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How do markets manage water resources? An experiment on resource market (de)centralization with endogenous quality

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Abstract

We test how a monopoly, a duopoly and a public monopoly manage and allocate water resources. Stock depletion for the public monopoly is fastest. However, it reaches the optimal stock level towards the end of the experimental sessions. The private monopoly and duopoly maintain inefficiently high levels of stock throughout the sessions. The average quality to price ratio offered by the public monopoly is substantially higher than that offered by the private monopoly or duopoly. A clear result from the experiments is that a public monopoly offers the highest (average) quality to price ratio and has the fastest rate of stock depletion compared to a private monopoly or duopoly.

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1. Introduction

The importance of efficient water allocation is being increasingly realised all over the world. Increasing demand on water resources has been one of the main reasons why water shortage is becoming an important issue. For example, recently, The Economist drew attention towards the impending water crisis in China[2]. It is being increasingly argued that one of the main reasons behind the mismanagement of water resources is the non-existence of economic criteria in water allocation. Till now, water has been allocated by government agencies motivated mostly through non-economic criteria. Agencies such as the World Bank increasingly argue that efficient allocation of water is only possible through market based mechanisms and state examples of functioning water markets in several developing and developed nations.

The problem is difficult given that historically water has been treated as a "social" rather than an economic good. It is well accepted by policy makers that allocating water within the existing systems is inefficient. A need for a market based mechanism to allocate water efficiently is widely gaining acceptance. In its 1993 policy paper (Water Resources Management) the World Bank states that the deterioration and scarcity of fresh water in recent times is due to the "failure to properly consider the economic value of water. Given that water *is given* little or no economic value it is misallocated and misused." The argument behind this is simple, i.e. understanding the economic value of water leads to its efficient use.

Water is a growing industry worldwide. Recent estimates put the world water market at $300 billion, with the United States accounting for more than half that amount. Two of the fastest growing markets are in water rights and municipal water supply systems. One should note that the development of water markets leads to a better definition of property rights. This by itself eliminates many of the problems related with inefficient allocation of water. The enforcement of property rights becomes difficult if incentives are not properly defined.

Proper definition of property rights and the introduction of markets can alone not solve the problem. Another important issue is the overexploitation of groundwater. For example, it has been shown that *competitive* water withdrawal can lead to

[2] The crisis has been a result of water shortage combined with bad management, pollution and pricing of water below cost.

overexploitation (Moench, 1992). Over exploitation is a serious problem in the case of allowing open access to water. Penalties for over exploitation may be one answer. Another answer may be varying the price of water as aquifer levels reach critical levels. The price would then reflect the "real" value of water based on future scarcity[3]. Such real time pricing schemes are difficult to implement due to political reasons.

Gordon (1954) showed that complete rent dissipation may occur from the exploitation of an open access resource. A single owner, internalizes exploitation externalities, and would be more efficient. The general result obtained in the literature is that there is an inverse relationship between the number of resource extractors and rent accrual. Mason and Philips (1997), for example, provide experimental evidence on the relationship between group size and the standing stock of a common resource.

Experiments have been used by Walker et al. (1990), Walker and Gardner (1992), Gardner et al. (1997) to study common pool resource problems. Walker et al. (1990) and Walker and Gardner (1992) both use experiments to study non-cooperative game common pool resources. Walker et al. (1990) conclude that a high degree of rent dissipation occurred with access limited to eight users. In Walker and Gardner (1992) they show that the common pool resource is destroyed in all cases where no institutions exist to foster cooperative behaviour. Gardner et al. (1997) study strategic behaviour in groundwater depletion within the setting of state governance of groundwater resources in West U.S. They experimentally study the performance of various groundwater property rights and the applicability of game theory in such systems. Limiting entry en such environments improves efficiency.

In a recent study, Murphy et al. (2000) use laboratory experiments to design "smart" computer assisted markets for water. The ‘smart’ computer assisted market institution was developed by McCabe et al. (1989, 1991). A ‘smart’ market allows decentralized agents to submit messages to a computer dispatch centre. The centre then computes prices and allocations by applying an optimization algorithm that maximizes the possible gains from exchange. Using California as a case study, Murphy et. al. (2000) test alternative institutional arrangements for a computer assisted spot market. In a thin market characterized by a limited set of trading opportunities, they show that the

[3] Such a policy would imply that the price of water goes up in times of water scarcity.

`smart' uniform price double auction yield highly efficient outcomes. Co-tenancy seemed to improve efficiency over a monopoly in transportation.

The studies mentioned above clearly show that experiments can be a useful test bed to study alternative property right mechanisms (Walker et al., 1990; Walker and Gardner, 1992), or undertake a direct test of an existing market mechanism (Murphy et al., 2000). Experiments can replicate important characteristics of existing markets and test them in a laboratory setting at a minimal cost to the regulator.

There is another aspect to water markets that has been given little attention. This has to do with the *quality* of water that each consumer, farm and household, receives. The quality of water for household use is regulated by quality standards. Quality standards for farm use are much weaker. Any firm supplying water to two different users that differ in their minimum acceptable qualities has an additional dimension to deal with. That is, what is the optimal mix of qualities that the firm should supply to its users?.

In this paper we define a water market that includes standard features such as common pool resource management, depuration costs and water quality. In our experimental market the firm has to also decide the quality that it should supply to households and to farmers. The quality of household water cannot be below a certain minimum standard while the quality of farm water has no such restriction. Our results indicate that a social monopolist offers the highest quality to price ratio and exploits the resource at a faster rate than a private monopoly or duopoly. The most stable stocks correspond to a private monopoly and duopoly. Though, their stock levels are inefficiently high. The average quality to price ratio offered by the public monopolist is the highest.

The paper is structured as follows. In Section 2 we discuss the model. In Section 3 we discuss our experimental design. Section 4 discusses the experimental results. Section 5 concludes.

2. The model

There are two renewable stocks S_H (high quality) and S_L (low quality) from which water may be extracted. For the sake of simplicity, we assume that the recharge to the respective basin is deterministic and constant. The inflow to the respective basins is assumed to cease when the storage capacity of the aquifer is reached. That is, once the maximum storable stock is reached, extra water inflow is lost. The return flow of consumed water is assumed to be negligible. Thus, changes in the stocks are exclusively due to extraction and recharge. Extraction costs are supposed to be twice differentiable functions of quantity and stock size. First derivatives are assumed to be, respectively, positive and negative, whereas second derivatives are positive.

We allow for the possibility that the water resources differ in qualities. Quality of water in an aquifer may be lower due to marine intrusion, or due to infiltration of fertilizer from agriculture. Let the qualities be denoted respectively by Q_H and Q_L, where $Q_H > Q_L > 0$. The qualities are assumed to be constant over time. However, any intermediate quality may be supplied to the consumers as a result of mixing water from the two sources. Mixing quantities K_H and K_L of the two qualities results in water whose quality is given by the weighted average:

$$Q_M(K_H, K_L, Q_H, Q_L) = \frac{K_H Q_H + K_L Q_L}{K_H + K_L} \tag{1}$$

Quality of potable water should weakly exceed the constant minimum quality standard Q_{min}, where $Q_H > Q_{min} > Q_L$. Mixed water of quality Q_M may, or may not, satisfy the minimum quality standard. This depends on the quantities and the qualities which are mixed. Quality may be improved at a cost. This cost is an increasing function of the difference between the quality before and after purification. Moreover, a given improvement ΔQ of a lower quality is less costly than the same improvement performed on a higher quality. Let the initial quality subject to purification be Q_0. The purification cost, denoted by $C_{\Delta Q}(K, \Delta Q, Q_0)$, for a certain water quality Q_0 and quantity $K=K_H+K_L$ requiring a quality improvement ΔQ, is assumed to satisfy the following conditions:

$$\frac{\partial C_{\Delta Q}}{\partial K} > 0, \frac{\partial^2 C_{\Delta Q}}{\partial K^2} > 0, \frac{\partial C_{\Delta Q}}{\partial \Delta Q} > 0, \frac{\partial^2 C_{\Delta Q}}{\partial (\Delta Q)^2} > 0, \left.\frac{\partial C_{\Delta Q}}{\partial Q_0}\right|_{\Delta Q} > 0, \left.\frac{\partial^2 C_{\Delta Q}}{\partial Q_0^2}\right|_{\Delta Q} > 0 \tag{2}$$

Resource flow between the sources and the consumers is coordinated by a centralized knot, which centralizes the decisions about quantity and quality supplied to the consumers. Figure 1 shows the distribution scheme described above.

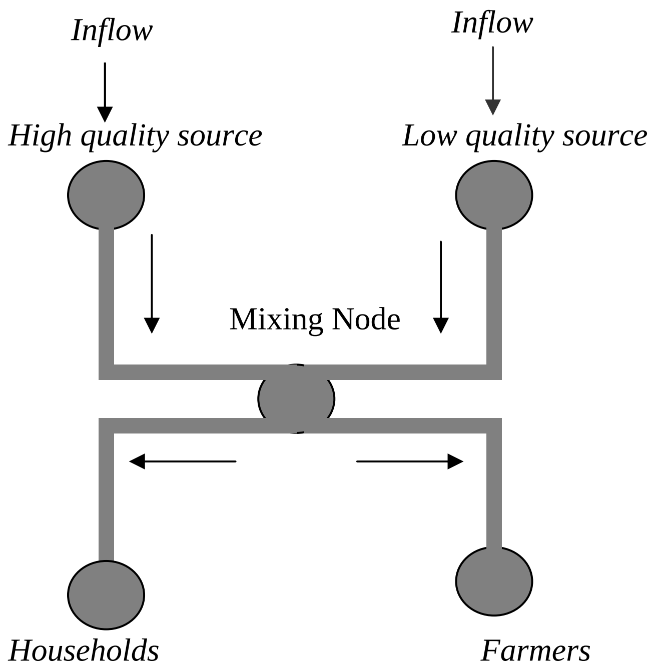

Figure 1. The hydrological network

Suppose that the behaviour of the consumers can be aggregated under one of two types: i) households (*h*) and ii) farmers (*F*). Consumers differ in their respective preferences regarding the quality of water. Both types prefer a higher quality of the water to a lower one. Farmers prefer more quantity of each product to less. Households consume water whose quality weakly exceeds a minimum standard. If mixed quality does not satisfy this condition, it will be subject to purification. The purification procedure is assumed to be costly enough such that it is not profitable to improve quality above the minimum standard. Hence, the quality consumed by households is the maximum between the minimum, and the mixed, quality. Thus, $Q_0 = Q_M$ and

$$\Delta Q = \begin{cases} Q_{\min} - Q_M \, , if \;\; Q_{\min} > Q_M \\ 0 \qquad\qquad\quad , if \;\; Q_{\min} \leq Q_M \end{cases}$$

Let the households take the purification cost into account in their utility function. Further, assume utility functions for the respective consumer-types, $U_h=U_h(K_h,Q_{Mh})$ and $U_F=U_F(K_F,Q_{MF})$ (where $K_h=K_{Hh}+K_{Lh}$, and $K_F=K_{HF}+K_{LF}$), to be twice differentiable with respect to the quantity and the mixed quality. A farmers' utility is increasing in both arguments. While depending on the purification cost function, the utility function of households might be increasing in the quantity of low quality only up to a certain limit[4]. From twice differentiability of the utility functions it follows that the sum of the functions is twice differentiable, too. The indirect social welfare function $V(K_H,K_L)$, which maximizes consumer surplus for a given quantity of water, can be obtained as a solution to the following problem:

$$
\begin{aligned}
& V(K_H, K_L) = \max_{K_{Hhh}, K_{Lhh}} U_h(K_{Hh}, K_{Lh}, Q_{Mh}; K_H, K_L) + U_F(K_{HF}, K_{LF}, Q_{MF}; K_H, K_L) \\
& s.t. \\
& (i)\ K_H = K_{Hh} + K_{HF} \\
& (ii)\ K_L = K_{Lh} + K_{LF} \\
& (iii)\ Q_{Mh} = \frac{Q_H K_{Hh} + Q_L K_{Lh}}{K_{Hh} + K_{Lh}} \\
& (iv)\ Q_{MF} = \frac{Q_H K_{HF} + Q_L K_{LF}}{K_{HF} + K_{LF}}
\end{aligned}
\tag{3}
$$

As a benchmark for our experimental results, we are interested in the socially optimal solution of water supply. Given the assumptions above, we formulate the program that maximizes social welfare.[5] Without loss of generality, suppose that initially the resource stocks are in the natural hydrological equilibrium, i.e. at the upper bound of the storage capacity. Let (a_H, a_L) denote recharges of the two water qualities of water, and t_0 the starting time of extraction. Assume that the social rate of discount is $\delta=1$. Thus, the intertemporal objective function is formulated as follows:

$$
\begin{aligned}
& \max_{K_{Ht}, K_{Lt}} \int_{t_0}^{\infty} e^{-\delta t} \left[V(K_{Ht}, K_{Lt}) - C_{Ht}(K_{Ht}, S_{Ht}) K_{Ht} - C_{Lt}(K_{Lt}, S_{Lt}) K_{Lt} \right] dt \\
& s.t. \\
& (i)\ \frac{dS_{Ht}}{dt} = \begin{cases} -K_{Ht} + a_H, \text{ if } S_H < S_H^{max} \\ S_H^{max}, \quad otherwise \end{cases} \\
& (ii)\ \frac{dS_{Lt}}{dt} = \begin{cases} -K_{Lt} + a_L, \text{ if } S_L < S_L^{max} \\ S_L^{max}, \quad otherwise \end{cases} \\
& (iii)\ S_{Ht_0} = S_H^{max} \\
& (iv)\ S_{Lt_0} = S_L^{max}
\end{aligned}
\tag{4}
$$

[4] In fact, it will be increasing if mixed quality weakly exceeds the minimum quality standard.
[5] This problem is solvable by means of optimal control theory, where the stocks are the states and the quantities the control variables.

By means of the resulting current value Hamiltonian and Pontryagin's maximum principle (assuming an interior solution) the two following conditions have to be satisfied in the hydro-economic equilibrium:

$$\begin{aligned} \left.\frac{\partial V}{\partial K_H}\right|_{K_H=a_H} &= a_H \left.\frac{\partial C_H}{\partial K_H}\right|_{K_H=a_H} + C_H(a_H, S_H) - a_H \frac{\partial C_H(a_H, S_H)}{\partial S_H} \\ \left.\frac{\partial V}{\partial K_L}\right|_{K_L=a_L} &= a_L \left.\frac{\partial C_L}{\partial K_L}\right|_{K_L=a_L} + C_L(a_L, S_L) - a_L \frac{\partial C_L(a_L, S_L)}{\partial S_L} \end{aligned} \tag{5}$$

The conditions in (5) simultaneously determine the steady-state standing-stocks of S_H and S_L. They basically state that, in the long-run, the marginal social utility, which embodies the respective resource price in the economy, should equal the social costs of extraction represented on the right hand side.[6]

3. Experimental design[7]

Our experimental design focuses on studying how different market structures affect water resource management. Upstream firms do not extract from a common resource[8]. We instead focus on situations where property rights to a given groundwater source are exclusively granted to a single decision making unit.

Two water sources supply water of two different qualities. The demand side is represented by two different types of consumers: households and farmers. Water supplied to them may be the result of purification, since households will only consume water whose quality exceeds a minimum level. Our model also highlights the vertical nature of these markets. In these markets coordination is required between water extraction, purification and supply[9].

Our assumptions concerning consumer utility are qualitatively similar to those in Williams et al. (1986) on multiple commodities which are interdependent in consumption. Two features, which are rather specific to the dynamics of water, are added to the structure: first, buyers are restricted to purchase up to a certain amount of

[6] In each condition, the first two terms (both positive) represent the marginal cost which results from extracting a quantity K_H (K_L) from the water stock S_H (S_L). The third term reflects the shadow price of the resource.
[7] Our experimental design is based on a previous paper by Georgantzís et al. (2004).
[8] Competitive extraction is not studied in this paper.
[9] We do not specifically address issues related to vertical integration.

each type of water[10]. Second, a constant inflow (recharge) in each period maintains the stock of water in the basins of each producer. In fact, following a standard formulation of similar groundwater extraction problems, a lower stock implies a higher extraction cost. Thus, each period's marginal cost and past levels of extraction are positively correlated.

All experiments ran for 50 periods. A seller can sell water of high and low quality. Sellers simultaneously post bids for a maximum of 5 units of each water quality. Demand is simulated in all treatments and buyers reveal perfectly. A utility maximizing consumer represents a population of farmers and households with different preferences for the quantity and quality of water. Different qualities are obtained from mixing the two qualities of water sold in the market. If quality falls below a certain "potable" threshold, an extra cost is borne by the consumer (reducing consumer surplus) in order for the water to be depurated up to the threshold level. Unit extraction costs increase in "steps" as the level of stock of each water quality decreases.

We use the model described above with the following values for the parameters:

(i) Recharge: (a_H, a_L)=(3, 3)

(ii) Initial and maximum stock sizes (S_H, S_L)=(20, 20)

(iii) Water qualities: (Q_H, Q_L)=(5, 1)

(iv) Minimum quality standard demanded by the household: $Q_{min} = 3$

The specific utility and cost functions used are provided in appendix C. Applying the above equations, in the steady state of the social optimum a stock size of (S_H, S_L)=(4.84, 5.01) is obtained associated with the prices (p_H, p_L)=(102, 86). However, in order to simplify subjects' perceived feedback conditional on their strategies, our design allows only for discrete quantities and prices. Thus, if subjects adopt the discrete version of this steady-state equilibrium stock policy, they must aim at stabilizing stocks at (S_H, S_L)=(5, 5). Obviously, this is achieved when exactly the 3-unit inflow of each water quality equals the quantity sold in each period. Assuming that this is so, then, maximizing total surplus the quantities, $(K_{Hh}, K_{Lh}) = (2.55, 0)$ and $(K_{HF}, K_{LF}) = (0.45, 3)$, are automatically assigned by the server, respectively, for household (h) and agriculture (F) consumption. To avoid subjects making uncontrolled guesses concerning the end of

[10] Given that their purchases in each period are used to serve their current needs.

the session, a deterministic end game horizon was used (a total of 50 periods), of which subjects were informed at the beginning of the experiment.[11]

Subjects knew the type of water they were managing. That is, they were conscious about a generic preference by consumers for one good (high quality) over the other. Moreover, they knew that their products were demand substitutes (though not perfectly) and that their extraction cost structures were identical. Subjects received a table with their unit costs depending on the stock size (see the instructions in the appendix). A simulator (made available to them) informs them on the hypothetical costs and gains they would make if they sold all the units of each product for which they are currently submitting post bids. They know that the actual number of units they sell will be known only after they have posted their period bids and that the (automated) demand's reaction to these bids is returned to them on the feedback screen.

Three different market structures are compared. We study resource management and water allocation under a private monopoly, a competing duopoly and the social planner. Three simplest markets are chosen given that we do not have a benchmark to start from. As we mention, the existing experimental literature has looked at problems motivated by specific problems.[12] We instead choose an experimental design that studies the effect of market structure upon resource management and water allocation. We do not focus on competitive resource extraction at this stage as several water allocation agencies are the sole suppliers of water to their respective areas. We study the following treatments:

T1 - Private Monopoly: The monopolist has joint ownership of both sources. Consumer behaviour is simulated. They reveal perfectly and accept trades at zero surplus. The monopolist posts price-bids for both water qualities. Given these offers, the maximal consumer rent is determined in the simulated centralized downstream market: $V(K_H,K_L)\text{-}w'\,k$, where w denotes the vector of sealed offers and k denotes the vector of quantities. Thus, the bundle of high quality and low quality water which produces the highest consumer rent is allocated in the economy.

T2 – Private Duopoly: The market is supplied by a non-cooperative duopoly. Each firm offers one type of water and independently decides on price-bids. There is

[11] Given the complex nature of the experiments a sufficiently long time horizon was chosen.
[12] For example, Murphy et al. motivate their research based on water allocation in California.

optimal simulated coordination in the downstream part of the market. Communication between competitors is not permitted. Duopolies are formed randomly at the beginning of the session and then matching remains fixed over the 50 periods of the session ("partners" protocol)[13].

T3 - Public Monopoly: The public monopoly decides on both water qualities. Note, however, that the public monopoly only decides on the price and quality offered, and not the quantity. It is required to meet demand at all stages. Like in all treatments reported here, there is optimal simulated coordination in the downstream part of the market. Subjects act as public monopolists, maximizing total social welfare rather than private profits.

A history window displays all past outcomes regarding own decisions, i.e. quantities, payoffs and market prices. In duopoly markets, each subject also receives the clearing price at which the "other" water quality was sold. In each period, subjects are asked to submit their respective reservation prices (offer bids) for each unit of product (from the 1st unit to the 5th, the maximum quantity each one of them could trade). In the case of the duopoly, rivals had to post, simultaneously, *five* sealed offers of each quality water which should equal the minimum price at which they were willing to sell the respective unit.[14] Subjects were told that offer bids had to exceed weakly the cost of the corresponding unit, and offers of subsequent units would have to be non-decreasing. Once offer bids are submitted, behaviour on the demand side is simulated by a programme automatically calculating the optimal consumption of each water quality and their distribution by consumer type for which total consumer surplus is maximized. After bids were announced, all units of the same product in a period were sold at the same market price (see instructions). This price was the maximum offer bid lying below the lowest willingness to pay on a demand function-like ranking from high to low. All subjects were informed about how the market price is determined.

[13] Two possible extensions can be run in this experimental design, the "strangers" protocol and a "co-ordinated" duopoly. "Strangers" protocol, forming a different subject-pair (duopoly) in each period, would be an interesting extension, the resulting noisy feedback would require allowing for longer experimental sessions. Pilot sessions not reported here indicate the sessions lasting longer than 70 periods are required. In the case of a coordinated duopoly each resource is managed by a different subject, but the interface used is that of the private monopoly with two subjects sitting in front of each one of the PC's. Communication and agreement on the timing of decision submission and the possibility of iterated inspection of the "competitor's" strategy before jointly pressing the "OK" button render this setup highly collusive. However, individual incentives remained uncoordinated and no side payments were feasible.

[14] Producers in treatments 1 and 3 had to post five sealed offers for each one of the two water qualities.

Experimental sessions were run at the *Laboratori d'Economia Experimental (LEE)* of the Universitat Jaume I of Castellón, Spain. Three 20-subject sessions were run for treatments 1 and 3, and five 20-subject (10 duopolies) sessions were run for treatment 2. A number of pilot rounds (not presented here) were run at the beginning of each session. Sessions from different treatments were run in a random order in order for "social learning" to be avoided. Sessions lasted an average of 80 minutes each. In all treatments, the subjects' monetary rewards were proportional to accumulated profits ('social benefits' in T3) along 15 (randomly chosen) over the 50 periods. Average per subject earnings were slightly below 25€, approximately. Duopoly sessions were systematically more expensive, as a higher exchange rate was used (see instructions in appendix B) in order to avoid significant differences in individual subject rewards, inducing the feeling of "unfair" variations of per capita earnings across treatments (apart from the horizontal externality due to competition, each duopolist manages only a part of the market).

4. Results

The steady state equilibrium stock level for our discrete strategy space version of the model implemented here is 5 for both water qualities. Once this level is reached, the optimal extraction rate is dictated by the rate of the inflow. That is, in each period a firm should aim at selling 3 units of each water type (equal to the amount entering into the tank due to the natural rate of inflow). An efficient management is one in which these predictions are fulfilled over the maximum number of periods possible. Given the specificity of our design and focus, we report data on price levels for each water quality and price-weighted average quality sold to the consumers, which cannot be contrasted to any previous finding in the literature.

The descriptive statistics (last 15 periods) in table 1 give us a good idea on how water resources were managed under each market structure. The first result that one sees is that the average stock of water under a private monopoly (T1) and duopoly (T2) is higher than under a social planner (T3). The average stock of the social planner is around 25% lower than under any other market structure. This is true for both high, and low, quality water. A welfare maximizing social planner, not operating under market incentives, tends to over extract the (non-competing) resource. Interestingly the average quality to price ratio is the same for a monopoly and duopoly.

Table 1

	Low Quality Stock			High Quality Stock			Low Quality Price			High Quality Price			Average Quality/Price			Low Quality Quantity			High Quality Quantity		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Avg.	11.4	12.4	9.5	12.7	11.1	9.3	101.9	69.8	51.1	108.8	75.7	67.1	0.04	0.04	0.11	3.0	3.0	3.1	2.9	3.0	3.1
S.D	1.2	1.2	1.7	1.1	1.2	1.9	11.9	5.2	9.1	12.0	8.1	12.3	0.01	0.01	0.05	0.3	0.2	0.3	0.2	0.3	0.3
Av. (20-50)	10.9	11.7	8.7	12.2	10.5	8.3	108.4	72.2	52.0	113.6	80	69.8	0.03	0.04	0.10	2.9	2.9	3.0	2.8	2.9	3.0
S.D. (20-50)	0.3	0.4	0.5	0.4	0.3	0.7	6.5	3.6	8.7	9.5	5.3	12.7	0.00	0.00	0.03	0.1	0.2	0.1	0.2	0.1	0.1

We will now individually analyze stock management, quantity sold and the average quality to price ratio in each treatment. This will then be followed by a brief discussion on the co-ordinated duopoly experiments.

4.1. *Stock Management*

In many countries (Spain being one example) water management is in the hand public monopolies. Studies by the World Bank indicate that inefficient water resources management is one of the problems faced by many countries across the world. Given this, we compare how a public monopoly manages its water resources relative to a (private) monopoly and a duopoly. Figures 2 and 3 compare water resource management across the three market structures for the low and high quality stock. All treatments produce average stocks which lie significantly above the steady state socially optimum level (5 units). Comparing across treatments, one sees that the average stock of both water qualities is the lowest in the public monopoly treatment, which is the only one presenting a sustained decreasing tendency. Note, however, that the steady state socially optimum level is reached by the public monopolist at the end of the experiment. Interestingly, in period 50 both the (private) monopoly and duopoly are substantially above this (around 10) steady state optimum. Figure 2 indicates that the duopoly maintains higher stock levels than the private monopoly for the low quality stock. The contrary is true for the high quality stock. A Wilcoxon test on the data indicates that the stocks maintained by the three market structures are statistically different (see Table 2).

Table 2

Low Quality Stock			High Quality Stock	
	Z	p>|z|	Z	p>|z|
T1 = T2	-6.393	0.00	6.384	0.00
T1 = T3	6.342	0.00	6.359	0.00
T3=T2	-6.384	0.00	-6.307	0.00

It is clearly seen that the private monopoly maintains a higher stock than the duopoly for the high quality water and the opposite is true for low quality water. Stocks maintained by the private monopoly and duopoly are higher than the stocks maintained by the public monopoly.

<Figure 2 here (stock: low quality)>

<Figure 3 here (stock: high quality)>

4.2. ***Quantity sold***

Observing figures 4 and 5, we see that there is significant variation in the quantity provided across the three market structures.

<Figure 4 here (quantity: low quality)>

<Figure 5 here (quantity: high quality)>

A Wilcoxon test on the high and low quantities sold indicates that the quantity sold by the private monopoly and the duopoly is not statistically different for the low quality water (see table 3 below). Note, however, that while the private monopoly sells (on average) greater quantity than the duopoly for the low quality, the converse if true for the high quality. For all the other pairings, the differences are statistically significant across all treatments. One also sees that the public monopoly sells a higher quantity compared to both the private monopoly and the duopoly. The quantity sold by the private monopolist is higher for the low, and lower for the high quality water. This result is consistent with the stock management results seen earlier.

Table 3

Quantity - Low Q			Quantity - High Q	
	z	p>|z|	z	p>|z|
T1 = T2	1.606	0.1083	-3.276	0.001
T1 = T3	-3.798	0.000	-5.64	0.000
T3 = T2	3.720	0.000	4.619	0.000

4.3. ***Average quality to price ratio***

Figure 6 presents the average quality/price ratio as $\overline{Q} / \overline{P}$, where:

$\overline{Q} = \frac{K_H \cdot Q_H + K_L \cdot Q_L}{K_H + K_L}$ and $\overline{P} = \frac{K_H \cdot P_H + K_L \cdot P_L}{K_H + K_L}$. It can be easily seen that the public monopoly provides the highest quality to price ratio relative to all other treatments. The ratio provided by the duopoly is slightly above the private monopoly. Another striking feature is the volatile pattern of the ratio obtained in the public monopoly treatment. This is in sharp contrast with the smooth patterns of the other two market structures. This difference can be understood knowing that the public monopolist receives feedback which partly, but directly, depends on the consumer's social welfare. Specifically, the consumer's loss associated with the cost of depuration, in case the quality falls below the "potable" threshold, negatively affects the feedback received by subjects on the success of their strategies. Volatility arises due to the continuous effort of subjects (representing the social planner) to cope with the additional objective of maintaining quality above a certain level (in order not to trigger the costly (inefficient) depuration procedure).

<Figure 6 here>

Table 4 below presents the Wilcoxon t-test comparing average quality levels across the three market structures. Average quality across all three market treatments is statistically different across all three treatments. Note, however, that the average quality supplied by the duopoly is greater than supplied by the private monopolist. The public monopoly meanwhile supplies higher quality compared to both the private monopoly and duopoly.

Table 4

Average Quality/price		
	z	p>|z|
T1 = T2	-6.393	0.00
T1 = T3	-6.393	0.00
T3 = T2	6.393	0.00

4.4. *Coordinated duopoly*

We only present the results for the Wilcoxon t-tests for the coordinated duopoly and private monopoly. Interestingly, while the low and high quality stocks maintained by the two are statistically different, the quantities offered for sale by the coordinated duopoly and private monopoly are not statistically different.

Table 5

	Private monopoly vs. Coordinated Duopoly	
	z	p>|z|
Low Quality Stock	2.639	0.008
High Quality Stock	4.994	0.00
Average Quality	-3.733	0.000
Low Quality Quantity	0.103	0.918
High Quality Quantity	-0.327	0.7435

5. Conclusions

Our setup assumes extraction from separate pools and competition in the distribution stage. This structure is inspired by the problem, of growing importance in many countries, concerning the level of aggregation (or disaggregation) of decision making and management of national aquifers. For example, recently the decision of the central Spanish government to centralize the decision making process and management of the river Ebro’s resources found strong opposition by local governments fearing a loss of control over the part they were previously monopolizing. Our experimental results suggest that, more than centralizing decision making,[15] what matters are the incentives. Prices are useful in allocating water resources even in the case of the public monopoly in our experiments. Compared to a public monopoly, a market based mechanism maintains higher, though inefficient, stock levels. Further note that output supplied by the private monopoly and duopoly is not significantly different in our experiments. Otherwise, all outputs across all treatments are statistically different.

One sees that the private monopoly and duopoly maintain inefficiently higher water stocks (low and high quality) than the public monopoly. The stocks maintained by the public monopoly are at the optimal level at the end of the sessions. Given that stocks are declining, it is not clear if the public monopoly would have been able to maintain stocks at the optimal level for longer experimental sessions. The average quality to price ratio is highest for the public monopoly and the difference across all treatments is statistically significant. Further experiments need to be run to see how increasing the number of firms, and/or increasing the number of periods, affects stock depletion.

One also needs to understand some fundamental differences under which a public monopoly operates in our experiments. In our setup the social planner is not allowed to set quantities. Instead, as occurs in real world situations, they have to regulate consumption by posting the right price at which an each extra unit should be sold. Incentives for the public monopoly are such that subjects post their bids aiming at simultaneously satisfying the condition for the hydrological equilibrium of the system ("stock recharge equals consumption") and, at the same time, keeping stocks at the desired "not too low" levels. This is done without letting average quality fall below the "potable" standard in order not to trigger depuration. Whether this induces a persistent learning shortcoming or not is not answered by our results so far. Therefore, an interesting extension of the experiments presented here would be to allow for longer sessions, or calling experienced subjects back to take part in another experiment.

[15] Both the public and private monopoly are equally centralized in our experiments. What differentiates them are the incentives under which they operate.

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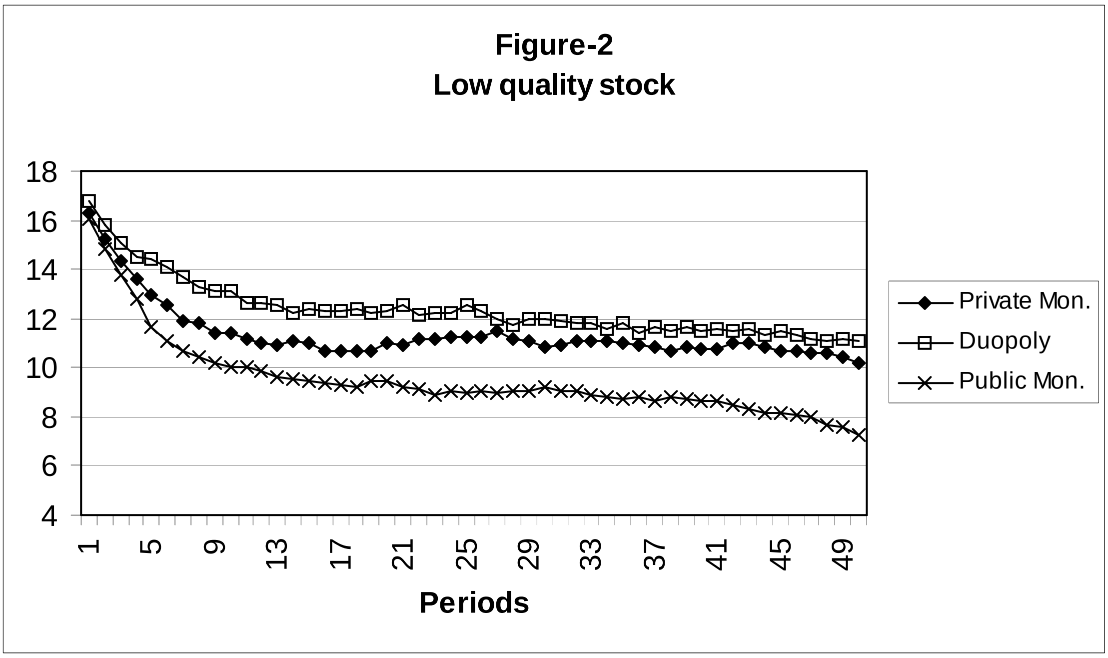
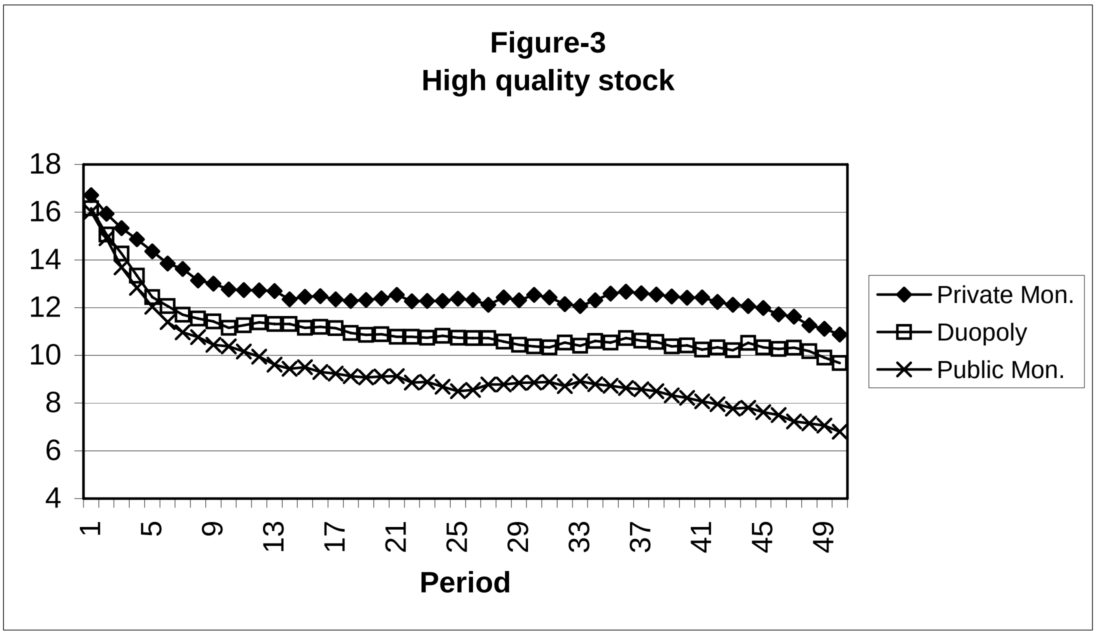
6. Appendix A: Figures





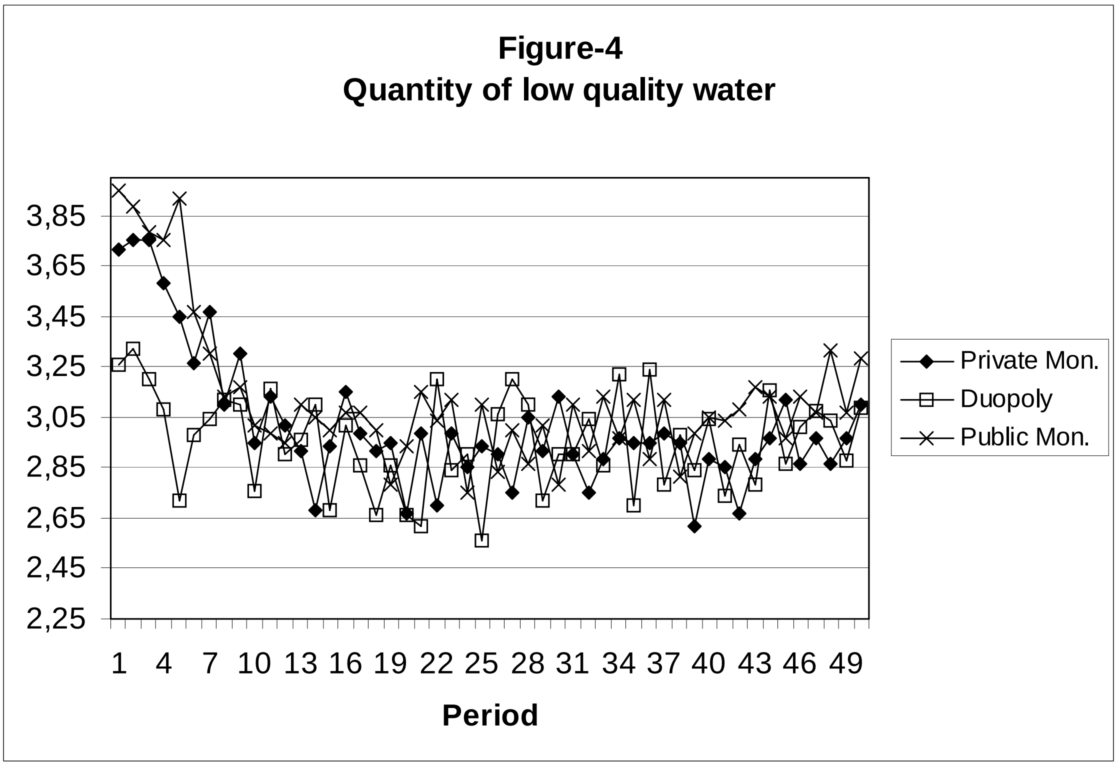


Figure-4
Quantity of low quality water
3,85
3,65
3,45
3,25
3,05
2,85
2,65
2,45
2,25
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49
Period
Private Mon.
Duopoly
Public Mon.

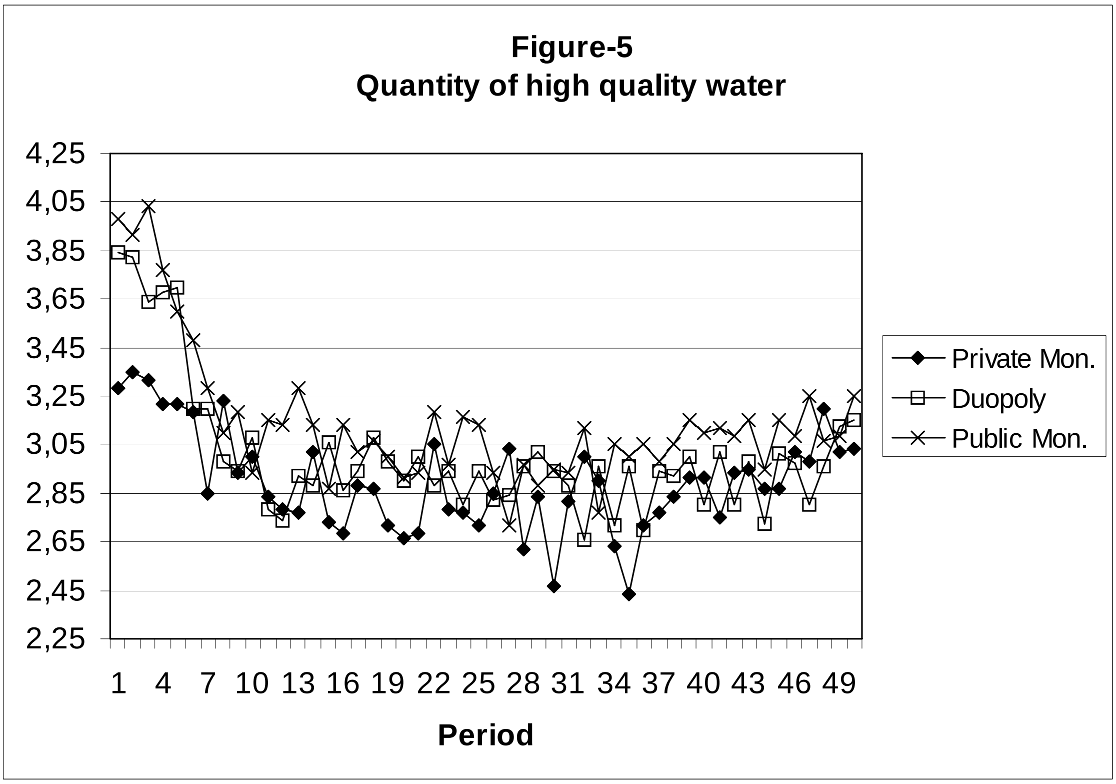
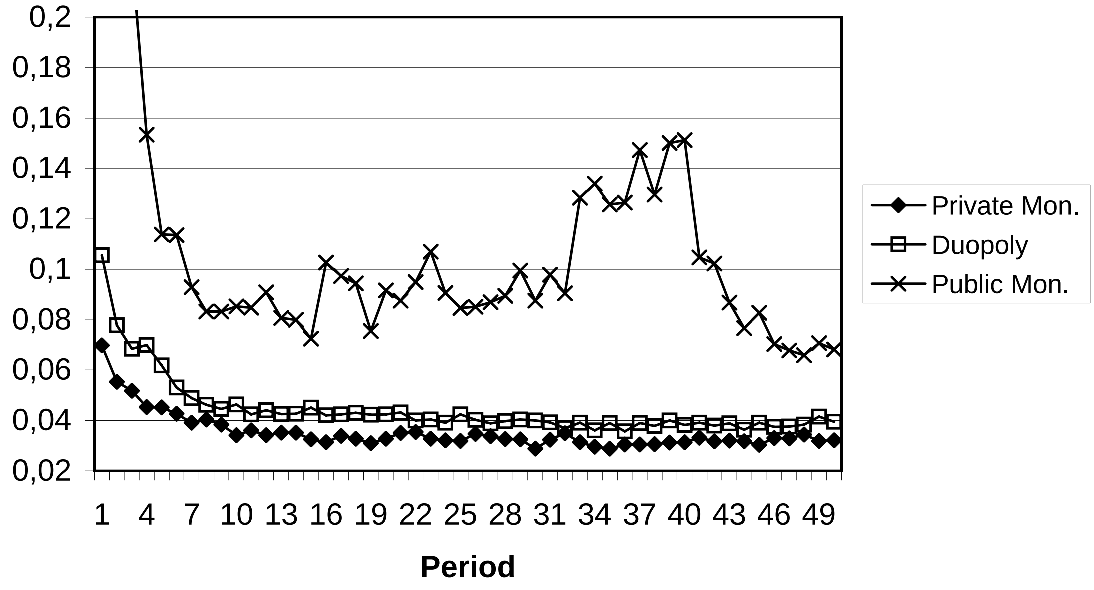


Figure-5
Quantity of high quality water
4,25
4,05
3,85
3,65
3,45
3,25
3,05
2,85
2,65
2,45
2,25
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49
Period
Private Mon.
Duopoly
Public Mon.

Figure-6
Average quality/price ratio



6. Appendix B: Instructions (translated from Spanish)

Treatment 1

The aim of this experiment is to study how people make their decisions in certain contexts. Your decisions in the scenario explained below in detail, will be directly related to a monetary reward you will receive in cash at the end of the experiment. Any doubt you may have will be clarified personally to you by one of the organizers after you raise your hand. Beyond these questions, any other communication is strictly forbidden and is subject to immediate exclusion from the experiment.

You participate in a market which is characterized by the following features:

- You are the only producer of two commodities: *product H* and *product L*. Specifically, product *H* is ***water of High quality***, while product *L* is ***water of Low quality***. Products *H* and *L* are substitutes, namely, consumers may, to a certain extent, substitute one type of water with the other.
- There are two types of consumers: *households* and *farmers*. Although they have different preferences with respect to the two types of water, they all prefer water of high quality (*product H)* to water of low quality (*product L)*. That is, they are willing to pay more for *H* than for *L*.
- The market lasts for 50 rounds.

Decision Making

Your only decision as a producer is announcing the minimum price at which you are willing to sell each one of the first five units of each product. Such announcements of minimum prices are called *price bids*. In order to make your biding decisions, you have to take into account that:

1. The extraction cost per additional unit extracted and by product is included in the "table of costs" bellow. These costs are the same for the two products, and they are expressed in ExCUs, a fictitious Experimental Currency Unit.
2. Taking into account the costs of the table, you have to announce *five minimum prices* at which you are willing to sell each unit of the first five units of each product. Therefore, your decision making consists of fixing *5 price bids* for each product.
3. You should have in mind that, in order not to make any losses, price bids cannot be lower than the corresponding unit costs included in the table of costs.
4. Price bids *cannot be decreasing*. That is, your bid for the 1st unit cannot be higher than your bid for the 2nd unit; the bid for the 2nd cannot be higher than the bid for the 3rd unit, and so on and so forth.

5. Observe in the table that the unit costs decrease with the stock size. At the beginning of the session, you have an *initial stock size* of *20 units* for each product. At the beginning of each round, you get *three* more *units* for each type of water.
6. Your stock size, for both types of water, can never exceed *20 units* and, therefore, any additional (over 20) units you may receive are immediately lost.

Table of costs (expressed in ExCUs)

Stock size	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**
Unit cost	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*2*	*2*	*4*
Stock size	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Unit cost	*7*	*11*	*18*	*30*	*50*	*82*	*135*	*223*	*368*	*607*

Example

Suppose that at the end of a round your stock size of, say product *H*, is 9 units. At the beginning of the new round, you get your additional 3 units (so that your stock now is 12 units). Observe in the table that, for a stock size of 12 units, the unit cost for the first five units extracted is the following:

- the cost of the 1st unit: 2 ExCUs
- the cost of the 2nd unit: 4 ExCUs
- the cost of the 3rd unit: 7 ExCUs
- the cost of the 4th unit: 11 ExCUs
- the cost of the 5th unit: 18 ExCUs

In order not to make any losses, each one of your bids should not be lower than the corresponding unit cost. Therefore, in this example, your bid for the 1st unit should not be lower than 2 ExCUs (cost of the 1st unit); your bid for the 2nd unit should not be lower than neither 4 ExCUs (cost of this unit) nor your bid for the 1st unit; your bid for the 3rd unit should not be lower than neither 7 ExCUs nor your bid for the 2nd unit, and so on for the rest of the units.

In case you sell 5 units of this product, the stock size at the beginning of next round would be 10 units (7 you kept plus 3 you get in the new round). If, given your bids for the five units, your sales are zero, your stock would be 15 units (12 you already had plus 3 you get at the beginning of the round).

Decisions

- You take decisions on the minimum price at which you are willing to sell each unit of each one of the the two products. You will fill in all the boxes that appear at your computer screen with your price bids (5 bids for product *H* and 5 for product *L*). In each box, you will also get information related to the corresponding unit cost. The bids you submit have to be integer numbers between zero and 2000.
- Although you may propose five different price bids, all units of the same product will be sold to consumers at a *single price*. This price will be your bid for the "last" unit sold of each product. The number of units sold each period is calculated by a program which simulates the optimal behaviour of consumers.

Example

In the example above, assume that your bids for one of the products are: 10 (for the 1st unit), 12 (for the 2nd), 14 (for the 3rd), 16 (for the 4th) and 20 (for the 5th). Given your bids, the program which simulates the optimal behaviour of consumers determines that 3 units of this product will be sold. The price at which you will sell the three units will be your bid for the 3rd unit, that is, 14 ExCUs.

The profits

- Your net profit of selling each unit of a product will be the difference between the market price at which you sold all units of that specific product (your unit income) and the corresponding unit extraction cost. Total profits will be the sum of the unit profits for all periods.

Example

Taking again the previous example, if, at the beginning of a round, your stock size is 12 units, your total profits in that round will be 29 ExCUs, which are decomposed as follows:

i) 12 ExCUs for the 1st unit sold (14 ExCUs you receive for that unit minus 2 ExCUs it costs you extracting it).

ii) 10 ExCUs for the 2nd unit sold (14 ExCUs you receive for that unit minus 4 ExCUs it costs you extracting it).

iii) 7 ExCUs for the 3rd unit sold (14 ExCUs you receive for that unit minus 7 ExCUs it costs you extracting it).

- Your ***monetary reward*** at the end of the session will be the sum of your profits accumulated in 15 rounds (randomly selected by the computer) of the total of 50 rounds, at an equivalence rate of **800 ExCUs=1 Euro**. You will be paid *in cash* at the end of the session.

The information

- During decision making, the computer will provide you with a table (for each product) on which, conditional to your bid and cost for the corresponding unit, the revenue as the net profit are calculated in each of the five possible scenarios: *a)* In case you only sell the 1st unit; *b)* If you just sell the first two units; …*e)* In case you sell 5 units.
- At the end of each round, the computer screen will show you the total profits obtained in that round, including information about unit cost, market price and number of units sold of each product.
- During the experiment, you will have at your computer screen a history of *past rounds* (market price for each product, number of units sold of each product, total revenue and total profits per product).

In order to make sure you understood correctly the market described, we will proceed next to run a *pilot session of 5 rounds*. Please, feel free to make any questions you may have during this pilot session. The aim is that you should take control of your own decision making.

Thank you very much for your collaboration. Good luck!

Treatment 2

The aim of this experiment is to study how people make their decisions in certain contexts. Your decisions in the scenario explained below in detail, will be directly related to a monetary reward you will receive in cash at the end of the experiment. Any doubt you may have will be clarified personally to you by one of the organizers after you raise your hand. Beyond these questions, any other communication is strictly forbidden and is subject to immediate exclusion from the experiment.

You are part of a market which is ruled out by the following characteristics:

- There are two producers (*1* and *2*) and two commodities (*product H* and *product L*). Specifically, product *H* is ***water of High quality***, while product *L* is ***water of Low quality***. Products *H* and *L* are substitutes, namely, consumers may, to a certain extent, substitute one type of water with the other.
- You are one of the two producers in this market. At the beginning of the session, the computer will indicate if you are producer *1* or *2*. Your competitor will be one (always the same) of the subjects in this room, randomly selected by the computer when the session starts.
- There are two types of consumers: *households* and *farmers*. Although they have different preferences with respect to the two types of water, they all prefer water of high quality (*product H)* to water of low quality (*product L)*. That is, they are willing to pay more for *H* than for *L*.
- The market will last for 50 rounds.

Decision Making

Your only decision as a producer is announcing the minimum price at which you are willing to sell each one of the first five units of your product. Such announcements of minimum prices are called *price bids*. In order to make your biding decisions, you have to take into account that:

1. The extraction cost per additional unit extracted and by product is included in the "table of costs" bellow. These costs are the same for the two products (therefore, costs conditions for you and your competitor are identical), and they are expressed in ExCUs, a fictitious Experimental Currency Unit.
2. Taking into account the costs of the table, you have to announce *five minimum prices* at which you are willing to sell each unit of the first five units of your product. Therefore, your decision making consists of fixing *5 price bids*.

3. You should have in mind that, in order not to make any losses, price bids cannot be lower than the corresponding unit costs included in the table of costs.
4. Price bids *cannot be decreasing*. That is, your bid for the 1st unit cannot be higher than your bid for the 2nd unit; the bid for the 2nd cannot be higher than the bid for the 3rd unit, and so on and so forth.
5. Observe in the table that the unit costs decrease with the stock size. At the beginning of the session, you have an *initial stock size* of *20 units* for each product. At the beginning of each round, you get *three* more *units* for each type of water.
6. Your stock size, for both types of water, can never exceed *20 units* and, therefore, any additional (over 20) units you may receive are immediately lost.

Table of costs (expressed in ExCUs)

Stock size	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**
Unit cost	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*2*	*2*	*4*
Stock size	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Unit cost	*7*	*11*	*18*	*30*	*50*	*82*	*135*	*223*	*368*	*607*

Example

Suppose that at the end of a round your stock size is 9 units. At the beginning of the new round, you get your additional 3 units (so that your stock now is 12 units). Observe in the table that, for a stock size of 12 units, the unit cost for the first five units extracted is the following:

- the cost of the 1st unit: 2 ExCUs
- the cost of the 2nd unit: 4 ExCUs
- the cost of the 3rd unit: 7 ExCUs
- the cost of the 4th unit: 11 ExCUs
- the cost of the 5th unit: 18 ExCUs

In order not to make any losses, each one of your bids should not be lower than the corresponding unit cost. Therefore, in this example, your bid for the 1st unit should not be lower than 2 ExCUs (cost of the 1st unit); your bid for the 2nd unit should not be lower than neither 4 ExCUs (cost of this unit) nor the bid you fixed for the 1st unit; your bid for the 3rd unit should not be lower than neither 7 ExCUs or your bid for the 2nd unit, and so on for the rest of the units.

In case you sell 5 units, the stock size at the beginning of next round would be 10 units (7 you kept plus 3 you get in the new round). If, given your bids for the five units, your sales are zero, your stock would be 15 units (12 you already had plus 3 you get at the beginning of the round).

Decisions

- You take decisions about price bids at which you are willing to sell your product. You will fill in the boxes that appear at your computer screen with your price bids. In each box, you will also get information related to the corresponding unit cost. The bids you submit have to be integer numbers between zero and 2000.
- Although you may propose five different price bids, all units of the same product will be sold to consumers at a *single price*. This price will be your bid for the "last" unit sold of your product. The number of units sold in each period is calculated by a program which simulates the optimal behaviour of consumers.

Example

In the example above, assume that your bids for one of the products are: 10 (for the 1st unit), 12 (for the 2nd), 14 (for the 3rd), 16 (for the 4th) and 20 (for the 5th). Given your bids, the program which simulates the optimal behaviour of consumers determines that 3 units of this product will be sold. The price at which you will sell the three units will be your bid for the 3rd unit, that is, 14 ExCUs.

The profits

- Your net profit of selling each unit will be the difference between the market price at which you sold all units of that specific product (your unit income) and the corresponding unit extraction cost. Total profits will be the sum of the unit profits for all periods.

Example

Taking again the previous example, if, at the beginning of a round, your stock size is 12 units, your total profits for that round will be 29 ExCUs, which are decomposed as follows:

i) 12 ExCUs for the 1st unit sold (14 ExCUs you receive for that unit minus 2 ExCUs it costs you extracting it).
ii) 10 ExCUs for the 2nd unit sold (14 ExCUs you receive for that unit minus 4 ExCUs it costs you extracting it).

ii) 7 ExCUs for the 3rd unit sold (14 ExCUs you receive for that unit minus 7 ExCUs it costs you extracting it).

- Your ***monetary reward*** at the end of the session will be the sum of all your profits accumulated along 15 rounds (randomly selected by the computer) of the total of 50 rounds, at an equivalence factor of **500 ExCUs=1 Euro**. You will be paid *in cash* at the end of the session.

The information

- During decision making, the computer will provide you with a table on which, conditional to your bid and cost for the corresponding unit, the revenue as the net profit are calculated in each of the five possible scenarios: *a)* In case you only sell the 1st unit; *b)* If you just sell the first two units; …*e)* In case you sell 5 units.
- At the end of each round, the computer screen will show you the total profits obtained in that round, including information about unit cost, market price and number of units sold of each product, as well as your rival's price.
- During the experiment, you will have at your computer screen a history of *past rounds* (own and rival market price, number of units sold, revenue and profits per product).

In order to make sure you understood correctly the market described, we will proceed next to run a *pilot session of 5 rounds*. Please, feel free to make any questions you may have during this pilot session. The aim is that you should take control of your own decision making.

Thank you very much for your collaboration. Good luck!

Treatment 3

The aim of this experiment is to study how people make their decisions in certain contexts. Your decisions in the scenario explained below in detail, will be directly related to a monetary reward you will receive in cash at the end of the experiment. Any doubt you may have will be clarified personally to you by one of the organizers after you raise your hand. Beyond these questions, any other communication is strictly forbidden and is subject to immediate exclusion from the experiment.

You participate in a market which is characterized by the following features:

- You represent a social planner who produces two commodities: *product H* and *product L*. Specifically, product *H* is ***water of High quality***, while product *L* is ***water of Low quality***. Products *H* and *L* are substitutes, namely, consumers may, to a certain extent, substitute one type of water with the other.
- There are two types of consumers: *households* and *farmers*. Although they have different preferences with respect to the two types of water, they all prefer water of high quality (*product H)* to water of low quality (*product L)*. That is, they are willing to pay more for *H* than for *L*.
- The market lasts for 50 rounds.

Decision Making

Your only decision as a producer is announcing the minimum price at which you are willing to sell each one of the first five units of each product. Such announcements of minimum prices are called *price bids*. In order to make your biding decisions, you have to take into account that:

1. The extraction cost per additional unit extracted and by product is included in the "table of costs" bellow. These costs are the same for the two products, and they are expressed in ExCUs, a fictitious Experimental Currency Unit.
2. Taking into account the costs of the table, you have to announce *five minimum prices* at which you are willing to sell each unit of the first five units of each product. Therefore, your decision making consists of fixing *5 price bids* for each type of water.
3. You should have in mind that, in order not to make any losses, price bids cannot be lower than the corresponding unit costs included in the table of costs.
4. Price bids *cannot be decreasing*. That is, your bid for the 1^{st} unit cannot be higher than your bid for the 2^{nd} unit; the bid for the 2^{nd} cannot be higher than the bid for the 3^{rd} unit, and so on and so forth.

5. Observe in the table that the unit costs decrease with the stock size. At the beginning of the session, you have an *initial stock size* of *20 units* for each product. At the beginning of each round, you get *three* more *units* for each type of water.
6. Your stock size, for both types of water, can never exceed *20 units* and, therefore, any additional (over 20) units you may receive are immediately lost.

Table of costs (expressed in ExCUs)

Stock size	**20**	**19**	**18**	**17**	**16**	**15**	**14**	**13**	**12**	**11**
Unit cost	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*2*	*2*	*4*
Stock size	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Unit cost	*7*	*11*	*18*	*30*	*50*	*82*	*135*	*223*	*368*	*607*

Example

Suppose that at the end of a round your stock size of, say product *H*, is 9 units. At the beginning of the new round, you get your additional 3 units (so that your stock now is 12 units). Observe in the table that, for a stock size of 12 units, the unit cost for the first five units extracted is the following:

- the cost of the 1st unit: 2 ExCUs
- the cost of the 2nd unit: 4 ExCUs
- the cost of the 3rd unit: 7 ExCUs
- the cost of the 4th unit: 11 ExCUs
- the cost of the 5th unit: 18 ExCUs

In order not to make any losses, each one of your bids should not be lower than the corresponding unit cost. Therefore, in this example, your bid for the 1^{st} unit should not be lower than 2 ExCUs (cost of the 1^{st} unit); your bid for the 2^{nd} unit should not be lower than neither 4 ExCUs (cost of this unit), nor than the bid you fixed for the 1^{st} unit; your bid for the 3^{rd} unit should not be lower than neither 7 ExCUs, nor than your bid for the 2^{nd} unit, and so on for the rest of the units.

In case you sell 5 units of this product, the stock size at the beginning of next round would be 10 units (7 you kept plus 3 you get in the new round). If, given your bids for the five units, your sales are zero, your stock would be 15 units (12 you already had plus 3 you get at the beginning of the round).

Decisions

- You take decisions about the minimum price at which you are willing to sell each unit of each one of the two products. You will fill in the boxes that appear at your computer screen with your price bids (5 bids for product *H* and 5 for product *L*). In each box, you will also get information related to the corresponding unit cost. The bids you submit have to be integer numbers between zero and 2000.
- Although you may propose five different price bids, all units of the same product will be sold to consumers at a *single price*. This price will be your bid for the last unit sold of each product. The number of units sold each period is calculated by a program which simulates the optimal behaviour of consumers.

Example

In the example above, assume that your bids for one of the products are: 10 (for the 1st unit), 12 (for the 2nd), 14 (for the 3rd), 16 (for the 4th) and 20 (for the 5th). Given your bids, the program which simulates the optimal behaviour of consumers determines that 3 units of this product will be sold. The price at which you will sell the three units will be your bid for the third unit, that is, 14 ExCUs.

The aim

- As a social planner, your aim in each round is to maximize the social benefit per unit sold in this market, which is defined as the difference between the utility level generated by each unit consumed and the corresponding unit extraction cost.

The information

- At the beginning of each round, the computer will provide you with a table containing, conditional to the stock size for each type of water and all possible combinations of consumption of the two products, the corresponding social benefits (measured as the difference between the utility level and corresponding extraction costs) of that round.

- At the end of each round, the computer screen will show you the social benefits obtained in that round. This information will include the unit cost, market price and number of units sold of each product.
- During the experiment, you will have on your computer screen a history of *past rounds* (market price for each product, number of units sold of each product an social benefit).

Monetary reward

- Your ***monetary reward*** for participating in this experiment will be the sum of the social benefits accumulated along 15 rounds (randomly selected by the computer) of the total of 50 rounds, at an equivalence rate of **800 ExCUs=1 Euro**. You will be paid *in cash* at the end of the session.

In order to make sure you understood correctly the market described, we will proceed next to run a *pilot session of 5 rounds*. Please, feel free to make any questions you may have during this pilot session. The aim is that you should take control of your own decision making.

Thank you very much for your collaboration. Good luck!

6.Appendix C:. Mathematical model

We provide here the specific mathematical expressions used here to implement the model outlined in the main text. The household's utility is given by the following function:

$$U^h(K_{Hh}, K_{Lh}, Q_{Mh}) = 20.5 \cdot \ln\left(1 + (\max\{Q_{\min}, Q_{Mh}\} + (K_{Lh} + K_{Hh})).(K_{Lh} + K_{Hh}) - C_{\Delta Q_h}\right),$$

where the last term in brackets denotes the purification costs:

$$C_{\Delta Q_h}(K_{Hh}, K_{Lh}, Q_{Mh}) = \begin{cases} \frac{\Delta Q_h{}^2}{3}(Q_{Mh}{}^2 + (K_{Hh} + K_{Lh})^2), if\, Q_{min} > Q_{Mh} \\ 0, \qquad otherwise \end{cases}$$

The farmer's utility function is as follows:

$$U^F(K_{HF}, K_{LF}, Q_{MF}) = 17 \cdot \ln[1 + 0.5 \cdot (Q_{MF} + 3 \cdot (K_{LF} + K_{HF})) \cdot (K_{LF} + K_{HF})]$$

The cost function of producer *i* (*i* = *H*, *L*) is given by: $C_i(K_i) = \int_0^{K_j} e^{-\frac{S_i - x_i}{2}} dx_i$. Given the quantity restriction of 5 units and the discrete quantity space allowed, the following *utility levels* were assigned to the household (*h*) and the farmer (*F*) populations:

Household	***Low* 0**	**1**	**2**	**3**	**4**	**5**
***High* 0**	0	174	301	356	378	378
1	399	492	579	637	679	711
2	555	624	690	753	797	832
3	660	717	771	822	869	906
4	740	789	836	880	920	959
5	806	849	890	929	965	999

Farmer	***Low* 0**	**1**	**2**	**3**	**4**	**5**
***High* 0**	0	187	354	471	560	631
1	274	391	491	572	639	696
2	422	509	584	647	702	749
3	525	594	655	707	753	794
4	604	662	712	757	798	834
5	668	717	761	801	836	869