, $D(p,\gamma) = \pi_w^{-1}(p,\gamma)$, is the farm‘s water demand. The slope of the demand function is $D_p = 1/\pi_{ww}$. In the section on comparative statics, it will be assumed that $D_{p\gamma} = 0$.

The allocation of water quotas, q, to the farms (all of them) is represented by the distribution function $k(q)$. The farm's water consumption is then given by $w(p,\gamma) = \min(D(p,\gamma), q)$. The price p and the distribution of quotas $k(q)$ are the instruments used by the government to control water consumption in agriculture. These controls are set through a political process wherein politicians may bend policies in favor of interest groups who, in return, provide political rewards. We omit the explicit formulation of the political game and instead rely on Peltzman (1976), Zusman (1976), Hillman (1982), Grossman and Helpman (1994), Damania, Fredriksson, and List (2003), and others who have shown that policies constituting

[1] The quotas are here a regulation instrument; there are no private property rights in the utilization of water.

equilibrium in a political system with rewards can be viewed as maximizing the following governmental objective function.

$$G = S\left(p, k\left(q\right)\right) + \beta U\left(p, k\left(q\right)\right) \tag{1}$$

In (1), $S\left(p, k\left(q\right)\right)$ and $U\left(p, k\left(q\right)\right)$ are social welfare and the organized interest groups' profits respectively, and $\beta, 0 \le \beta$ is the extra weight attached by the politicians to the welfare of politically organized groups [in the political models, suggested by Zusman (1976) and Grossman and Helpman (1994), β is the weight attached to political rewards]. In our context, β may also reflect weight attached by decision-makers to social objectives such as food security, viability of family farms, and the development of rural areas.

Consistently with the practice in Israel, we visualize prices as modified and set before the rainy season, while the quotas are announced only after the winter rains have been observed. We are therefore considering a two-stage political game, wherein quotas are set subsequent to price determination. Political activities differ as per the stage of the game. Lowering the price is in the entire farming sector's interest, and hence is in the nature of a public good. Partial participation in the political struggle for price cuts can therefore be expected. In contrast, since quotas are farm-specific assets, free-riding in lobbying for higher quotas is less probable; however, only farmers whose quotas are binding can be expected to negotiate quota raises. The separation into the two interest groups — the entire sector, and the operators constrained by the quotas — yields the political separating equilibrium.

Given the price of water, whether a farm is constrained by the quota depends both on its technological level and the size of its specific water allotment. We wish to order the farms and consequently divide them into two groups so that water use in one group is dictated by the price, while those in the second group utilize their allotments fully. Formally, let q^0 denote the farm's historical, pre-modification quota (the unit index is omitted) and $k^0\left(q^0\right)$, the associated continuous distribution function with the support $\left[q^l, q^h\right]$. Define $\nu \equiv \pi_w\left(q^0, \gamma\right)$, $\nu \in \left[\nu^l, \nu^h\right]$, as the VMP of water measured at the historical quota. The joint distribution of $z\left(\gamma\right)$ and $k^0\left(q^0\right)$ induces the continuous distribution function $f(\nu)$ on the support $\left[\nu^l, \nu^h\right]$. Given p and $f(\nu)$, the water consumption of the farms with $\nu^l \le \nu \le p$ is dictated by the price, while those with $p < \nu \le \nu^h$ consume water quantities equal to their quotas. In other words, for the historical regulation parameters,

$$w(p,\nu) = \begin{cases} D(p,\nu) = \pi_w^{-1}(p,\nu), & \nu \in \left[\nu^l, p\right] \\ q(\nu), & \nu \in \left(p, \nu^h\right] \end{cases}$$

where $q(\nu)$ is the quota associated with ν. The controls are examined and modified annually. Our interest is in the emerging political equilibrium price p^* and quota allocation rule $q^*(\nu)$. The economic value of a quota is a decreasing function of the price paid for water; hence, the higher the price, the less intense the political struggle for quotas (this assertion is proven formally in subsection II.C). The politicians may take this effect into account when setting the price in the first stage of the political game (this conjecture is tested in the empirical sections). Accordingly, the game is solved recursively, starting with the second stage.

A. *The Second Stage: Allocating Quotas*

Using the above notations and definitions, total water consumption in the economy is given by:

$$W\left(p, f(\nu)\right) = \int_{\nu^l}^{\nu^h} w(p,\nu) f(\nu) d\nu = \int_{\nu^l}^{p} D(p,\nu) f(\nu) d\nu + \int_{p}^{\nu^h} q(\nu) f(\nu) d\nu \qquad (2)$$

Given p^* and $f(\nu)$, quotas are reallocated to farmers whose quotas are binding, i.e., having $\nu \in \left(p^*, \nu^h\right]$. Denoting by c the constant per-unit water supply cost, and recalling (1), the equilibrium quota allocation is solved as an optimal control problem with the objective

$$\begin{aligned} &\max_{q(\nu)} G\left(q(\nu)\right) = \int_{p^*}^{\nu^h} \left[\pi\left(q(\nu),\nu\right)(1+\beta) - \beta p^* q(\nu)\right] f(\nu) d\nu - cW\left(p, f(\nu)\right) \\ &s.t.\ \ \dot{W} = q(\nu) f(\nu) \end{aligned} \qquad (3)$$

The solution of (3) yields the equilibrium rule with respect to $q(\nu)$:

$$\frac{c+\beta p^*}{1+\beta} = \pi_w\left(q^*(\nu),\nu\right)\Big|_{\nu\in\left(p^*,\nu^h\right]} \equiv \pi_w^h \tag{4}$$

Or, writing explicitly, the inversion of (4) yields

$$q^*(p,\nu)\Big|_{\nu\in\left(p^*,\nu^h\right]} = \pi_w^{-1}\left(p^*,c,\beta,\nu\right) \tag{4'}$$

Eq. (4') will be used in the empirical analysis below. As $\pi_w^h > 0$ in Eq. (4) is a constant with respect to ν, the political process yields efficient intra-group water use equating the VMPs of all farms with $\nu \in \left(p^*,\nu^h\right]$. However, it will be shown below that as long as $\beta > 0$, $c > \pi_w^h > p^*$; this inequality implies a welfare loss. Finally, we note that in the special case of $p^* = 0$, Eq. (4) becomes

$$\frac{c}{1+\beta} = \pi_w\left(q^*(\nu),\nu\right)\forall\ \nu \in \left[\nu^l,\nu^h\right], \tag{4''}$$

characterizing a pooling quota equilibrium.

Note that the lower bound of the integral in (3) is the equilibrium price reached in the first stage of the political game. Farmers with $\pi_w\left(q^0(\nu),\nu\right) > p^*$ are bound by their historical quotas (they belong to the group $\nu \in \left(p^*,\nu^h\right]$) and they all participate in lobbying activity in the second stage. Since, as shown above, $\pi_w^h > p^*$, they will all belong to the same group in the equilibrium reached after the second stage.

B. The First Stage: Setting the Price

Again rewriting (1), the equilibrium price p^* is the solution to the following problem:

$$\begin{aligned}\max_p\ G(p) = &\int_{\nu^l}^{\nu^h} \pi\left(w(p,\nu),\nu\right) f(\nu)d\nu - cW\left(p, f(\nu)\right) \\ &+\beta\theta\int_{\nu^l}^{\nu^h}\left[\pi\left(w(p,\nu),\nu\right) - pw(p,\nu)\right] f(\nu)d\nu\end{aligned} \tag{5}$$

In (5), $0 \le \theta \le 1$ represents the portion of the farming population supporting the lobby in its struggle for price reduction. The necessary condition for the maximum in (5) is:

$$\int_{\nu^l}^{\nu^h}\left(\pi_w\left(p,\nu\right)-c\right)w_p f\left(\nu\right)d\nu=\beta\theta\left[W\left(p,f\left(\nu\right)\right)-\int_{\nu^l}^{\nu^h}\left(\pi_w\left(p,\nu\right)-p\right)w_p f\left(\nu\right)d\nu\right] \quad (6)$$

where $w_p=\frac{\partial D\left(p,\nu\right)}{\partial p}\ \forall\,\nu\in\left[\nu^l,p\right]$ and $w_p=\frac{\partial q^*\left(\nu\right)}{\partial p}\ \forall\,\nu\in\left(p,\nu^h\right]$.

The left-hand side of (6) is the price change's marginal effect on social welfare. It is the sum, over all farms, of the per-unit deadweight loss. On the right-hand side, the terms in the square brackets are the price change's marginal effect on farmers' welfare. In equilibrium, the former equals $\beta\theta$ times the latter. Since $\pi_w\left(p,\nu\right)\geq p$ and $w_p<0\ \forall\,\nu\in\left[\nu^l,\nu^h\right]$, the right-hand side of (6) is positive, and it follows that

$$\int_{\nu^l}^{\nu^h}\left(p-c\right)w_p f\left(\nu\right)d\nu>\int_{\nu^l}^{\nu^h}\left(\pi_w\left(p,\nu\right)-c\right)w_p f\left(\nu\right)d\nu>0 \quad\Rightarrow\quad c>p\,.$$

That is, the equilibrium price is lower than marginal cost. Moreover, substituting $c>p$ in (4), it follows that $c>\pi_w^h>p^*$. Hence (a) water's VMP is below marginal cost; welfare loss is indicated for both groups of farms; and (b) water is allocated inefficiently between the group with binding quotas and the other farms. In analogy to the quota case, Eq. (6) with *p* binding for all farmers characterizes a pooling price equilibrium. In this case, Eq. (6) is rewritten as:

$$p^*=c+\beta\theta W\left(p,f\left(\nu\right)\right)\Big/\int_{\nu^l}^{\nu^h}\frac{\partial D\left(p,\nu\right)}{\partial p}f\left(\nu\right)d\nu \quad (6')$$

Note that the pooling equilibria, Eqs. (4'') and (6'), may emerge, either if the "constitution" dictates a single-control regime, or in the case of a mixed regime with no solution, $\nu^l<p^*<\nu^h$, to Eq. (6).

C. Comparative Statics

The regulation instruments' sequential setting implies that the comparative statics exercises should also be performed in two stages. The effect of an exogenous change on the price is analyzed in the first stage. The direct effect of the exogenous change and the indirect effect (through the price) on the quotas are examined in the second stage. Table 1 summarizes the results; the proofs are presented in Appendix A.

The effects on the price of marginal shifts in political parameters β and θ and of the supply cost *c* can be recognized intuitively; i.e., the larger the power or representation of the farming sector in the political arena, the lower the price, whereas higher supply costs increase the price. The impacts on the quotas are also expected; i.e., allotments increase with β and θ and shrink with *c*. Note that θ, the parameter measuring participation in the political struggle, has no direct effect on the quotas; its indirect impact is lowering the price and thereby increasing the quotas.

Technological improvements and alternative schemes of quotas' historical allocations are modeled as variations in the distribution functions $z(\gamma)$ and $k^0(q^0)$, both of which affect the $f(v)$ distribution. In particular, technological improvement or a rise in the agricultural terms of trade are modeled as a first-order stochastic dominant (FSD) shift of $z(\gamma \mid q^0)$, the conditional distribution of γ, given q^0. Recalling our assumption that the demand function's slope is invariant to changes in γ, such a change leads to a price reduction and indirectly increases the quotas and total water usage and hence enlarges the deadweight losses (the last effect is not reported explicitly in the table). Intuitively, for a given *p*, technological improvement (or an improvement in terms of trade) increases the number of farmers with binding quotas (N^h) and shifts the entire farmers' population towards larger water consumption. These effects lead to an increase in the farmers' marginal gain from a price decrease, the right-hand side of Eq. (6), and hence augments the pressure on the price. Moreover, the increase in N^h reduces the social gain from price increase. This follows from two reasons. First, for the farmers with binding quotas, water consumption is less responsive to a price hike. Secondly, the per cubic meter dead weight losses of the "high" *v* group is smaller than that of "low" *v* group farmers. This means that technological improvement makes it "cheaper" for the politicians to discount the water price. Therefore, the equilibrium is restored at a lower price, higher quotas, and higher level of the marginal deadweight loss; i.e., the left-hand side of Eq. (6).

Ceteris paribus, an economy with higher initial quotas will have a higher equilibrium price, and paradoxically, smaller quotas and less water use. The explanation is that when historical quotas are comparatively high, more farmers who would otherwise be in the "high" *v* group find themselves in the "low" range. This means an increase in the share of the water controlled by the price and more farmers with larger per-unit dead weight loss, which increases government resistance to pressure on the price. While the change has no direct effect on the equilibrium quotas, the indirect effect through the price reduces quotas' allocation, aggregate water use and the deadweight losses.

In Section IV, the above comparative statics effects are quantified for the Israeli case in simulations based on the estimated parameters. In addition, the comparative statics results suggest several testable implications of the model, such as an increase in the administrative water price in periods of declining terms of trade. Below, we indicate that the Israeli data are consistent with this prediction of the model.

III. Empirical Analysis

All water sources in Israel are publicly owned, and their use is regulated by the state. In the period covered by our analysis, the regulator was the Water Commissioner, but other government agencies and politicians were deeply involved in the decisions on prices and quantity allocation (Zusman 1997; Mizrahi 2004; Kislev 2006; and Margoninsky 2006). Our data set covers prices and quotas for cooperative and communal villages (*moshavim* and *kibbutzim* respectively) that received their water from the national company, Mekorot, the provider of most of the water in the country. The village, not the individual farmer, is the consuming unit in the sample, receiving water up to its specific quota and paying for the quantity used.

The data in the study cover the period 1985-88, when prices were linear and region-specific (today farmers pay increasing block rate prices, and the same tariff structure applies nationwide). The prices' variation across regions and over time allows econometric estimates. Strictly speaking, this means that lobbying is conducted in each region separately; however, since regional prices were correlated, political activity at the nationwide level was also observed. During the study period, the agricultural sector utilized less water than allowed by the aggregate quota; while some farmers were constrained by their quantitative allocations, others did not fully use the water they were allotted (a separating equilibrium, in the proposed terminology). The empirical analysis is conducted at two levels: The parameters of demand function and the quota allocation rules, including the magnitude β, are estimated at the village level, while price setting is estimated at the regional level. Obtaining the size of the parameter θ is based on these estimations' output.

A. The Demand Function and the Quota-Allocation Rule

The challenge of the econometric analysis is to "explain" two observed magnitudes: per-village water use, and its quota. Recall that (a) water use is determined either by price or by quota; and (b) quotas are endogenously set in the political process. Consequently, our task is to estimate two structural equations: water demand, and the quota-setting function.

For convenience, write water's VMP for village *i* and year *t* as the linear function

$$\pi_{w\,it} = \omega_{it} + \psi w_{it} \tag{7}$$

In (7), w_{it} and ω_{it} are respectively, the village-year-specific water consumption and the function's intercept, and ψ is its slope, assumed identical for all *i* and *t*. The derived water demand function is $D(p_{it}, \mathbf{z}_{it}) = \boldsymbol{\mu}\mathbf{z}_{it} + \delta_1 p_{it}$, where p_{it} is the price (villages in the same region may have identical prices), $\mathbf{z}_{it}$ is a vector of village-year-specific variables, $\boldsymbol{\mu}$ is the vector of corresponding coefficients, and $\delta_1 \equiv \psi^{-1}$. Let q_{it} be the village annual water quota. By substituting the linear VMP specification into Eq. (4'), $\pi_{w\,it}\big|_{w_{it}=q_{it}} = \omega_{it} + \psi q_{it}$, and rearranging, we get a linear political equilibrium quota allocation rule: $Q(p_{it}, \mathbf{x}_{it}) = \boldsymbol{\xi}\mathbf{x}_{it} + \delta_2 p_{it}$, where $\mathbf{x}_{it}$ is a vector of village-year-specific variables, $\boldsymbol{\xi}$ is the associated vector of coefficients, and $\delta_2 \equiv \psi^{-1}\beta/(1+\beta)$. The political parameter β is identifiable through $\beta/(1+\beta) = \delta_2/\delta_1$.

Following Burtless and Hausman (1978) and Mofitt (1986), we add to the structural equations three random components. The first is heterogeneity across villages and along time, not explained by p_{it} and $\mathbf{z}_{it}$; it is represented by the random variable α_{it}, which stands for managerial skills and other factors not observed by the modeler, yet known to the farmers and therefore affecting their individual demand for water. Two additional sources of randomness are those associated with measurement errors and optimization mistakes that may emerge in both the farmer's decision on water usage and the allocation of quotas by the government, which are represented respectively by the terms ε_{it} and u_{it}. A linear additive formulation is adopted, with two interrelated equations of water demand and quota allocation:

$$w_{it} = \begin{cases} D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} + \varepsilon_{it} & \text{if} \quad D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} \le q_{it} \\ q_{it} + \varepsilon_{it} & \text{if} \quad D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} > q_{it} \end{cases} \tag{8}$$

$$q_{it} = \begin{cases} q_{it-1} + u_{it} & \text{if} \quad D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} \le q_{it-1} \\ Q(p_{it}, \mathbf{x}_{it}) + u_{it} & \text{if} \quad D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} > q_{it-1} \end{cases} \tag{9}$$

By Eq. (8), wherever the quantity demanded at the given price is less than the quota, consumption equals the demand function $D(p_{it}, \mathbf{z}_{it}) + \alpha_{it}$ plus a stochastic error term. If water demand exceeds the quota, then the observed water consumption equals the quota q_{it} plus the stochastic error term. The quota's endogenous setting is formulated in Eq. (9): If the historical quota q_{it-1} exceeds demand, and is therefore unbinding, then, $q_{it} = q_{it-1}$ plus an error term. An effective historical quota, on the other hand, would lead to bargaining and to a political equilibrium characterized by the equilibrium quota allocation rule $Q(p_{it}, \mathbf{x}_{it})$.

Our estimation strategy is based on maximization of the sample likelihood. Let $\Pr_{it}(w_{it}, q_{it} | p_{it}, q_{it-1}, \mathbf{z}_{it}, \mathbf{x}_{it}, \boldsymbol{\theta})$ be the probability of observing a pair of water consumption w_{it} and quota q_{it}, where $\boldsymbol{\theta}$ is the set of parameters of the functions $D(p_{it}, \mathbf{z}_{it})$ and $Q(p_{it}, \mathbf{x}_{it})$ and the joint density distribution functions of α, ε, and u. This probability encompasses all the combinations associated with the options in (8) and (9), as elaborated below.

$$\begin{aligned} &\Pr_{it}(w_{it}, q_{it} | p_{it}, q_{it-1}, \mathbf{z}_{it}, \mathbf{x}_{it}, \boldsymbol{\theta}) = \\ &\quad \Pr\left[\alpha_{it} + \varepsilon_{it} = w_{it} - D(p_{it}, \mathbf{z}_{it}), \alpha_{it} \le \min(q_{it}, q_{it-1}) - D(p_{it}, \mathbf{z}_{it}), u_{it} = q_{it} - q_{it-1}\right] \\ &+ \Pr\left[\alpha_{it} + \varepsilon_{it} = w_{it} - D(p_{it}, \mathbf{z}_{it}), q_{it-1} < D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} \le q_{it}, u_{it} = q_{it} - Q(p_{it}, \mathbf{x}_{it})\right] \\ &+ \Pr\left[\varepsilon_{it} = w_{it} - q_{it}, q_{it} < D(p_{it}, \mathbf{z}_{it}) + \alpha_{it} \le q_{it-1}, u_{it} = q_{it} - q_{it-1}\right] \\ &+ \Pr\left[\varepsilon_{it} = w_{it} - q_{it}, \alpha_{it} > \max(q_{it}, q_{it-1}) - D(p_{it}, \mathbf{z}_{it}), u_{it} = q_{it} - Q(p_{it}, \mathbf{x}_{it})\right] \end{aligned} \tag{10}$$

The sample likelihood function is

$$L = \prod_i \prod_t \Pr_{it}(w_{it}, q_{it} | p_{it}, q_{it-1}, \mathbf{z}_{it}, \mathbf{x}_{it}, \boldsymbol{\theta}) \tag{11}$$

Assuming that the random variables α, ε, and u are statistically independent and normally distributed, such that $\alpha \sim N\left(0,\sigma_\alpha^2\right)$, $\varepsilon \sim N\left(0,\sigma_\varepsilon^2\right)$, and $u \sim N\left(0,\sigma_u^2\right)$, the likelihood function in (11) is readily derivable in terms of the standard normal density (Appendix B).

B. The Price Formation Equation

The price formation parameters are estimated at the regional level. Let N_{jt}^l and N_{jt}^h be the number of price and quotas' effective observations, respectively, in region j in year t; W_{jt} stands for total water consumption in the same observation. With our linear specification for the demand function, Eq. (6) becomes:

$$p_{jt} = \boldsymbol{\zeta}\mathbf{c}_{jt} + \psi\beta\theta \frac{W_{jt}}{N_{jt}^l + \lambda\left(1-\theta\right)\left(\frac{\beta}{1+\beta}\right)^2 N_{jt}^h} + \upsilon_{jt} \qquad (12)$$

where $\mathbf{c}_{jt}$ is a vector of region-level supply cost-related variables, $\boldsymbol{\zeta}$ is the set of corresponding coefficients, and υ_{jt} is an error term. The parameter λ indicates the politicians' "conjectural variation," i.e., the degree by which $\partial q^*\left(\nu\right)/\partial p$ is taken into account when determining the price. If $\lambda = 1$, then the politicians have complete comprehension of the mechanism by which p affects $q^*\left(\nu\right)$ in Eq. (4), and this effect is perfectly accounted for when setting the price (Eq. (6)). At the other extreme $\lambda = 0$, and $\partial q^*\left(\nu\right)/\partial p$ is ignored.

Eq. (12) is highly nonlinear; and N_{jt}^l, N_{jt}^h, and W_{jt} may be endogenous. We therefore employed a nonlinear limited information maximum likelihood (LIML) procedure (Amemiya 1986, pp. 252-255) to estimate it, and found that the hypothesis of $\lambda = 0$ could not be rejected, implying that (12) is reduced to:

$$p_{jt} = \boldsymbol{\zeta}\mathbf{c}_{jt} + \delta_3 W_{jt}/N_{jt}^l + \upsilon_{jt}\ , \qquad (12')$$

where $\delta_3 \equiv \psi\beta\theta$. Accordingly, and to improve the efficiency of the estimation procedure, in the sequel, we employ Eq. (12') and a linear LIML procedure to estimate the model parameters. In particular, we note that using Eqs. (7) and (12'), θ is identifiable through $\theta = \delta_3\delta_1\left(\delta_1 - \delta_2\right)/\delta_2$.

C. Data and Variables

The estimation is based on a panel of 1,051 observations of freshwater use in agriculture. The information covered prices and quotas for the years 1985-88, encompassing 303 villages located in 23 water-price regions. The observations in the panel were selected according to three criteria: (a) the villages included used only fresh water; they did not apply brackish or recycled water; (b) the included villages received their water from Mekorot only, whose prices were, and still are, set by the government; (c) villages with cultivated areas of less than 50ha or water quotas of less then 200,000 m^3 / year were excluded from the sample. In the period of the study, water use in the sample villages accounted for 20% of agricultural freshwater consumption in the country.

Table 2 provides descriptive statistics of the variables in the dataset and their sources. Water use, quota, price, and cost were explicitly incorporated into the theoretical formulation presented above. The other variables in the table are the components of the vectors $\mathbf{z}_{it}$ and $\mathbf{x}_{it}$ in Eqs. (8) and (9). Note that on average, water consumption was lower than village quota. In fact, the consumption of water was less than the quota in 56% of the observations (not in the table). As suggested earlier, this is an indication of a separating equilibrium.

Delivery costs, in 1987 US dollars, were available by Enterprise, a part of Mekorot's network covering a delivery area, mostly to points of similar altitudes (Shaham 2007) and assigned to villages as per their water utilization. As indicated, prices in the study period (1985-88) were region specific. For the region-level analysis, village costs were aggregated to 23 regional averages.

Capital and operating outlays form the fixed part of water supply's cost; unlike energy, they do not vary with the quantity delivered. Capital costs were often neglected when prices were determined because a large portion of Mekorot's investment was covered by public budgets. Moreover, in 17 of the 23 regions, average price was lower even than energy cost, and in all regions it was lower than total cost.

Farmers did not face the full cost of the input they used; apparently they succeeded in lobbying for lower prices.

The last two variables in Table 2 are at the nationwide, not village, level. Enrichment is the annual recharge of rainwater added to the reservoirs — the aquifers and the Sea of Galilee — and terms of trade is an index of the ratio of the price of agricultural products (field crops and orchards) to the price of farm inputs.

D. Estimation Results

We begin with the estimation of Eqs. (8) and (9). The goodness of fit is evaluated by comparing the predicted to the actual distribution of the variables, in our case water use and quotas. The scatter diagrams in Figure 1 present the predicted (expected) values versus the observed magnitudes for both consumption and quotas.[2] The correlation between the predicted and observed series is 0.91 for quotas and 0.63 for water consumption, both indicating reasonable fit. We also compare the distributions of the actual and the predicted quantities. While the distribution of predicted consumption is less dispersed than the one corresponding to the actual quantities, all other moments are quite similar. In particular, note that the average water use and quota predicted by the model are 958 and 1,028 (1,000 m^3), compared with the actual average use and quota of 940 and 1,033 respectively.

The estimation results are summarized in Tables 3a for Eqs. (8) and (9) at the village level, and 3b for the setting of prices. In Eq. (8), based on the estimated values of σ_α and σ_ε of the error terms in the demand function, 61% [383/(383+241)] of the unexplained variation in water consumption is associated with the heterogeneity among villages. As expected, the price coefficient (δ_1) is negative and significant; the elasticity of demand will be discussed below.

Only a few of the village-specific variables seem to significantly affect annual water demand, among them elevation, indicating cooler, hilly areas; and cultivatable land in the village, particularly areas of orchards. Water consumption is relatively

[2] The expected values were calculated in the simulations presented in Section IV below.

higher in the drier south; cooperative villages use less water than communal entities; and improved terms of trade encourage intensification of water utilization.

The estimated parameters of the quota allocation function, presented in the second column of Table 3a, are consistent with the theory. The price coefficient (δ_2) is negative; i.e., higher prices reduce the intensity of the political activity. The two components of the delivery cost operate in opposite directions: On the one hand, higher energy cost, which indicates an increased marginal cost, increases the equilibrium VMP in Eq. (4), and hence adversely affects the allotted quotas in the political equilibrium. On the other hand, capital and operational costs serve as indicators of installed capacity and lower marginal cost, and therefore, villages connected to capital-intensive enterprises enjoy comparatively higher quotas.

As indicated, the political determination of the quotas is a reallocation process, modifying historical distribution; hence the significant effect of q_{t-1}, which is introduced in the empirical estimation to control for quota-adjustment constraints and farm characteristics. The interpretation of most other parameters in the quota equation is straightforward; we comment only on April rainfall and annual recharge. While spring rainfall's effect on demand is not significant, a good rain may reduce farmers' pressure for higher quotas, hence the negative sign in the second column.

As for natural enrichment, reservoirs enable smoothing of supply by carrying water from rainy to drier years. In light of this possibility, the withdrawal policy often recommended is to limit extraction to "safe yield," a stable quantity that may constitute an essentially constant yearly supply. The disadvantage of this policy is that it allows some water to drain into the ocean (or in our case the Dead Sea). A positive effect of annual recharge on quota allocation, as shown in Table 3a, is an indication of political pressure to "make use of every drop of water" and extract yearly the entire recharged quantity. Such a policy increases the risk of shortages and severe crises in drought years, and may even damage the reservoirs. As Zusman and Amiad (1977) showed, the agricultural lobby in Israel and the politicians it influenced tended to be shortsighted.

The ratio $\beta/(1+\beta)$ is estimated at 0.48, where the equality to both zero and one is rejected in the 5% confidence level. Again, Zusman and Amiad (1977) reported

$\beta/(1+\beta)$ values of similar magnitudes, considerably higher than those obtained in studies of the influence of lobbying on trade policies (Gawande and Magee 2010).

The price formation equation, estimated at the regional level, is reported in Table 3b. There are 72 region-year observations and they were weighted by the number of villages in the region (weighting did not affect the estimates markedly). Based on the estimates, higher capital and operating costs increase equilibrium prices, whereas energy costs do not exhibit a significant impact. The δ_3 $(=\psi\beta\theta)$ coefficient is negative and statistically significant, thereby rejecting the hypothesis of no political pressure.

The point estimation for the lobbying participation rate, θ, is 0.23, indicating considerable free-riding. Moreover, the latter conclusion is strengthened by noting that θ is significantly less than 1 (no free-riding). Finally, we could not rule out the possibility that $\theta = 0$, indicating zero organization for price lobbying.

IV. Simulations

The parameters estimated in the previous section are employed here for simulations. The simulations are of expected village water use and quotas conditional on prices, village characteristics, and the estimated political and technological parameters. Expected values were calculated by numerical integration of the estimated bivariate likelihood function:

$$E(w_{it}) = \iint w \Pr\left(w, q \middle| p_{it}, q_{it-1}, \mathbf{z}_{it}, \mathbf{x}_{it}, \hat{\boldsymbol{\theta}}\right) dwdq \tag{13}$$

$$E(q_{it}) = \iint q \Pr\left(w, q \middle| p_{it}, q_{it-1}, \mathbf{z}_{it}, \mathbf{x}_{it}, \hat{\boldsymbol{\theta}}\right) dwdq \tag{14}$$

The range for the numerical integration was the observed quantities ± 10 millions m^3, with 100 partitions. We begin with the demand elasticity.

A. *Price Elasticity*

Prices are endogenous in our model. Still, the question may be asked, how does water consumption change with its price? Three concepts of elasticity emerge. The first is the calculated individual village demand elasticity, computed utilizing the regression coefficient at the sample mean (Tables 2, 3a); this elasticity value is -0.87 (-7,619*0.11 / 958). The second concept is the “constrained market elasticity,” corresponding to a market experiment wherein villages constrained by their quota do not respond to a change in the prices, and the quotas are assumed irresponsive to price changes. The calculation is conducted by a simulation of Eq. (13) for prices 5% above and below the observed sample levels, holding the sample quotas constant. The value of the elasticity thus computed is -0.19, or slightly higher than the short-run elasticity value of -0.13 estimated by Bar-Shira et al. (2006).

To obtain the third elasticity concept, recall that the quotas may change when prices change. Simulation of Eq. (14) with 5% price changes yields “elasticity” of quota with respect to price of -0.27. The third concept is accordingly the “unconstrained market elasticity,” reached by simulation of Eq. (13) with price changes of 5%, this time allowing quotas to change. The computed elasticity is now -0.50.

Quantitative controls for irrigation water are employed in many countries. The above findings imply that, at least for conditions in Israel, assertive price policy may greatly enhance the effectiveness of direct control instruments.

B. *Exogenous Changes*

In this subsection, we investigate the impact of exogenous shocks on the separating equilibrium, quantifying the comparative statics effects. Table 4 reports the results, expressed in terms of elasticities. The first two rows show variations associated with the first stage, i.e., the price formation and the allocation of users between the two interest groups, indicated by the probability $\Pr(\nu \le p^*)$. The price change was calculated using Eq. (12’), wherein W_{jt} equals the regional sum of village-level expected value of consumption, $E(w_{it})$, as computed by Eq. (13), and $N_{jt}^{l} = N_j \Pr_{jt}(\nu \le p^*)$, where N_j is the number of villages in region *j* and $\Pr_{jt}(\nu \le p^*)$

is the region's average probability of $D\left(p_{it}^{*}, \mathbf{z}_{it}\right) + \alpha_{it} \le q_{it}$; the latter was calculated by a variant of Eq. (10) that includes the terms corresponding to this condition only. Recalling $\lambda = 0$, the price, $E(w_{it})$ and $\Pr_{jt}\left(\nu \le p^{*}\right)$ were all calculated while holding the quotas at their observed levels. The equilibrium values' responses shown in the last four rows of Table 4 incorporate the second-stage effect; they were computed by introducing the exogenous change as well as the updated price from the first stage into Eqs. (13) and (14), while allowing the quotas to change according to the estimated function $Q\left(p_{it}^{*}, \mathbf{x}_{it}\right)$.

From the theory (subsection II.C), we already know that a rise in the terms of trade and the technology level would lead to a price reduction, increased quotas, and deadweight losses. The simulation results (first column of Table 4) demonstrate that these effects are sizeable. In particular, note that the water price elasticity with respect to the terms of trade is -2.73. In the five decades 1952-2002, crops' terms of trade in Israel declined by more than 50%, while the water price tripled (Kislev and Vaksin 2003). Political scientists (e.g., Menahem 1998) tend to attribute those changes to erosion in the farmers' lobbying or a shift in society's and politicians' attitudes toward agriculture. The above political-economic model with steady political organization (θ) and government attitudes (β), provides an alternative explanation for the water-price hike; namely, an exogenous decline in the terms of trade.

The effect of a change in the historical quotas, as indicated by the elasticities in Table 4, is opposite in sign and an order of magnitude smaller than the effect of the terms of trade.

The equilibrium values' elasticities in Table 4, with respect both to β and θ, are less than 1, yet significant and tend to be similar in their magnitudes. While lower communication costs in the future may lead to increased transparency of governmental policies and higher politicians' ethical norms (lower β), they may also strengthen farmers' organization and lobbying (larger θ). The simulations results suggest that such changes may offset each other, thereby perpetuating overutilization of water resources.

C. Political Equilibria

If, as in agriculture in Israel, both prices and quotas are effective, the sector can be characterized as being, in our terms, in a separating political equilibrium. If prices are low and the quantity demanded exceeds the quota in every water-consuming unit, a pooling quota equilibrium emerges; a pooling price equilibrium appears where prices are set high and the quotas also high enough. In this subsection, we simulate the two pooling equlibria and compare them to the observed separating equilibrium. Before proceeding with the simulation, it will be useful to review the implications of the theory concerning the normative ranking of the three equilibria.

Finkelshtain and Kislev (1997) examined the relative efficiency of pooling price and pooling quota equilibrium in a regulated sector with homogeneous users. It was shown that if the demand elasticity is higher than the share of the resource utilized by the politically organized users, pooling price equilibrium dominates quotas equilibrium. Considering the estimated parameters in our study (demand elasticity -0.87, lobbying participation rate 0.23), one would accept the supremacy of the price regime.

However, this need not always be the case. In principle, where delivery costs vary between water users, the individually tailored quotas could potentially perform better than a uniform price regime that does not account for cost differences. In such a case, a two-pronged instrument may be superior. The conclusion drawn from this discussion is that normative ranking of the various equilibria is an empirical question.

Turing to the simulations, water consumption and quotas for the pooling quota equilibrium were simulated for each village separately, by Equations (13) and (14), setting $p_{it} = 0$ for all *i* and *t*. For the pooling price equilibrium, we used Eq. (6'), and it becomes:

$$p^*_{it} = \frac{\overline{c}_{jt} - \beta\theta\overline{\omega}_{jt}}{1 - \beta\theta} \tag{15}$$

where $\overline{c}_{jt}$ and $\overline{\omega}_{jt}$ are the regional average costs and the estimated intercept of the linear VMP function respectively. Village-level water consumption for the pooling-price equilibrium was simulated by Eq. (13) using the regional prices calculated in (15). Village magnitudes were then averaged.

As indicated earlier, the political equilibrium is not welfare maximizing. Deadweight losses for the equilibrium values were calculated by

$$\Delta W_{it} = \tfrac{1}{2}\left(c_{it} - \pi^{*}_{wit}\right)^{2} / \psi \tag{16}$$

and averaged over the sample.

The results are reported in Table 5 in terms of expected per-village values, averaged over the sample. For the circumstances in Israel and for the period of the study, the pooling price equilibrium was dominant in terms of welfare (recall that prices were set regionally). The average price under the pooling-price regime is, as shown in Table 5, twice the observed average, and closer to the marginal cost, thereby yielding higher welfare. The VMP under the pooling-quotas equilibrium is lower than the observed value, implying that pooling-quotas equilibrium is inferior to the other possibilities. Thus, despite the cost and technological heterogeneity that may lead to superiority of quotas or of an integrated regime, pooling price equilibrium dominates. The principal factor leading to this result is free-riding in lobbying. The uniform price regime in each region allows, or even encourages, considerable free-riding in farmers' organization relative to the individual quota regimes, and therefore yields a welfare-superior equilibrium. To show this, we simulate the pooling price regime in the extreme case of perfect lobbying, $\theta = 1$. As can be seen in the last column of Table 5, the normative ranking is reversed in this case, and both the separating and pooling quota equlibria are better.[3] One can only speculate that a nationwide uniform price could lead to even less effective lobbying and higher welfare.

V. Concluding Comment

Realizing that political involvement tends to distort resource allocation and reduce social welfare, several years ago the Knesset (Israeli parliament) established an independent Water Authority with the power to determine water allotments and

[3] We have also tried to simulate a separating equilibrium with $\theta = 1$ but could not find positive prices associated with this equilibrium. The implication is that for the circumstance of the study, if all farmers were to participate in the lobbying activity for lower price, the regulation regime would have become a pooling quota equilibrium with water utilization determined solely by quantitative allocation.

prices. The law specifically and explicitly prevented the minister (Cabinet member) responsible for the water sector from involvement in the areas of responsibility assigned to the Water Authority.

While the intent was laudable, the legislators could not adhere to the law they themselves approved and could not resist the temptation to influence prices. During 2009, when the Authority was deliberating a new price structure, its Director-General was summoned six times to parliamentary committees and was even threatened with the law being amended unless prices were structured consistently with political desires, reflecting public outcry and goals of interest groups. Indeed, as of this writing (July 2011), the Knesset is considering a proposal to reverse the law: ‘‘The power to regulate prices must be restored to the members of the parliament, the reality being that the bureaucracy has been raising prices at will …” This time, the prices to be set are for urban water, however the same attitude can be expected to emerge when agricultural tariffs and allocations are considered. It appears impossible to “sanitize” the political process from involvement — even in the details — of administrative functions.

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Appendix A – Comparative Statics

The recursive decision-making process implies that the comparative statics exercises should be executed in two stages. The effect of an exogenous change on the price is analyzed in the first stage. In the second stage, the transformation in the quotas due to the direct effect of the exogenous change and the indirect effect (through the price) are examined.

A. The Price

Recalling Eq. (6), for any exogenous parameter, a, $\frac{dp^*}{da} = -\frac{G_{pa}}{G_{pp}}$ and since $G_{pp} < 0$, it follows that $\operatorname{sgn}\left(dp^*/da\right) = \operatorname{sgn}\left(G_{pa}\right)$. The results regarding β, θ, and c are shown first:

$$G_{p\beta} = -\theta\left[W\left(p, f\left(\nu\right)\right) - \int_{\nu^l}^{\nu^h}\left(\pi_w\left(p,\nu\right) - p\right)w_p f\left(\nu\right)d\nu\right] < 0, \tag{A1}$$

$$G_{p\theta} = -\beta\left[W\left(p, f\left(\nu\right)\right) - \int_{\nu^l}^{\nu^h}\left(\pi_w\left(p,\nu\right) - p\right)w_p f\left(\nu\right)d\nu\right] < 0, \tag{A2}$$

$$G_{pc} = -c\int_{\nu^l}^{\nu^h} w_p f\left(\nu\right)d\nu > 0 \tag{A3}$$

We shell now examine the impact of a technological improvement or an increase in the terms of trade. We model such changes by a shift in the distribution of (γ, q^0), such that the ex-post conditional distribution of γ, conditioned on any q^0, FSD the ex-ante one. For the comparative statics exercises, we examine the effect of small changes in the distribution. An increase in a parameter, a, represents FSD shift of the conditional distribution of γ, conditioned on q^0, if and only if:

$$\int_{\gamma^l}^{\gamma} Z_a(x, a \mid q^0)dx \le 0 \quad \forall \gamma \in (\gamma^l, \gamma^h),\ q^0$$

Define $\gamma^p(q^0,p)$ by $\pi_w(q^0,\gamma^p)=p$. That is, for any price and quota level, $\gamma^p(q^0,p)$ is the level of technology for which the VMP of water equals its price. Using this notation, water consumption can be rewritten in terms of γ:

$$w(q^0,p,\gamma)=\begin{cases} D(p,\gamma) & \gamma\in[\gamma^l,\gamma^p] \\ q^0 & \gamma\in(\gamma^p,\gamma^h] \end{cases}$$

We can now rewrite Eq. (6) in terms of the quota distribution and the conditional distribution of γ, given q^0:

$$\int_{q^l}^{q^h}\left[\int_{\gamma^l}^{\gamma^h}\left(\pi_w(p,\gamma)-c\right)w_p Z\left(\gamma,a\,|\,q^0\right)d\gamma\right]k(q^0)dq^0$$
$$=\beta\theta\int_{q^l}^{q^h}\left[\int_{\gamma^l}^{\gamma^h}\left(w(p,q^0,\gamma)-\left(\pi_w(p,\gamma)-p\right)w_p\right)Z\left(\gamma,a\,|\,q^0\right)d\gamma\right]k(q^0)dq^0$$

Examining the effect on p:

$$\begin{aligned} G_{pa}=&\int_{q^l}^{q^h}\left[\int_{\gamma^l}^{\gamma^h}\left(\pi_w(p,\gamma)-c\right)w_p Z_a\left(\gamma,a\,|\,q^0\right)d\gamma\right]k(q^0)dq^0 \\ &-\beta\theta\int_{q^l}^{q^h}\left[\int_{\gamma^l}^{\gamma^h}\left(w(p,\gamma)-\left(\pi_w(p,\gamma)-p\right)w_p\right)Z_a\left(\gamma,a\,|\,q^0\right)d\gamma\right]k(q^0)dq^0 \end{aligned} \tag{A4}$$

Assuming that $w_{p\gamma}=0$, all three: $\left(\pi_w(p,\gamma)-c\right)w_p$, $\left(\pi_w(p,\gamma)-p\right)w_p$ and $-w\left(p,\gamma\right)$ are decreasing functions of γ and hence their expected value is decreasing in a (Hadar and Russel (1969)). Therefore, $G_{pa}<0$, proving that the price decreases with FSD shift in $Z\left(\gamma,a\,|\,q^0\right)$. An increase in the historical quotas is modeled by a shift in the distribution of (γ,q^0), such that the ex-post conditional distribution of q^0, conditioned on any γ, FSD the ex-ante one. Following the same line of proof as of the technological improvement, it can be shown that $G_{pa}>0$, proving that the price increases with FSD shift in $k\left(q^0,a\,|\,\gamma\right)$.

B. The Quotas Allocation

Recalling Eq. (4), for any exogenous parameter, a, $\frac{dq^*}{da} = -\frac{G_{qa}}{G_{qq}}$ and since $G_{qq} = \pi_{ww}\left(q^*\left(\nu\right), \nu\right) < 0$, it follows that $\operatorname{sgn}\left(dq^*/da\right) = \operatorname{sgn}\left(G_{qa}\right)$. Employing Eq. (4) it can easily verified that $G_{q\theta} = 0$, $G_{qc} = -\frac{\beta p^*}{1+\beta} < 0$ and $G_{q\beta} = -\frac{p-c}{(1+\beta)^2} > 0$. Moreover, the changes in the initial quota distributions and technological level have no direct effects on the quota allocation rule.

Appendix B - Likelihood Function

Let $\varphi = \alpha + \varepsilon$ and let $g_{\varphi\alpha}(\varphi, \alpha)$ denote the joint density of φ and ε, where the density $g_{\varphi\alpha}$ is bivariate normal with parameters $\sigma_\varphi^2 = \sigma_\alpha^2 + \sigma_\varepsilon^2$, σ_α^2, and $\rho = \frac{Cov(\alpha, \alpha+\varepsilon)}{\sigma_\varphi \sigma_\alpha} = \frac{\sigma_\alpha^2}{\sqrt{(\sigma_\alpha^2 + \sigma_\varepsilon^2)\sigma_\alpha^2}} = \frac{\sigma_\alpha}{\sigma_\varphi}$. In the same manner, $g_{\varphi\alpha u}$ and $g_{\alpha\varepsilon u}$ are the joint densities of φ, α, and u; and α, ε, and u respectively. The distribution of α conditional on φ implies $g_{\varphi\alpha}(\varphi, \alpha) = g_{\alpha|\varphi}(\alpha|\varphi) g_\varphi(\varphi)$, and due to the independence of α, ε, and u there are $g_{\varphi\alpha u} = g_{\alpha|\varphi} g_\varphi g_u$ and $g_{\alpha\varepsilon u} = g_\alpha g_\varepsilon g_u$. Omitting nonessential indices and functions' operators, the probability of observing a certain pair of w and q_t can be expressed in terms of g:

$$
\begin{aligned}
&L\left(w, q_t, \boldsymbol{\theta}\right) = \\
&g_\phi\left(w-D\right) g_u\left(q_t - q_{t-1}\right) \int_{-\infty}^{\min\left(\hat{\alpha}^t, \hat{\alpha}^{t-1}\right)} g_{\alpha|\phi}\left(\alpha\right) d\alpha + g_\phi\left(w-D\right) g_u\left(q_t - Q\right) \int_{\hat{\alpha}^{t-1}}^{\hat{\alpha}^t} g_{\alpha|\phi}\left(\alpha\right) d\alpha \; + \\
&g_\varepsilon\left(w-q_t\right) g_u\left(q_t - q_{t-1}\right) \int_{\hat{\alpha}^t}^{\hat{\alpha}^{t-1}} g_\alpha\left(\alpha\right) d\alpha \; + \; g_\varepsilon\left(w-q_t\right) g_u\left(q_t - Q\right) \int_{\max\left(\hat{\alpha}^t, \hat{\alpha}^{t-1}\right)}^{\infty} g_\alpha\left(\alpha\right) d\alpha
\end{aligned}
$$

where $\hat{\alpha}^t = q_t - D$ and $\hat{\alpha}^{t-1} = q_{t-1} - D$. The distribution $g_{\varphi\alpha}$ is bivariate normal, hence $g_{\alpha|\varphi}(\alpha|\varphi)$ is distributed $N\left(\rho^2\varphi, \sigma_\alpha^2\left(1-\rho^2\right)\right)$. Using ϕ and Φ to denote the density and the cumulative distribution functions of a standard normal random variable respectively, the probability function can be written:

$$L\left(w, q_t, \boldsymbol{\theta}\right) =$$

$$\frac{1}{\sigma_\phi}\phi(h)\frac{1}{\sigma_u}\phi(o)\Phi\left(\min\left(r^t, r^{t-1}\right)\right) + \frac{1}{\sigma_\phi}\phi(h)\frac{1}{\sigma_u}\phi(y)\left|\Phi\left(r^t\right) - \Phi\left(r^{t-1}\right)\right| +$$

$$\frac{1}{\sigma_\varepsilon}\phi(s)\frac{1}{\sigma_u}\phi(o)\left|\Phi\left(k^{t-1}\right) - \Phi\left(k^t\right)\right| + \frac{1}{\sigma_\varepsilon}\phi(s)\frac{1}{\sigma_u}\phi(y)\left[1 - \Phi\left(\max\left(k^t, k^{t-1}\right)\right)\right]$$

where $o = \dfrac{q_t - q_{t-1}}{\sigma_u}$, $h = \dfrac{w - D}{\sigma_\varphi}$, $r^t = \dfrac{\hat{\alpha}^t - \rho^2\left(w - D\right)}{\sigma_\alpha\sqrt{1-\rho^2}}$, $r^{t-1} = \dfrac{\hat{\alpha}^{t-1} - \rho^2\left(w - D\right)}{\sigma_\alpha\sqrt{1-\rho^2}}$,

$y = \dfrac{q_t - Q}{\sigma_u}$, $s = \dfrac{w - q_t}{\sigma_\varepsilon}$, $k^t = \dfrac{\hat{\alpha}^t}{\sigma_\alpha}$, and $k^{t-1} = \dfrac{\hat{\alpha}^{t-1}}{\sigma_\alpha}$.

Table 1 – Comparative statics of separating equilibrium

Parameter	**Impact on** p^*	**Impact on** $q^*(\nu)$
β	-	+
θ	-	+
c	+	-
$z(\gamma)$ [a]	-	+
$k^0(q^0)$ [a]	+	-

a. Analyzed based on a linear water's VMP function

Table 2 – Description of variables

Variable	**Spatial unit**	**Units**	**Mean / Frequency**	**Std. Dev.**
Freshwater use[a]	Village	[10^3 m^3 $year^{-1}$]	958	472
Freshwater quota[a]	Village	[10^3 m^3 $year^{-1}$]	1,028	408
Freshwater price[a,b]	Region	[$ $(m^3)^{-1}$]	0.11	0.02
Energy delivery costs[c,b]	Village	[$ $(m^3)^{-1}$]	0.23	0.10
Capital & operation costs[c,b]	Village	[$ $(m^3)^{-1}$]	0.14	0.08
October rainfall[d]	Village	[mm $month^{-1}$]	35.9	26.2
April rainfall[d]	Village	[mm $month^{-1}$]	22.3	22.5
Annual rainfall[d]	Village	[mm $year^{-1}$]	526	183
Elevation above sea level[a]	Village	[m]	183	223
Agricultural land[a]	Village	[10^3 m^2]	2,745	2,201
Orchards, area[a]	Village	[10^3 m^2]	738	578
Light soil[d]	Village	Dummy	2%	-
Medium-light soil[e]	Village	Dummy	44%	-
Heavy-medium soil[e]	Village	Dummy	6%	-
Heavy soil[e]	Village	Dummy	48%	-
North[a]	Village	Dummy	37%	-
Center[a]	Village	Dummy	43%	-
South[a]	Village	Dummy	20%	-
Cooperative (*moshavim*)[a]	Village	Dummy	78%	-
Communal (*kibbutzim*)[a]	Village	Dummy	22%	-
Natural enrichment[f]	Nationwide	[10^6 m^3 $year^{-1}$]	1,280	313
Terms of trade[g]	Nationwide	Index (1952=100)	65.2	1.30

a. Obtained from the Agriculture and Rural Development Ministry

b. Monetary terms are in 1987 US dollars

c. Calculated using data obtained from engineer Gabriel Shaham [personal communication]

d. Obtained from the Israeli Meteorological Service

e. Based on Ravikovitch (1992)

f. Enrichment of natural storages in the previous year as calculated by the Israeli Water Commission

g. From the dataset of Kislev and Vaksin (2003)

Table 3a – Demand and quota allocation functions

Observations	1,051	
Wald $\chi^2(14)$	159.6	
σ_α	383**	
σ_ε	241**	
σ_{you}	144**	
	<u>Demand (*D*)</u>	<u>Quota (*Q*)</u>
Price	-7,619** (δ_1)	-3,686** (δ_2)
Energy costs	-	-311.8**
Capital & operation costs	-	321.0**
Natural enrichment	-	0.117**
q_{t-1}	-	0.757**
Elevation	-0.858**	-
October rainfall	-0.994	-
April rainfall	1.761	-3.098**
Annual rainfall	0.273	-0.004
Agricultural land	0.049**	0.013**
Orchard area	0.352**	0.078**
Light soil	-75.39	128.7**
Medium-light soil	94.08	-29.33**
Heavy-medium soil	2,645	139.6**
Terms of trade	72.48*	29.55**
Center	-6.96	57.66**
South	258.6*	30.35
Cooperative	-164.27*	-4.41
Constant	-2,849	-1,452**
$\frac{\beta}{1+\beta}=\delta_2/\delta_1$ [a]	0.48** (95% Conf.: 0.06 to 0.91)	

* = significant at 10%; ** = significant at 5%

a. Calculated using the delta method for computing standard deviations (Green 2003)

Table 3b – Price formation equation

Observations	**1,039**
Wald $\chi^2(4)$	202.4
W/N^l (instrumented)[a]	-2.81×10^{-5}** (δ_3)
Energy costs	7.64×10^{-2}**
Capital & operational costs	-0.19**
Natural enrichment	-1.21×10^{-5}**
Constant	0.193**
$\theta = \delta_3\delta_1\left(\delta_1 - \delta_2\right)/\delta_2$ [b]	0.23 (95% Conf.: -0.30 to 0.75)

* = significant at 10%’ ** = significant at 5%

a. Instruments include rainfall during October and April, elevation, and dummies for years and location in the central and southern areas of the country

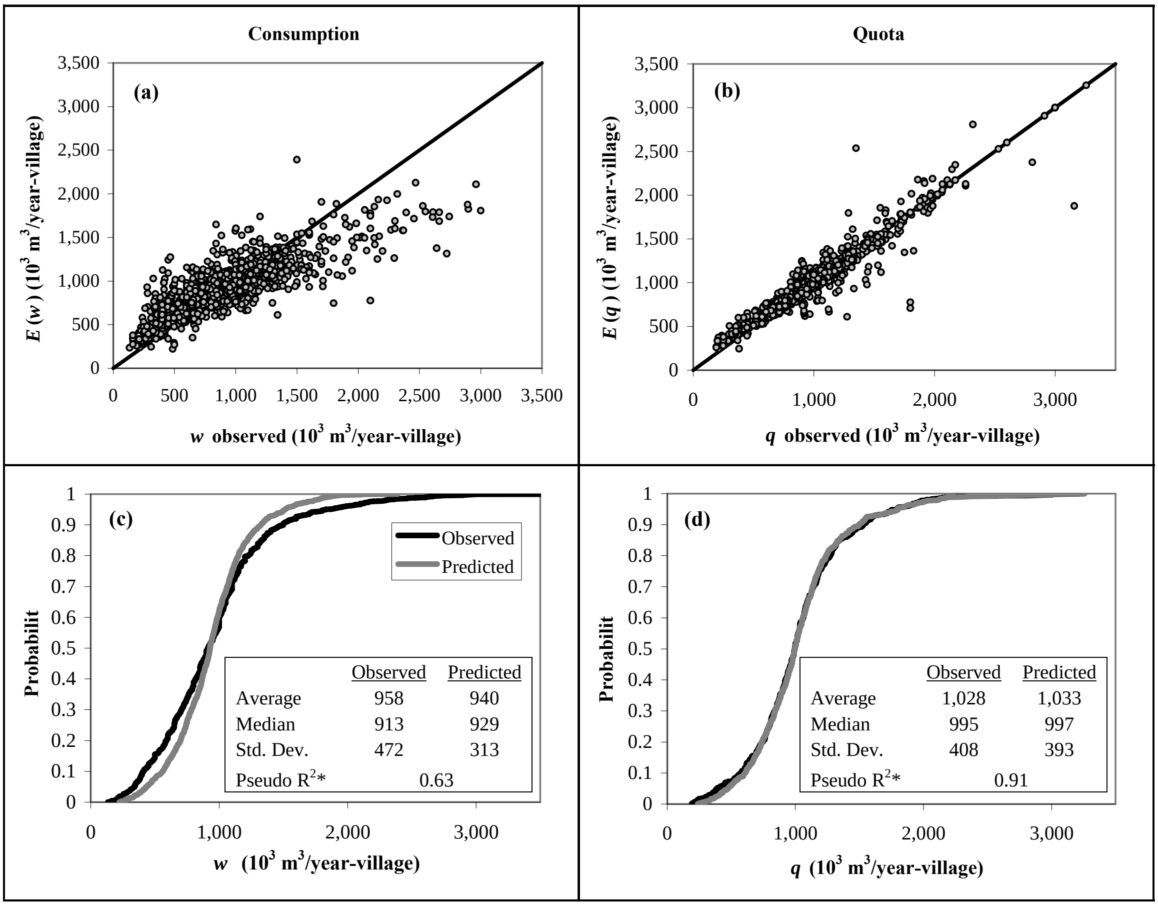
b. Calculated using the delta method for computing standard deviations

Table 4 – Impact of exogenous changes (Elasticities)

	Stage	Terms of Trade	Rainfall	β	θ	Energy Costs	q_{t-1}
p^*	I	-2.73	-0.05	-0.77	-0.69	2.89	0.28
$\Pr(\nu \leq p^*)$	I	-10.43	-0.25	-0.83	-0.72	4.09	0.88
$E(q)$	II	0.77	0.25	0.12	0.33	-0.58	-0.07
$E(w)$	II	3.47	0.30	0.22	0.44	-1.88	-0.09
E(Deadweight Loss)	II	1.74	0.59	1.06	1.25	-0.10	-0.30

Table 5 – Simulated control regimes (per-village average)

	Separating (observed)	**Pooling quota**	**Pooling price**	**Pooling price ($\theta = 1$)**
Average cost (\$ / m^3)	0.37	0.37	0.37	0.37
Average price (\$ / m^3)	0.11	-	0.18	0.09
$E(\pi_w(q))$ (\$ / m^3)	0.19	0.13	-	-
$E(w)$ (10^3 m^3 / year-village)	940	1,403	835	1,543
$E(q)$ (10^3 m^3 / year-village)	1,033	1,412	-	-
$E(DWL)$ (10^3 \$ / year-village)	60	94	5	115



* Pseudo R^2 refers here to the square of the correlation between predicted and observed values.

Figure 1 – Predicted versus observed distributions of water consumption ((a) and (c)) and quota ((b) and (d))