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Mixture and distribution of different water qualities: *An experiment on vertical structure in a complex market**

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Abstract

We report results from experimental markets in which two different qualities of water are supplied to two types of consumers: households and farmers. In the scenarios studied, we vary strategic complexity (and centralization) by varying the number of agents per market. Centralization of information by a multiproduct monopolist (scenario 1) improves market performance with respect to a duopoly (scenario 2). A downstream coordinator (scenario 3) succeeds in mitigating upstream market power. In a complex setup like ours, some centralization on the supply or the demand side may enhance market efficiency.

Key words: water quality, experimental market, complex system, centralization, market efficiency

JEL: C91, D43, L13, L95, Q25

1. Introduction

Water is necessary for multiple purposes ranging from its use as a consumption good (potable water and water for recreational activities) to water as a production factor (industrial usage, energy generation, intrinsic usage to clean up used water). Interaction of usage is complex, since used water returns in different forms and may be subject to irreversibility (let alone the problems accruing due to water's spatial and temporal dimensions).

Since early debates on market regulation, the management of natural resources (among which water is usually mentioned as the most necessary for life) has been considered a task of major economic, ecological and political importance. In most cases, water management has been undertaken by state or local authorities. However, in some countries with a strong tradition in decentralized market institutions, the problem of water scarcity has been tackled with decentralized management by more or less coordinated economic agents. A usual critique of such solutions is inspired by the fact that water is a necessary commodity whose accessibility by all should not depend on market conditions and the fear that market prices might make water a «luxury good» for low income citizens. This fear is basically founded on two arguments: First, utility maximization by decentralized agents may be incompatible with global maximization of welfare. Second, decentralized agents may fail to efficiently deal with the dynamic aspects of the exploitation of a resource and its distribution across different uses, mainly because they lack information on the general functioning of the system. While the first argument has been extensively studied, controlling for dynamic inefficiencies and learning failures in complex markets has been a far more demanding task.

In his seminal article, Gordon (1954) showed that complete rent dissipation may emerge from the exploitation of an open access resource, whereas a single owner of the resource would be more efficient by internalizing exploitation externalities. Eswaran and Lewis (1984) established the related result of inverse dependence of rent accrual and the number of resource extractors. Mason and Phillips (1997) provided experimental evidence of this relationship for small groups showing that an increase of the industry size may induce a smaller standing stock of a common resource. In the context of groundwater, Burt (1964) proved analytically that a monopoly induces a more conservative usage of the resource, while perfect competition would induce depletion of the economic rent.

Up to now, there has been limited experimental research on water resources, but the few studies undertaken in (rather simple) competitive settings fed the pessimism that resources may be inefficiently used[1]. In an experiment with a static setting, Gardner et al. (1997) show that higher efficiency is achieved when a lower number of extractors exploit a common resource, although the expected non-cooperative equilibrium values are not supported by the results. In a water pumping game experiment (with limited entry), Herr et al. (1997) observed that subjects faced with an intertemporal problem acted even more myopically and less successfully than in a time-independent setting. Their results suggest that the tragedy of the commons arises also in a world with minimal institutional constraints on behavior, and that myopic behavior in a time-dependent setting exacerbates this problem.

In all these papers, dynamic and static (in)efficiencies relate to horizontal externalities due to competition in the extraction of a common resource. However, it is reasonable to assume that externalities may also arise due to downstream competition (in the supply or distribution) among firms extracting from independent resources[2].

[1] In the resource management front, a number of interesting issues are dealt with in a series of experimental papers on natural gas transportation through pipeline networks by Rassenti et al. (1988) and McCabe et al. (1989).

[2] For less complex setups, the existence of vertical relations among markets has been studied in the laboratory in several occasions. For example, Goodfellow and Plott (1990) and Durham (2000) report the results from a series of experiments on a simple —in terms of its parametric structure— setup with two vertically related markets.

Our setup rules out competition in the extraction of the resource[3]. In the economy considered here, there are two water sources of different qualities. The demand side is represented by two different types of consumers: households and farmers. The water supplied to them may be the result of purification, since households will consume water whose quality exceeds a minimum level. The experimental design focuses on three different levels of strategic complexity (and decentralization), which are characterized by the number of different types of (human) agents acting in the market. We study water allocation in a market where a monopoly (treatment 1), or a duopoly (treatment 2), sell water of two different qualities to the consumers. In a third treatment, the duopoly sells to a monopsonist (downstream coordinator) acting on behalf of both types of consumers[4]. Given that in treatments 1 and 2 consumption is simulated by the computer, treatment 3 is the only one in which human agents act on both sides of the market (supply and demand). A novel feature of our framework is that we allow for mixing of different water qualities. This acts as a bridge between dynamic efficiency of water flow administration, on one hand, and market functioning under heterogeneous market valuations of two goods sold into a «thin»[5] market, on the other. Our interest in such a setting relates to some market features which have been already dealt with in the literature[6], and some of which are rather specific to the case of water markets[7]. Among such features, we mention market power, water flow administration, decentralization (*vs.* cooperative decision-making aimed at global efficiency), etc.

Generally speaking, our assumptions concerning consumer utility are qualitatively similar to those in Williams et al. (1986) on multiple commodities which are

[3] By defining property rights of a resource or more to a sole owner, we concentrate on the effects which arise from the vertical market structures studied and neglect the 'public good' nature of the resource.

[4] Inspired on the practice by many politicians and suggestions by authors like Anderson and Leal (1989), adopting the formation of coalitions as an efficient method of water management.

[5] As used by Saleth et al. (1991) to refer to a market in which there are relatively few agents.

[6] Howe et al. (1986), using a much simpler model than ours, offer some justification of our concerns for a solution to a problem of water flow management in the presence of quality considerations in an upstream-downstream framework.

[7] Administration of dynamic flow problems are a famous example of such characteristics, but the interest in human behavior under alternative market structures has been the most popular in resource economics, despite the argument by Wong and Eheart (1983) that inefficiency due to imperfections in market design and organization can be observed even in the case of simulated (thus, perfect) behavior.

interdependent in consumption. Two further features which are rather specific to the dynamics of water are added to the structure described so far: First, buyers are restricted to buy up to a certain amount of each type of water, given that their purchases in each period are used to serve their current needs. Second, a constant inflow (recharge) comes to increase in each period the stock of water in the basins of each producer. In fact, following a standard formulation of similar groundwater extraction problems[8], a lower stock implies a higher extraction cost, giving rise to a positive correlation between each period's marginal costs and past levels of extraction.

We find that competition on the supply side (treatment 2) results in lower social welfare as compared to a monopoly (treatment 1). Introducing downstream coordination (treatment 3) in the duopolistic market increases market competition. The monopsonist is unable to exercise its market power and the deadweight loss decreases. Therefore, some centralization (upstream or downstream) is socially desirable even in the presence of human actions[9].

The remaining part of the paper is organized in the following way: section 2 provides some discussion of the theoretical framework in which we derive the socially optimal solution. Section 3 describes the experimental design. In section 4 we discuss the results obtained and, in section 5, we conclude.

2. Theoretical framework and social optimum

Due to the obvious difficulties associated with the multiple interactions among all the socio-economic and environmental aspects of water management, theoretical hydro-economic models focus only on specific questions. Thus, most of the literature is based on partial equilibrium analysis.

[8] See, for example, Gisser and Sánchez (1984) and Rubio and Casino (1999).

[9] Which are sub-optimal compared to simulated agents in treatments 1 and 2 who, by design, act in an individually optimal way. In fact, a vast literature is dedicated to various factors which may be responsible for observed shortcomings of human behavior in complex environments, like misperception of feedback (Paich and Sterman, 1993, and Sterman,1994), limitations in subjects' learning when exposed to strategic complexity (Richards and Hays, 1998), or multi-task decision making (Kelly, 1995) with asymmetries (García-Gallego and Georgantzís, 2001, and García-Gallego et al., 2001). A number of factors that favour subjects' improvement of performance have, also, been identified. For example, trial-and-error algorithms have been shown to facilitate convergence of the strategies played by uninformed subjects towards symmetric, full-information equilibrium predictions, as shown in García-Gallego (1998) for the case of a price-setting oligopoly.

Aquifers should be considered as different both from renewable and non-renewable resources, because the recharge does not imply an intrinsic growth rate of the existing stock but is, generally speaking, exogenously generated. However, if the extraction rate exceeds the recharge rate, the stock will be exhausted, while, given an extraction which equals the recharge, a hydro-economic equilibrium emerges, enabling an infinite exploitation. Costs of extraction, which arise from pumping, are inversely related to the aquifer's water table.

In our model there are two renewable stocks (aquifers) S_H and S_L from which water may be extracted. For the sake of simplicity, assume that the recharge to the respective basin is deterministic and constant. The inflow to the respective basin is assumed to cease when the storage capacity of the aquifer is reached. The return flow of consumed water is assumed to be negligible. Thus, changes in the stocks are due to extraction and recharge only. 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 consider the possibility that the water resources differ in their respective 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, there exists the possibility of providing any intermediate quality by mixing water of the two sources. Mixing quantities K_H and K_L of the two qualities results in water whose quality is given by:

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

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, depending on the quantities and the qualities which are mixed. In any case, any quality may be improved at a cost, which is an increasing function of the difference between the quality before and after purification. Moreover, a given improvement DQ 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 $C_{\Delta Q}(K,$ D$Q, Q_0)$, for a certain water quantity $K=K_H+K_L$, is assumed to satisfy the following conditions:

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

A centralized knot may exist which co-ordinates the resource flow between the sources and the consumers. The principal objective of the distribution knot is the centralization of the decisions about quantity and quality supply and the distribution to the respective consumers. Figures 1 and 2 show the distribution scheme that operates in each scenario.

Suppose there are many consumers in the economy whose behavior can be aggregated under one of two types: i) the households (*h*) and ii) the farmers (*F*). Consumers differ in their respective preferences regarding the quality of water. Both types prefer a higher quality of the resource to a lower one. Farmers prefer more quantity of each product to less. However, households will 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 that it is not profitable to improve quality above the minimum standard. Hence, the quality consumed by households will be the maximum between the minimum quality and the mixed quality. Thus, $Q_0 = Q_M$ and

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

Let the households take the purification cost into account in their utility function and assume the utility functions $U_h = U_h\ (K_h, Q_{Mh})$ and $U_F = U_F\ (K_F, Q_{MF})$ (where $K_h = K_{Hh} + K_{Lh}$, and $K_F = K_{HF} + K_{LF}$) of the respective consumer-types to be twice differentiable with respect to quantity and mixed quality. 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. In fact, it will be increasing if mixed quality weakly exceeds the minimum quality standard. From the assumption of 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 described as follows:

$$V(K_H, K_L) = \max_{K_{Hhh}, K_{Lhh}} U_h(K_{Hh}, K_{Lh}, Q_{Mh}; K_H, K_L) + \mathrm{UF}(K_{HF}, K_{LF}, Q_{MF}; K_{H,} K_L)$$

s.t.

$$\begin{aligned}
&(i) \quad K_H = K_{Hh} + K_{HF} \\
&(ii) \quad K_L = K_{Lh} + K_{LF} \\
&(iii) \quad Q_{Mh} = \frac{Q_H K_{Hh} + Q_L K_{Lh}}{K_{Hh} + K_{Lh}} \\
&(iv) \quad Q_{MF} = \frac{Q_H K_{HF} + Q_L K_{LF}}{K_{HF} + K_{LF}}
\end{aligned} \tag{3}$$

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[10]. 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 , denote, respectively, recharges of each quality water, and t_0 the starting time of extraction. Assume the social rate of discount is $d=1$. Thus, the intertemporal objective function is formulated as follows

$$\max_{K_{Ht}, K_{Lt}} \int_{t_0}^{\infty} e^{-\delta t} \left[V(K_{Ht}, K_{Lt}) - C_{Ht}(K_{Ht}, S_{Ht}) K_{Ht} - C_{Lt}(K_{Lt}, S_{Lt}) K_{Lt}\right] dt$$

s.t.

$$\begin{aligned}
&(i) \quad \frac{dS_{Ht}}{dt} = \begin{cases} -K_{Ht} + a_H, \textit{ if } S_H < S_H^{max} \\ S_H^{max}, \textit{ otherwise} \end{cases} \\
&(ii) \quad \frac{dS_{Lt}}{dt} = \begin{cases} -K_{Lt} + a_L, \textit{ if } S_L < S_L^{max} \\ S_L^{max}, \textit{ otherwise} \end{cases} \\
&(iii) \quad S_{Ht_0} = S_H^{max} \\
&(iv) \quad S_{Lt_0} = S_L^{max}
\end{aligned} \tag{4}$$

[10] Indeed, it is a problem which 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:

$$\left.\frac{\partial V}{\partial K_H}\right|_{K_H = a_H} = a_H \left.\frac{\partial C_H}{\partial K_H}\right|_{K_H = a_H} + C_H\,(a_H, S_H) - a_H\,\frac{\partial C_H\,(a_H, S_H)}{\partial S_H}$$

$$\left.\frac{\partial V}{\partial K_L}\right|_{K_L = a_L} = a_L \left.\frac{\partial C_L}{\partial K_L}\right|_{K_L = a_L} + C_L\,(a_L, S_L) - a_L\,\frac{\partial C_L\,(a_L, S_L)}{\partial S_L} \quad (5)$$

These 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[11].

3. EXPERIMENTAL PARAMETERS AND MARKET DESIGN

The experiments were conducted at the *Laboratorio de Investigación en Economía Experimental* (*LINEEX*), at the University of Valencia (Spain). Three treatments with 14 independent markets (per treatment) were studied in which a total of 84 subjects participated. They were recruited among undergraduate students of Economics at the University of Valencia. Urs Fischbacher's software *z-Tree 2011* was used for the programing of the design. An experimental session took between two and two and a half hours. Subjects earned an average of 3500 ptas ($20).

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: $Q_{min} = 3$

[11] In each condition, the first two terms, both positive, represent the marginal costs which result from extracting a quantity K_H (respectively K_L) from the water stock S_H (S_L). The third term reflects the shadow price of the resource, that is, the implied costs induced by a lower water table, which are imposed on all future extraction.

The utility and cost functions used are provided in the appendix. 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 $(p_H, p_L) = (102, 86)$. The quantities $(K_{Hh}, K_{Lh}) = (2.55, 0)$ and $(K_{HF}, K_{LF}) = (0.45, 3)$ are assigned, respectively, to household (h) and agricultural (F) consumptions. Subjects were told that sessions would last 45 periods[12].

3.1. *Experimental design*

The experiment adopted a discrete time framework. No explicit reference was made to water in the instructions aiming at a no-label experiment. Producer-subjects knew their product «type», in the sense that 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 production cost structures were identical. Subjects received a table with their unit costs depending on the stock size (see the instructions in the appendix).

Consumers received specific information about the increases in their 'satisfaction level' from each additional unit bought. Experimental subjects (consumers and producers) were introduced separately to their tasks and did not know any details about the restrictions on the other side of the market (the information was provided privately at any instance on their computer screens). A history window would display all past outcomes regarding own decisions, quantities, payoffs and market prices. Producers and consumers were asked to decide about their respective reservation prices for each unit of product within the range 1 to 5 (the maximum quantity each one of them could trade in each period)[13]. Producers had to post, simultaneously, *five* sealed offers which should equal the minimum price at which they were willing to sell the respective unit[14]. The offers had to exceed weakly the cost of the corresponding unit, and offers of subsequent units would have to be non-decreasing. On the demand side, subjects would have to submit five sealed bids for each product, which had to be non (monotonically) increasing for subsequent units and, at most as high as the rent that would arise from one extra unit. The bids should reflect the maximum price at which

[12] However, in order to avoid end-game behavior, we stopped sessions after period 35.

[13] The quantity limitation was designed to account for the time restrictions of experimental exposition.

[14] Producers in treatment 1 had to post five sealed offers for each product.

consumers were willing to purchase an additional unit. Subjects knew that, after bids were announced, all units of the same product in a period would be sold at the same market price (see instructions).

3.2. *Market institutions*

We aim at comparing three different market structures. Our basic market (treatment 2) is designed to be a fully decentralized structure in which resources are independently owned and run and consumers act in an individually optimal (simulated) way. Two alternative structures are designed in which either upstream (treatment 1) or downstream (treatment 3) action is coordinated and, in both cases, coordinating agents are human subjects. The non coordinated part of the market (suppliers) in treatment 3 is also run by human subjects. Therefore, together with upstream and downstream centralization, other shortcomings of human behavior in dynamically and strategically complex environments can be analysed.

Treatment 1 involves a monopoly (joint ownership of both sources) in the upstream market, and optimal (simulated) coordination of downstream behavior. One subject is posting price offers for both water qualities. Given these offers, the maximal consumer rent is determined in the simulated centralized downstream market: $V(K_H,K_L) - w' k$, 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, and the corresponding offers of the subject stablish the clearing prices.

Treatment 2 is our «basic» and least centralized one with which the other two treatments could be directly compared. In this treatment, we assume uncoordinated action on both sides of the market with a duopoly (decentralized ownership of resources) selling to two simulated (decentralized) utility-maximizing consumers. Given the multiplicity of independent agents, further problems in market design had to be solved. The producer-subjects did not receive information about how markets would clear and, therefore, they did not know what influence the decisions of the competitor would have on the own demand. Although subjects posted their offers simultaneously, markets cleared in a random order determined by the computer[15]. This mecha-

[15] We used this mechanism because we were not interested in a systematic Stackelberg market structure, favoring one of the two markets and the correspondingly consumer type.

nism was introduced aiming at avoiding totally inefficient outcomes in which consumers buy too much of the product which least fits their specific needs. Thus, farmers were given preference in the low quality market and households were preferred in the high quality market. Therefore, a consumer was allowed to buy in the 'other' market only if the 'own' market was the first to clear and the consumer had been left with some excess demand.

In treatment 3, three subjects participated in each session. Two of them, the owners of the sources, acted on the (decentralized) supply side of the market. The third one, a representative consumer, would be on the (centralized) demand side, acting as a monopsonist and representing both consumer types[16]. Like in treatment 2, a market day comprises a sequence of two, in which the subject who acted as the consumer representative buys subsequently in both markets which opened in a random order. In the second market, the number of units purchased in the first market, were taken into account[17]. The market-clearing is determined by means of comparison across unit offers and unit bids. In particular, the market-clearing price is the maximin (within the producer's price offers) exceeded by the maximum price (within the consumer's bids), for the same unit, which the consumer were willing to pay. Then, the quantity would be determined too.

4. Results and discussion

This section is organized in three subsections. The first one is dedicated to the observations concerning stock sizes. In the second subsection, market prices and the bid-and-offer results are presented and discussed. Finally, in the third subsection, we undertake the comparison of the three treatments in terms of welfare and efficiency.

[16] Since his/her earnings were proportional (50%) to the consumers' rent.

[17] Subjects' screens would display the maximal satisfaction level associated with the consumption of an additional unit.

4.1. *Stock data*

In figure 3, the (cummulative) distributions of end-period stock sizes are presented. Stock sizes below the socially optimal hydrological steady state stock size of (S_H, S_L) = (4.84, 5.01) were hardly observed in treatment 1, whereas, in treatments 2 and 3 a few times a high quality stock size of 3 units was reached —which stemmed from one subject's strategies in each treatment. Considering the distributions, we see that each one of the scenarios resulted in a different resource-management. It can be seen from figure 3 that treatment 1 did not produce any perceivable stock differences across water qualities. On the other hand, in treatment 2, the low quality stock dominates the high quality one, while in treatment 3 almost the opposite prevails.

Table 1 contains data on the stock sizes in the 14 markets after 35 experimental periods. A Mann-Whitney test does not reject the hypotheses of stochastic equivalence of last period stock sizes across treatments for low (respectively, high) qualities[18]. A common feature can be seen in figure 4, in which we observe a declining tendency in (average) stocks during the course of the sessions. However, this trend is much weaker in treatment 1 (only significant during the first five periods). This observation is, generally speaking, an indicator of the fact that subjects, in treatment 1, have given priority to the goal of maintaining the hydrological equilibrium of the system, whereas competing producers, in the other two treatments, have been trying to sell as many units as possible. In fact, in treatment 3, the decreasing rate at which this trend is produced indicates that producers have also tried to avoid selling beyond a certain point leading to stocks which fall too low (so that extraction costs would not increase to levels implying a serious competitive disadvantage to them).

In any case, the relatively high extraction costs associated with low stock sizes led subjects in all regimes —on average— to more conservative extraction than would correspond to the socially optimal steady state solution. In other words, we obtain the opposite of the common resource overexploitation result attributed to competition in the extraction stage. That is, the setup studied here results in some kind of horizontal externality leading to under-exploitation of the resource by firms who are competitors in the downstream market.

[18] Throughout the paper, we use a a=.05 level of significance. We use standard tests from Siegel and Castellan (1988).

4.2. *Posted offers, bids and market prices*

Following the theoretical framework, the hypothesis has to be verified that prices, posted bids and offers should correctly reflect the difference in qualities[19]. That is, high quality water is expected to yield higher prices, offers and bids than the low quality one. However, in a setting like ours, in which human subjects take decisions in an environment whose market equilibrium is far from obvious, the experimentalist should not expect this to be a trivial or even a usual result. In fact, the recharge problem implies a further issue to be taken into account by subjects who should not only care about what they sell and earn in each period but, also, what this implies for each product's stock and, consequently, each producer's unit costs in future periods.

The most important descriptor of the supply side of our experimental markets, and also an indicator for the cognitive processes of subjects with respect to beliefs and learning, is given through the posted offers (since they are the control variables of producer-subjects). Figure 5 plots the average of the posted offers and bids for the first unit of each water quality over the 35 periods of the experiment. Table 2 reports, for each treatment, the posted offers (for the first unit of each quality water) observed in periods 1 and 35.

In the first period, the monopolist in treatment 1 posted, in all markets, a higher offer for the first unit of high quality water than for the low quality one. In the same period, the rest of the units were also offered at prices which correctly reflect quality differences. In this treatment, the same applies for period 35 and, for the rest of the periods, only three times (out of seventy possibilities) an inverse order was observed. Along the 35 periods, and considering all treatments, 155 times (out of 2450) low quality water was offered at a higher price than high quality one. Given that the only way for producers of controlling their level of sales was through (very high) offers, we observe excessively high offers for the last units (mainly, the 4^{th} and 5^{th}). In particular, the frequency of the event of a higher offer for the low quality is highest for the fifth unit[20]. In some cases, subjects were able to increase their sales of high quality water (selling less low quality's) by raising offers for the water of low quality.

[19] This finding should not be confused with a similar argument by Saliba et al. (1987) concerning prices which do not reflect water values, where value differences are due to water scarcity, etc.

[20] In fact, in most of the occasions in which sellers posted a higher price for low quality water than for high quality one, the corresponding unit of low quality was not sold.

Unlike the monopolist in treatment 1, sellers of low quality water in treatments 2 and 3 lack any incentive to post higher offers as a means of promoting the sale of high quality water. This observation follows text-book theory on monopoly *vs.* duopoly pricing in static differentiated product markets, according to which monopolist pricing leads to lower price differences than duopoly pricing does. Focusing on the first period of each treatment, stochastic equivalence of posted offers for any unit of high quality and low quality water cannot be rejected by a (pair-wise) *U*-test in any of treatments 2 and 3. In treatment 2, the low quality producer posted a higher offer for the 1^{st} (2^{nd}, 3^{rd}, 4^{th}, 5^{th}) unit of his/her product in 8 (8, 7, 7, 6) out of the 14 markets. In this treatment, offers by the seller of low quality water were, on average, higher than those posted by the seller of high quality water. In treatment 3, the same is true on average but, for the 1^{st} (2^{nd}, 3^{rd}, 4^{th}, 5^{th}) unit, we find only 4 (5, 5, 4, 4) observations in which the offer posted by the seller of low quality was higher than the corresponding offer posted by the seller of high quality (see table 3).

More specifically, in period 35, the 1^{st} (respectively, 2^{nd},..., 5^{th}) offer posted by the low quality seller exceeded 6 (respectively, 7, 8, 9, 10) times the corresponding offers posted by the sellers of high quality water in treatment 3 and 1 (respectively, 1, 0, 0, 0) time in treatment 2. During the experiment, the number of times that the low quality producer posted higher offers (for any unit of his/her product) than the high quality producer significantly decreased over time in treatment 2 and increased in treatment 3. A two-tailed Spearman rank correlation test of the null hypothesis of no correlation of time and the number of observations in which the low quality offer exceeds the high one is rejected (favoring a positive trend).

In few words, treatments 1 and 2 have reflected better the quality differences on price offers as compared to treatment 3, in which we observe a tendency towards equalization of the offers across products. Therefore, subjects who acted as monopsonistic distribution knots, have influenced the market outcome in a sense that tends to distort the expected difference in prices as a result of the difference in qualities.

In treatments 2 and 3, the average offers were lower in the 35^{th} period than in the first one and low quality producers posted, on average, lower offers than high quality producers did. In treatment 1, the offers for both products were higher in period 35 than in the first one. In all markets and in all treatments, it is observed that subjects who submitted in period 1 offers below 100 posted higher offers in the 35^{th} period, and those who posted offers above 100 posted lower offers in period 35. Look at table 4.

The comparison of posted offers across treatments yields that, in the first period, the monopolists (treatment 1) posted lower offers than duopolists (treatments 2 and 3). The Mann-Whitney *U*-test rejects the null hypothesis of equal posted offers in treatments 1 and 2 in most occasions, with lower offers in treatment 1. A comparable result is obtained between treatments 1 and 3 for some units (especially for the sellers of high quality water). Contrary to what static theory would predict, it is surprising that, in the duopoly (treatment 2) offers are higher than in the monopoly (treatment 1). Considering the dynamic nature of the experiment, an interpretation for this apparently odd behavioral pattern is that subjects signal cooperation in the competitive environment at the beginning of a session, hoping to achieve the collusive outcome in future periods. In the case of monopoly, subjects approach equilibrium prices from below as has been already pointed out in other experimental studies[21]. Finally, it seems that high first-period offers are rather specific to oligopolists' strategies aiming at establishing the collusive outcome. On the contrary, low offers in the first period seem rather specific to monopolists' strategies aiming at reaching from below the initially unknown optimal strategy. A further factor which could favor this kind of behavior observed in treatment 1 may be found in the priors of our subjects, who may, initially, apply theories based on real world situations in every new scenario they face. In this sense, promotion of new products with low prices may be a strategy, although it seems less reasonable in our context. Moreover, period 1's posted offers in treatments 2 and 3 are not stochastically different from each other. However, offers in period 35 (treatment 3) are lower than in the other treatments, especially those posted by high quality sellers. The monopsonistic subjects have used their market power and pushed down the offers posted by sellers of high quality water.

The resulting market-prices reflect what has been stated above: in period 1, prices of high/low quality water across treatments are stochastically equivalent. Figure 6 presents a chart of the average prices in the experiment. In treatment 1, the average prices increase significantly over time (showed by a Spearman rank correlation test). In treatment 2, the high quality price increases and the low quality price decreases, while in treatment 3 the contrary happens. However, these observations are not statistically significant. Prices in treatment 3 are lower than prices in treatments 1 and 2. Specifically, prices of high quality water in treatment 3 are stochastically dominated by those of treatment 2 in 25 periods, with increasing importance along the experiment.

On the demand side of the market, in treatment 3, monopsonistic subjects posted bids for high quality and low quality units (average bids for the first unit are plotted in figure 5). As would have been expected, subjects use their market power to

[21] See, especially, García-Gallego and Georgantzís (2001).

influence market prices through their bids. As can be conjectured from the chart, average bids present a non-increasing trend. Moreover, based on individual data, we find that only in four markets (7, 8, 9, 11) a (significant) decrease of the bids (table 5) is observed, while, in market 9, this decrease is only observed for the first unit. In the other three cases (7, 8, 11), market power has been exercised by downstream subjects who posted very similar bids (negatively correlated with time) for the units along the session.

Let us look at table 6. Except from the three markets (7, 8, 11) mentioned above, the correlation between the satisfaction level for one extra unit and the bids is usually positive and, specially in markets 1, 2, 10 y 14, this relation is significant.

In treatment 3, some subjects (at least 3 out of 14: in markets 2, 10, 14) nearly equalized the satisfaction levels for one extra unit from their screens, thus, behaving as in perfect competition. Therefore, the random shocks resulting from sequential sales were not smoothened by downstream behavior and were transmitted to upstream markets. As a consequence, the levels of satisfaction of the monopsonistic subjects in treatment 3 decrease over time. Yet, in markets 7, 8, and 10 in which subjects exercised their monopsonistic market power, consumer surplus increased. Figure 7 plots the average payoffs of experimental subjects for each treatment over the horizon of the experiment. Observe that, in treatment 1, monopolists' average profits present a (significant) increasing trend. Table 7 includes data on (average) earnings for each type of firm (per treatment) and levels of satisfaction of monopsonists. Observe that the decreasing trend of satisfaction levels for consumers in treatment 3 is significant ($r_s = -0.38$ [–2.39])[22].

As far as the quantity of water (of each quality) allocated in each treatment, look at figure 8. Comparing graphs in this figure, we find that treatment 1 exhibits most the extraction path which we would assume in the optimal solution, i.e., maximal production at the beginning, and stabilizing at the hydrological equilibrium (where extraction equals recharge). Over the 35 periods, an average quantity was supplied of, respectively, (K_L, K_H) = (2.8 (1.4); 2.8 (1.2)) in treatment 1, (2.5 (1.3); 2.8 (1.2)) in treatment 2, and (2.8 (1.6); 3 (1.3)) in treatment 3. Table 8 reports the average quantities allocated in the three markets. No significant trend is found.

[22] Small numbers indicate standard deviation.

4.3. *Market Performance*

Let us compare the three treatments in terms of market efficiency. Data on social welfare averages (aggregated utility *minus* production costs) are reported in table 9.

At an aggregate level, no significant trend is observed. However, all treatments present markets in which the level of social welfare (on average) increases (significantly) over time (markets 1, 2 in treatment 1; markets 5, 14 in treatment 2; market 8 in treatment 3), as well as markets in which this trend is (significantly) decreasing (markets 4, 6, 11, 12, 13 in treatment 1; markets 9, 12 in treatment 2; markets 1, 9, 10 in treatment 3). As far as treatment 3 is concerned, observe that markets 7, 8 and 10, even in the presence of monopsonistic power, present levels of *ASW* that are below the average social welfare (on aggregate) and, in the case of market 8, as indicated by the Spearman correlation coefficient, average social welfare increases over time ((r_s= 0.4; (2.51))).

Figure 9 shows average social welfare along the 35 periods. Notice that there is less volatility in the trajectory of the averages in treatment 1 than in the other two treatments. With respect to treatment 3, since monopsonistic subjects, generally speaking, failed to dictate the market, the introduction of an additional subject could have been responsible for more noise.

An indicator for inefficiency in our hydrological model is the quantity of water lost because the stock is at its upper limit. Inefficiency arises since resources that flow into the economy are foregone. From table 10, we perceive that the most 'saving' usage, in terms of water management, prevailed under the conditions of treatment 3 and specially for the high quality water (loss equal to 119) .

Moreover, in treatment 3, the recharge rate was more frequently exceeded by the production than in the other treatments (less number of observations which felt short of the constant periodical recharge).

5. Final remarks. Policy implications

In a series of experimental markets we have tested the performance of three alternative ways of administrating the flow and the market for two different water qualities. Some of the results reported above have straightforward implications for economic policy in the presence of dynamic and strategic complexity.

First, centralization of agent decisions on the supply or the demand side is socially desirable. Specifically, centralization of consumer actions mitigates upstream market power and helps internalize the horizontal externality among consumers and consumer types. In fact, even a market with ideally behaving decentralized buyers was shown to be dominated in terms of social efficiency by a market with human (thus, imperfect) agents acting as downstream coordinators. Furthermore, the introduction of a monopsony tends to equalize prices across product qualities, which has a direct positive impact on social welfare, because high quality water has been kept relatively cheap.

Second, contrary to standard wisdom concerning market power in simpler setups, centralization of decisions by an upstream monopoly also leads to higher levels of social welfare and a more efficient water management. That is, given that the dynamic aspects of water resource management are important, upstream centralization is also desirable because it is more likely to guarantee an efficient exploitation of the resource, and avoid market (price, quantity, profit) volatility.

In fact, our results indicate that volatility in all magnitudes has been higher in the presence of a larger number of human agents in the market, which seems to support the view that learning in enhanced in the presence of a more reliable feedback which is more likely to be received when subjects act in a more stable environment[23]. Furthermore, the shock introduced by the market clearing mechanism in treatment 2 does not seem to have been a serious obstacle for learning, given that price offers posted by subjects tend to stabilize over time, despite the volatility in the quantities sold and payoffs earned. Together with the remark on the reliability of the feedback, this observation leads us to the conclusion that strategic complexity is a more serious problem for humans learning in unknown environments than are moderate stochastic shocks. A further remark supporting this conclusion is that buyer subjects' strategies present the highest volatility among all data obtained. To the aforementioned shortcomings in our subjects' learning, we have to add the fact that subjects of this type are «unique» in each session and any imitation of successful subjects of the same or similar types is impossible[24].

[23] A feature which would give some but not full support to the very pessimistic view of psychologists like Brehmer (1980) who claimed that learning is difficult when not impossible unless subjects are exposed to (very simple) linear and deterministic environments.

[24] As suggested, among other authors, by Offerman and Sonnemans (1998) and Duffy and Feltovich (1999).

Comparison of water flow management across treatments, indicates that consumer coordination has led to a lower waste of the resource than any other of the market structures studied, although a constantly declining trend of the stocks indicates that in a longer experiment this scenario is the most likely to cause a problem of shortage. In fact, this can also be concluded from the fact that, in this treatment, sales above the recharge rate were observed more often than in any other treatment. However, in all treatments, average productions have been almost as much (ranging from slightly lower to equal) as natural inflow, which suggests that the majority of our subjects have managed to keep the system close to its hydrological equilibrium (inflow=sales). This also indicates that the dynamic factor has played an important role in subjects' actions. The consumption of high quality water exceeded on average the consumption of low quality water in all treatments.

Regarding the usual problems in resource extraction games, depletion of the resource does not appear to be an important issue, because the cost structure prevented subjects from sailing too much in each period. However, we found that, even in a deterministic environment in which one agent managed two resource stocks under optimal demand conditions, a non-trivial allocation problem arises, since the monopolistic subjects needed to improve (along time) their performance . The lesson that we draw from our experiment is that an appropriate definition of property rights[25] may be not enough for an efficient management of resource markets.

6. Appendix

6.1. *Utility and cost functions used in the experiment*

The household's utility is given by the following function:

$$U^h\,(K_{Hh}, K_{Lh}, Q_{Mh}) = 20.5 \cdot \ln[1 + (max\{Q_{min}, Q_{Mh}\} + (K_{Lh} + K_{Hh})) \cdot (K_{LH} + K_{Hh}) - C_{\Delta Qh}]$$

where the last term in brackets denotes the purification costs:

[25] Often mentioned as a solution to a huge variety of resource-related problems like, for example, in Colby et al. (1993).

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

The farmer's utility function is as follows:

$$U^F\,(K_{HF}, K_{LF}, Q_{MF}) = 1.7 \cdot \ln[1 + 0.5 \cdot (Q_{MF} + 3 \cdot (K_{LF} + K_{HF})) \cdot (K_{LF} + K_{HF})]$$

The cost function of producer i ($i = H, L$) is given by:

$$C_i\,(K_i) = \int_0^{K_j} e^{-\frac{S_i - x_i}{2}}\, d_{xi}$$

Thus, the following *utils* (unit utilities) for high quality and low quality were assigned to the household (h) and the farmer (F):

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

6.2. *Instructions*[26]

6.2.1. Producers

The goal of this experiment is the study of decision-making in experimental markets. The decisions you'll make are directly related to your monetary reward. At the end of the session, you will be paid privately in cash. You can make any questions regarding these instructions by raising your hand. Any communication is strictly forbidden and it will be penalized with the immediate exclusion of the experiment.

The Experiment

For 45 rounds, you are going to participate in a Market Experiment with the following characteristics:

1. You take part on a market in which there are two consumers (**represented by one single agent in treatment 2**) and two producers. Producers compete to sell their production and *you* are one of them.
2. Two commodities (good 1 and good 2) which are demand substitutes (but are not identical), are supplied in the market (each one supplied by one producer). Both producers have similar costs structures. The computer will tell you which of the two producers you are.
3. Although consumers have different tastes, they both prefer good 2 to good 1.

You have to decide about the *minimum selling price* for each unit of your product. To do that, you may use the following information:

1. The table bellow shows the production costs per unit of your product (using ECUs as our Experimental Currency Unit).
2. Using the information included in the table, you have to announce *five* (minimum) *prices* at which you are willing to sell your units (afterwards, you will sell a maximum of 5 units).

[26] In bold, we add some details that might help the reader to understand the experimental sessions.

3. Pricing schemes for the 5ht unit bundle cannot be decreasing monotonically: the price for the first unit must not be higher than the price for the second unit; the second unit price must not be higher than the third unit price, and so on.

4. The unit cost decreases with the stock size. Your initial stock size is *20 units* and you will get, every round, *three* more units. Your stock can never exceed 20 units and, therefore, any additional (over 20) units you may receive are immediately vanished.

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

An example: Imagine you are at the beginning of a round with a stock of 10 units of product and you get your additional 3 units (as you will at the beginning of each round), so your stock now is 13 units. Your unit costs for the units you produce are the following:

The cost of the first unit produced is 2 ECUs,
the cost of the second unit produced is 2 ECUs,
the cost of the third unit produced is 4 ECUs,
the cost of the fourth unit you produced is 7 ECUs,
and, finally, the cost of the fifth unit produced is 11 ECUs

In order to earn money, your pricing schedules must be such that each unit's price exceeds the corresponding cost. Following the example, the lowest profitable price for your first unit should not lie below 2 ECUs (its unit cost), etc., nor should it exceed the price you fix for the second unit. These rules also apply for the rest of the units.

If you sell 5 units, your stock size, in the following round, would be 11 units (8 you kept plus 3 you get in the new round). If you don't sell any unit after your announcing price scheme, your stock would be 16 units (13 you had plus 3 you get).

Decision making and earnings

1. You have to fill in the boxes that appear at your computer screen with the minimum prices at which you are willing to sell your units. In each box, you will also get information about each unit cost.

2. Both producers decide on prices simultaneously and, as a consequence, information about the other producer's decisions will be available only after the round is over.

3. Although you have to propose five different minimum prices, all units will be sold at the same price: the highest unit price proposed (by a producer) which is exceeded by the correspondent bid proposed by the buyer (which reflects his willingness to pay). In this way, it is also possible to know the number of units sold (all units with a price offer higher than the proposed consumer bid).

4. The money you will earn at the end of the experiment will be the sum of the earnings you get in each round. The exchange rate is 10 ECU = 3 ptas.

6.2.2. Representative Consumer **(only treatment 3)**

The goal of this experiment is the study of decision-making in experimental markets. The decisions you'll make are directly related to your monetary reward. At the end of the session, you will be paid privately in cash. You can make any questions regarding these instructions by raising your hand. Any communication is strictly forbidden and it will be penalized with the immediate exclusion of the experiment.

The Experiment

For 45 rounds, you are going to participate in a Market Experiment with the following characteristics:

1. In the market, there are one consumer representative and two producers. The producers compete to sell their production and *you are the consumer representative*.

2. Two commodities (good 1 and good 2) which are demand substitutes (but are not identical), are supplied in the market (each one supplied by one producer). Both producers have similar costs structures.

3. Your are the representative of all potential consumers in the market. All you know about consumers preferences is that they prefer good 1 to good 2.

4. The table bellow includes levels of satisfaction (measured in ECUs, an Experimental Currency Unit) for any combination of commodities you can buy. Your earnings, at the end of each round, will be exactly the difference between your satisfaction level and your expenditure.

Good1/Good2	0	1	2	3	4	5
0	0	187	361	528	655	772
1	399	586	753	870	963	1052
2	673	790	909	1026	1115	1186
3	829	946	1046	1131	1220	1291
4	977	1064	1151	1232	1300	1371
5	1082	1169	1244	1312	1379	1437

You have to decide on your reservation price (i.e. the highest amount of money you are willing to pay for each unit of product) for *five* units of each product. To do that, you may use the following facts:

a) The reservation price schedule you submit in each round should be not monotonically increasing. That is, the highest price you are willing to pay for the second unit of any good must not be higher than the highest price you are willing to pay for the first unit of the same product, and so on and so forth.

b) Each round, your real consumption will be restricted to a maximum of 5 units of each product.

Decision making and earnings

1. Introduce (in the computer) your decisions about reservation prices and be careful to use the appropriate boxes. In a round, all units of the same product are sold at the same price: the *maximin* (the highest of the minimum prices which results from the producer's willingness to accept) which lies below some (highest) price which commes from your willingness to pay. This way, the number of units that are sold in the market is directly determined.

2. Every time you choose the highest price you are willing to pay for each unit of product, you will get specific information about the incremental value on the utility got by the consumers you represent.

3. In each round, although you have to propose five different reservation prices, all units of the same product are sold at the same market price: the highest price offer which is exceeded by your corresponding bid. Since this unit is the last one the producer is willing to sell (and you to buy), this unit is the last unit sold in the market.

4. Your earnings will be the difference between the value got from the consumption (the value reflected in the table) and the expenditure in purchasing the units.

An example: Look at the table above. If, in the previous round, you bought 2 units of good 2, your potential earnings, as a function of the units of good 1 you buy (see the correspondent column), are:

If you buy no units of good 1 consumers get a utility value of 361 ECUs,
if you buy 1 unit of good 1, consumers get a utility value of 753 ECUs,
if you buy 2 units of good 1, consumers get a utility value of 909 ECUs,
if you buy 3 units of good 1, consumers get a utility value of 1046 ECUs,
if you buy 4 units of good 1, consumers get a utility value of 1151 ECUs,
and, finally, if you buy 5 units of good 2: consumers get a utility value of 1244 ECUs.

5. In the interface of your computer, you will find boxes in which you have to write your bids for each unit of product. You also find the utility value got with the purchase. For example, if you prefer to buy one unit of product 1 rather than none, the increase in the utility value you got is 392 ECUs (the difference between 753 and 361).

Your net payment will be half of consumer earnings. The exchange rate is 10 ECUs=3 ptas.

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8. FIGURES

Figure 1. Water distribution structure in treatments 1 and 3

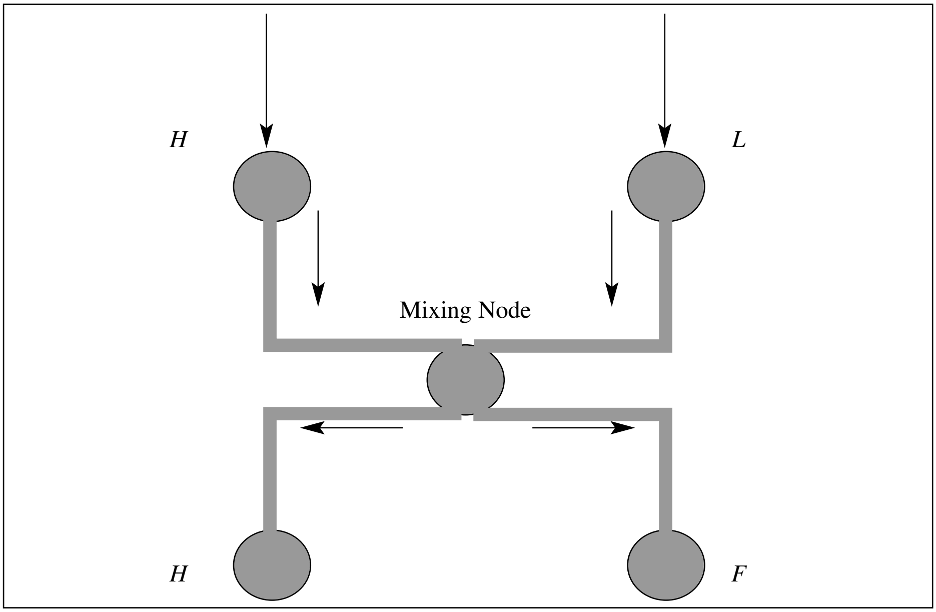


Figure 2. Water distribution structure in treatment 2

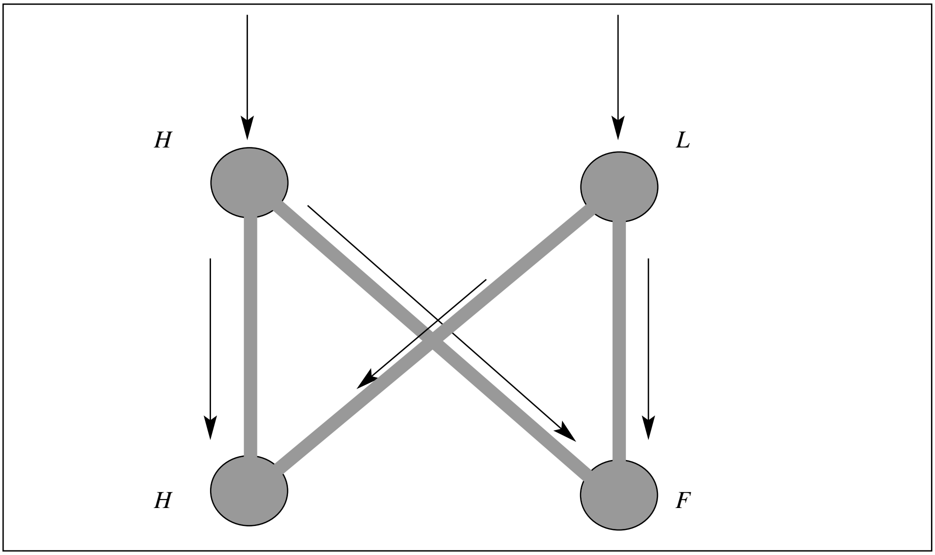


Figure 3. End-period stock: cummulative distribution for the three treatments. Vertical axis: percentage of the total stock; horizontal axis: interval of stocks

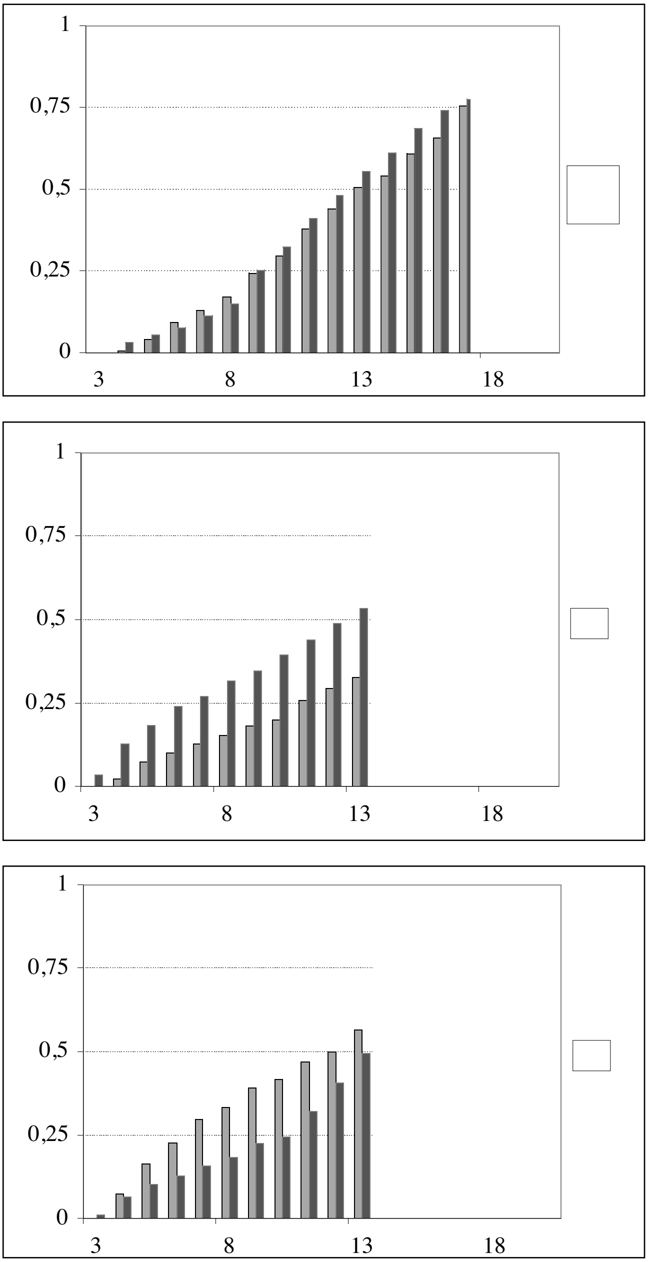


Figure 4. Average stock sizes (treatments 1-3)

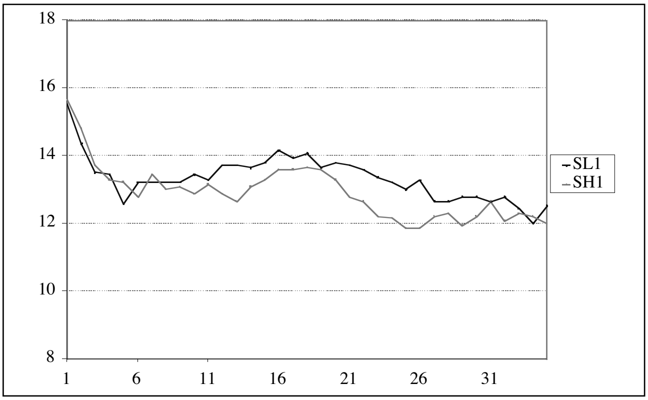


Figure 5. End-period stock: cummulative distribution for the three treatments. Vertical axis: percentage of the total stock; horizontal axis: interval of stocks

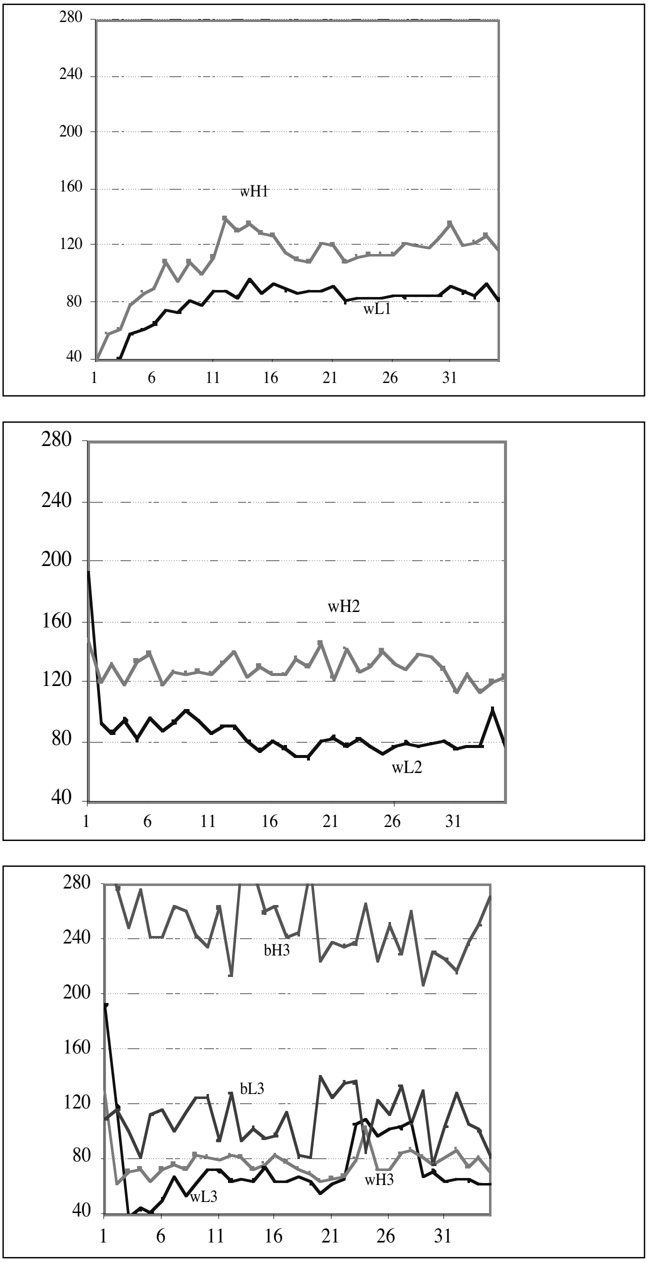


Figure 6. Average clearing prices for low/high quality water (treatments1-3)

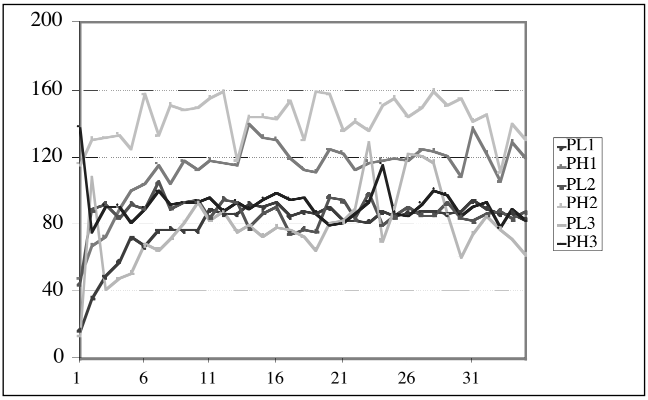


Figure 7. Average payoffs (treatments 1-3)

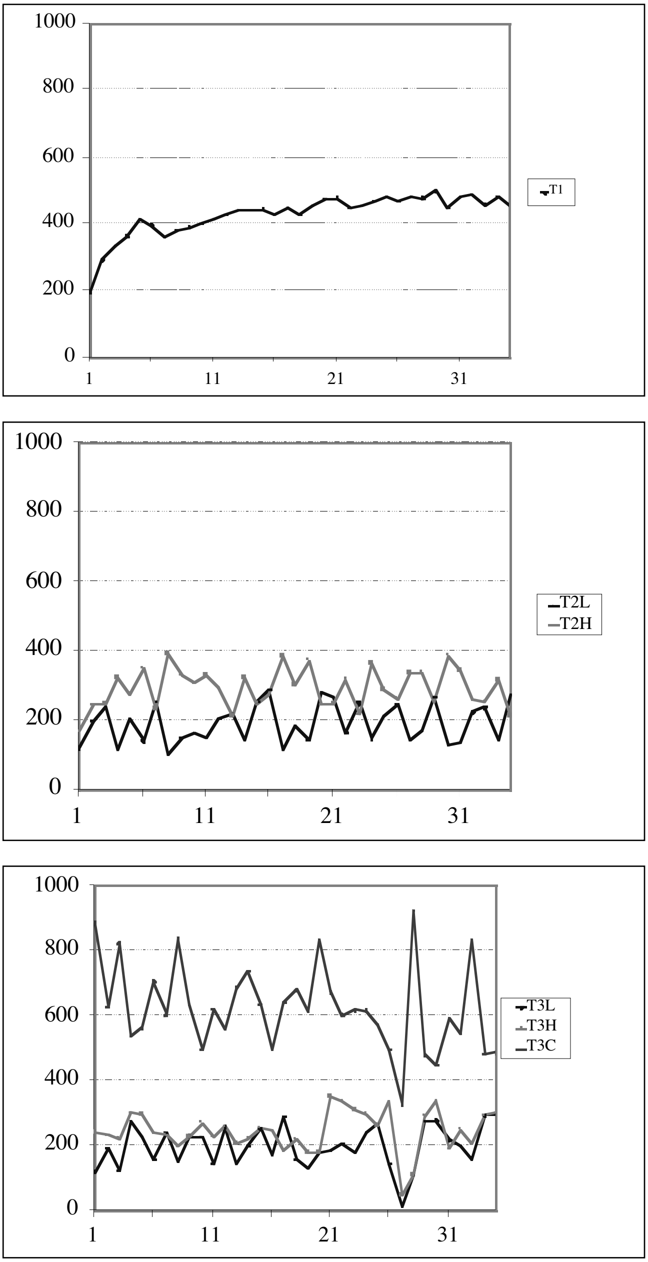


Figure 8. Average quantity sold of each quality (treatments 1-3)

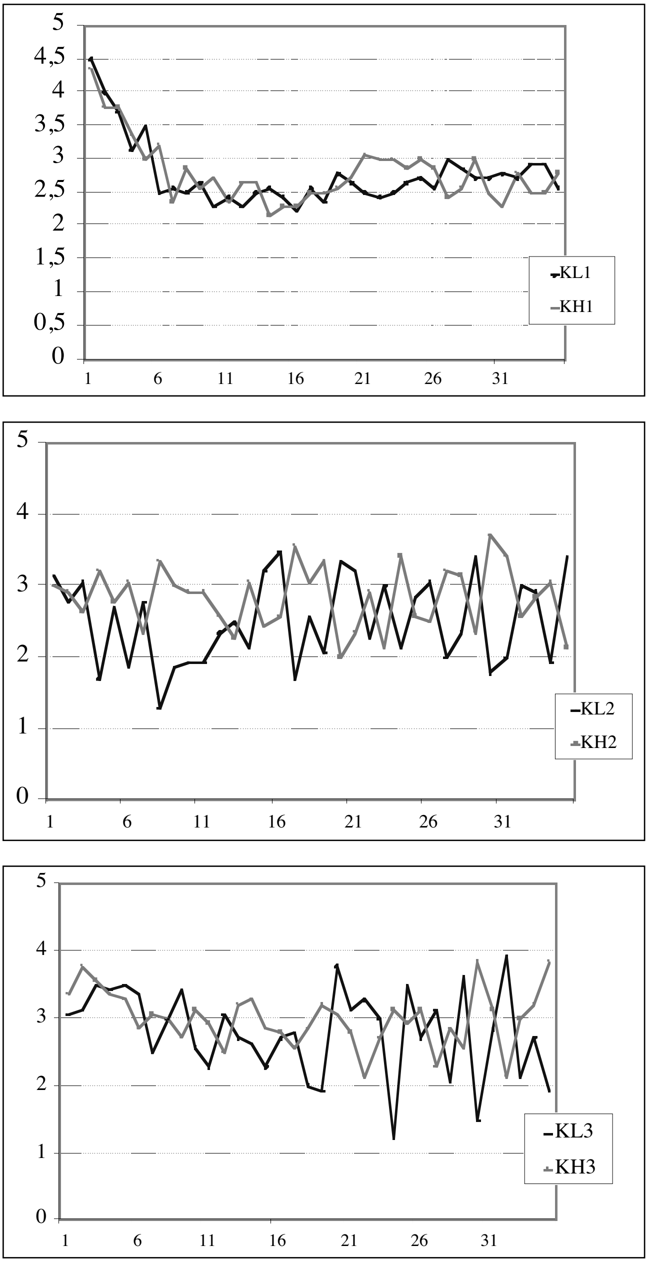
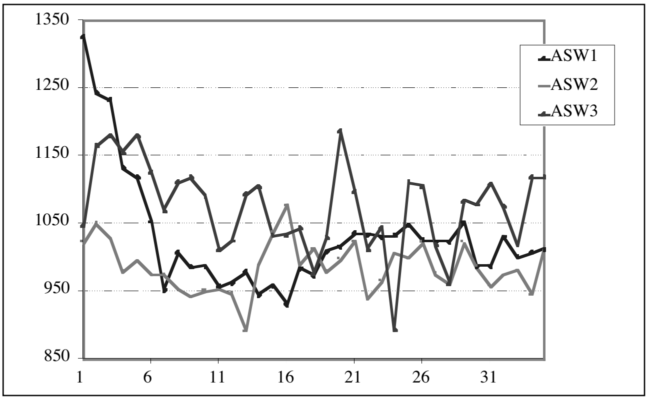


Figure 9. Average Social Welfare (treatments 1-3)



9. Tables

Table 1. Stock sizes (Low/High quality) in treatments 1-3 after 35 periods

Market	SL1	SH1	SL2	SH2	SL3	SH3
1	15	16	17	6	9	11
2	18	19	11	5	9	13
3	9	13	17	4	15	14
4	9	11	6	10	9	16
5	18	16	11	13	20	15
6	19	19	18	15	6	12
7	5	8	17	7	7	10
8	8	9	14	15	10	5
9	11	9	7	5	4	8
10	18	7	11	17	4	5
11	6	4	11	11	13	13
12	11	11	5	4	20	15
13	18	17	15	12	20	13
14	10	9	17	8	17	4
Av.	12.5	12	12.6	9.4	11.6	11

Table 2. First unit posted offers (w) in periods 1and 35 (treatments 1-3). Consumers' posted bids (b) (treatment 3).

Period	Sess	wL1	wH1	wL2	wH2	wL3	wH3	bL3	bH3
1	1	2	3	30	5	1	10	55	300
	2	300	300	11	5	4	10	82	380
	3	20	25	450	100	3	25	40	300
	4	8	18	975	300	5	10	40	260
	5	20	30	5	450	15	20	65	270
	6	2	5	900	10	12	400	125	200
	7	10	60	25	10	330	500	186	375
	8	3	4	2	350	15	300	150	250
	9	3	5	50	5	1	75	70	300
	10	3	4	6	400	300	125	115	350
	11	1	3	20	10	1000	300	187	363
	12	5	8	10	50	10	10	100	260
	13	20	80	35	60	400	10	175	350
	14	4	8	200	300	607	10	150	385
		wL1	wH1	wL2	wH2	wL3	wH3	bL3	bH3
35	1	72	92	90	150	30	65	117	399
	2	165	385	60	65	60	95	84	396
	3	65	150	60	75	65	80	47	350
	4	80	100	65	100	60	100	65	250
	5	95	110	60	99	120	65	85	388
	6	75	95	100	130	30	75	80	215
	7	70	86	80	150	77	51	89	79
	8	50	80	86	100	50	49	80	100
	9	82	93	85	90	50	99	105	200
	10	66	81	115	395	68	40	180	341
	11	85	90	75	100	25	18	25	25
	12	79	94	25	50	110	140	65	340
	13	85	90	75	120	70	74	50	325
	14	85	100	100	99	55	50	82	391

Table 3. Spearman rank correlation coefficient (rs) and t-test of time dependence of 'dise-quilibrium' offers (i.e., wL>wH)

	Treatment 1					Treatment 2					Treatment 3				
	w1	w2	w3	w4	w5	w1	w2	w3	w4	w5	w1	w2	w3	w4	W5
r_s	-0.2	-0.4	-0.2	-0.1	0.2	-0.7	-0.8	-0.7	-0.7	-0.7	0.6	0.5	0.5	0.6	0.7
t	-1.4	-2.4*	-1.3	-0.4	1.4	-6.3*	-7.7*	-5.7*	-5.2*	-5.9*	4.3*	3.1*	3.1*	4.7*	5.3*

Note: H_0: rs[t,#(wL>wH)]=0

*: rejection of H0 at a=.05-level of significance (|t|>2.04)

-: the minus sign indicates negative correlation

Table 4. *U* statistics of pairwise comparison between posted offers (treatments 1-3)

		period 1			period 35		
		T1-T2	T1-T3	T2-T3	T1-T2	T1-T3	T2-T3
Low	w1	40.5*	67.5	81	96.5	44**	81
	w2	43*	68	83	93,5	65	7.5
	w3	47*	44.5*	82	94	90	59
	w4	51*	78.5	82	89.5	86	83.5
	w5	43*	80.5	75	86	72	72
High	w1	52.5*	49.5*	93.5	81	40**	67.5
	w2	56.5	53*	92	80	38.5**	29**
	w3	56.5	61	87	47.5*	39**	14.5**
	w4	55*	57	87	45*	47**	10.5**
	w5	53*	61	85.5	46*	58.5	16.5**

Note: Note: The expected value of the *U*-statistic is 98.

H_0: equivalent distributions of offers across treatments.

* (**): Rejection of H_0 in favour of the alternative of higher offers in the latter* (former**) treatment (α=.05; U<55)

Table 5. Spearman rank (r_s) correlation coefficient and t-test of posted bids (b) and time (treatment 3)

market		b1[L]	b2[L]	b3[L]	b4[L]	b5[L]	b1[H]	b2[H]	b3[H]	b4[H]	b5[H]
1	r_s	0.67	0.53	0.37	0.34	0.40	0.62	0.09	-0.21	-0.16	0.04
	t	5.19*	3.58*	2.26*	2.05*	2.48*	4.56*	0.49	-1.26	-0.93	0.24
2	r_s	0.47	0.44	0.37	0.32	0.36	0.24	0.26	0.30	0.17	0.24
	t	3.02*	2.81*	2.27*	1.91	2.23*	1.45	1.54	1.78	0.98	1.45
3	r_s	0.16	0.15	0.17	0.14	0.10	0.31	-0.03	-0.06	-0.02	-0.03
	t	0.95	0.84	1.02	0.80	0.60	1.86	-0.19	-0.32	-0.14	-0.16
4	r_s	0.27	0.30	0.35	0.42	0.51	0.05	0.11	0.41	0.38	0.61
	t	1.61	1.80	2.18*	2.69*	3.39*	0.31	0.61	2.56*	2.33*	4.47*
5	r_s	0.45	0.49	0.35	0.23	0.15	0.49	0.24	0.16	0.22	0.20
	t	2.93*	3.20*	2.12*	1.35*	0.89	3.21*	1.44	0.90	1.29	1.15
6	r_s	0.40	0.45	0.51	0.65	0.68	-0.21	0.11	0.12	0.08	0.38
	t	2.53*	2.87*	3.44*	4.98*	5.38*	-1.26	0.61	0.70	0.43	2.36*
7	r_s	-0.21	-0.20	-0.10	-0.08	-0.02	-0.51	-0.46	-0.44	-0.37	-0.32
	t	-1.25	-1.17	-0.59	-0.46	-0.14	-3.43*	-2.99*	-2.82*	-2.30*	-1.92
8	r_s	-0.40	-0.35	-0.35	-0.21	0.02	-0.72	-0.75	-0.73	-0.62	-0.26
	t	-2.47*	-2.16*	-2.14*	-1.22	0.10	-5.94*	-6.48*	-6.12*	-4.51*	-1.52
9	r_s	0.38	0.37	0.36	0.43	0.31	-0.75	-0.33	-0.09	0.05	0.06
	t	2.36*	2.28*	2.22*	2.75*	1.84	-6.52*	-1.98	-0.49	0.29	0.37
10	r_s	0.63	0.57	0.60	0.59	0.58	0.23	0.23	0.09	-0.10	-0.14
	t	4.66*	4.00*	4.32*	4.16*	4.14*	1.34	1.35	0.54	-0.57	-0.78
11	r_s	-0.77	-0.78	-0.74	-0.57	-0.24	-0.85	-0.88	-0.89	-0.86	-0.37
	t	-6.97*	-7.05*	-6.32*	-4.00*	-1.39	-9.33*	-10.82*	-11.38*	-9.49*	-2.31*
12	r_s	-0.14	-0.16	-0.06	0.22	0.09	0.12	0.27	0.18	0.27	0.23
	t	-0.81	-0.93	-0.37	1.33	0.52	0.68	1.60	1.05	1.64	1.36
13	r_s	-0.14	-0.16	-0.06	0.22	0.09	0.12	0.27	0.18	0.27	0.23
	t	-0.81	-0.93	-0.37	1.33	0.52	0.68	1.60	1.05	1.64	1.36
14	r_s	0.13	0.14	0.19	0.19	0.19	0.26	0.33	0.46	0.21	0.36
	t	0.74	0.81	1.12	1.14	1.10	1.55	2.03*	3.01*	1.22	2.18*
Agre-gate	r_s	0.03	0.089	0.071	0.076	0.141	-0.41	-0.34	-0.46	-0.33	-0.2
	t	0.174	0.514	0.41	0.439	0.818	-2.6*	-2.07*	-2.94*	-2.02	-1.2

Note: H_0: $r_s[t,b(.)]=0$

*: rejection of H0 at a=.05 level of significance (|t|>2.04)

-: the minus sign indicates negative correlation

Table 6. Spearman rank (r_s) correlation coefficient and t-test of posted bids (b) with consumer's unit satisfaction level (for one extra unit) which was displayed on the subject's screen (treatment 3).

market		b1[L]	b2[L]	b3[L]	b4[L]	b5[L]	b1[H]	b2[H]	b3[H]	b4[H]	b5[H]
1	r_s	0.47	0.21	0.50	0.55	0.24	0.19	0.20	-0.11	-0.09	-0.04
	t	3.04*	1.24	3.31*	3.81*	1.45	1.13	1.19	-0.62	-0.51	-0.21
2	r_s	0.77	0.83	0.47	0.51	0.45	0.90	0.94	0.89	0.69	0.76
	t	7.03*	8.46*	3.07*	3.40*	2.93*	11.76*	15.64*	11.02*	5.44*	6.69*
3	r_s	0.34	0.17	0.08	0.07	-0.20	-0.05	0.35	0.16	0.22	-0.05
	t	2.05*	0.97	0.47	0.40	-1.17	-0.31	2.16*	0.96	1.31	-0.31
4	r_s	-0.02	0.06	0.02	0.09	0.09	-0.14	0.33	0.43	0.23	0.37
	t	-0.11	0.33	0.10	0.52	0.50	-0.78	2.02*	2.72*	1.35	2.28*
5	r_s	0.63	0.35	0.19	-0.17	-0.20	0.15	0.88	0.24	0.00	-0.06
	t	4.63*	2.13*	1.14	-0.96	-1.18	0.84	10.41*	1.39	-0.01	-0.33
6	r_s	0.14	0.26	0.21	0.31	0.75	-0.37	0.44	0.44	0.32	0.30
	t	0.80	1.53	1.26	1.87	6.56*	-2.27*	2.85*	2.78*	1.92	1.83
7	r_s	-0.18	-0.41	-0.41	-0.33	-0.25	-0.26	-0.36	-0.18	-0.11	-0.25
	t	-1.03	-2.56*	-2.55*	-2.02*	-1.48	-1.54	-2.23*	-1.05	-0.61	-1.48
8	r_s	-0.43	-0.41	-0.44	-0.44	-0.24	0.09	0.03	-0.08	-0.03	-0.45
	t	-2.76*	-2.61*	-2.83*	-2.83*	-1.42	0.52	0.18	-0.47	-0.19	-2.86*
9	r_s	0.22	0.20	0.18	0.36	0.11	0.33	-0.24	0.19	-0.05	0.06
	t	1.30	1.17	1.06	2.19*	0.65	2.03*	-1.41	1.13	-0.29	0.35
10	r_s	0.54	0.27	0.55	0.47	0.62	-0.01	0.02	-0.04	0.23	0.41
	t	3.65*	1.61	3.74*	3.05*	4.50*	-0.04	0.11	-0.25	1.37	2.59*
11	r_s	-0.74	-0.67	-0.66	-0.66	-0.38	-0.68	-0.63	-0.56	-0.55	-0.36
	t	-6.24*	-5.16*	-5.08*	-5.10*	-2.34*	-5.33*	-4.61*	-3.91*	-3.79*	-2.24*
12	r_s	-0.01	0.00	0.26	0.72	0.44	0.12	0.29	0.30	0.57	0.18
	t	-0.07	0.01	1.55	5.88*	2.85*	0.71	1.77	1.78	4.01*	1.06
13	r_s	0.26	0.10	0.08	0.25	0.00	0.07	0.13	-0.06	0.32	0.04
	t	1.52	0.57	0.46	1.46	0.00	0.41	0.75	-0.34	1.94	0.21
14	r_s	0.64	0.75	0.82	0.68	0.78	0.91	0.64	0.96	0.70	0.44
	t	4.79*	6.43*	8.31*	5.39*	7.12*	12.53*	4.84*	19.39*	5.57*	2.85*

Note: H_0: r_s[b(.), u'(.)]=0

*:rejection of H0 at a=.05 level of significance (|t|>2.04)

-: the minus sign indicates negative correlation

Table 7. Average profits for each type of firm and each water quality (treatments 1-3), and levels of satisfaction (on average) for the monopsonist (C3) in treatment 3. Spearman-rank (r_s) correlation coefficient and t-test of time dependence for subjects' payoffs

Treat.	Market	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Tr.1	Av. P tot.	456	538	476	485	502	261	476	405	422	408	199	438	450	505
	r_s	0.18	0.68	0.15	0.51	0.51	0.03	-0.30	0.53	0.76	0.62	0.80	0.63	0.58	0.70
	t	1.06	5.28*	0.87	3.38*	3.39*	0.16	-1.50	3.59*	6.64*	4.48*	7.64*	4.63*	4.07*	5.63*
	Av. P (L1)	196	222	188	210	209	113	188	185	188	168	109	196	193	228
	r_s	0.12	0.85	0.01	0.37	0.28	0	-0.30	0.33	0.60	0.40	0.73	0.52	0.29	0.50
	t	0.69	9.31*	0.08	2.3*	1.68	-0.20	-1.50	2.03	4.35*	2.52*	6.07*	3.53*	1.74*	3.36*
	Av. P (H1)	260	316	288	275	293	148	288	220	234	240	89.9	242	257	277
	r_s	0.22	0.28	0.08	0.32	0.16	0.24	0.27	0.47	0.70	0.48	0.76	0.32	0.25	0.38
	t	1.30	1.65	0.45	1.92	0.93	1.45	1.58	3.05*	5.57*	3.18*	6.76*	1.96	1.49	2.36*
Tr. 2	Av. P (L2)	177	316	170	184	208	160	166	261	206	271	211	120	216	194
	r_s	0.12	0.29	0.19	0.12	0.16	0.14	0.29	0.07	-0.4	0.61	0.13	-0.3	0.07	0.30
	t	0.69	1.74	1.12	0.72	0.95	0.83	1.73	0.40	-2.5*	4.42*	0.74	-1.6	0.38	1.82
	Av. P (H2)	321	170	347	355	325	380	315	347	195	298	282	156	338	309
	r_s	-0.20	0	-0.40	-0.20	0.19	0.34	0.07	0.56	-0.20	0.61	0.65	-0.40	0	0
	t	-1.20	-0.20	-2.2*	-1.30	1.08	2.08*	0.40	3.83*	-1.10	4.39*	4.92*	-2.40	-0.10	-0.30
Tr. 3	Av. P (L3)	101	142	202	134	199	183	211	148	142	154	79.5	241	197	268
	r_s	0.34	0.20	0.21	0.27	0.19	0.24	0.10	0.43	-0.10	0	0.02	0.14	0.11	0.26
	t	2.07*	1.18	1.22	1.59	1.13	1.4	0.57	2.77*	-0.50	-0.20	0.10	0.81	0.65	1.57
	Av. P (H3)	212	288	237	232	249	222	204	174	329	207	166	286	231	143
	r_s	-0.10	0.28	0.02	0.53	0.25	0.47	-0.10	-0.40	-0.30	-0.40	-0.70	0.57	0.28	0.63
	t	-0.30	1.70	0.12	3.57*	1.50	3.05*	-0.60	-2.4*	-1.70	-2.7*	-5.4*	4.02*	1.68	4.68*
	Av. P (C3)	746	631	660	656	581	717	579	731	628	608	517	558	587	595
	r_s	-0.59	-0.29	0.02	-0.71	-0.28	-0.57	0.25	0.56	-0.45	-0.14	0.25	-0.36	0.20	-0.48
	t	-4.23*	-1.77	0.13	-5.8*	-1.65	-3.95*	1.51	3.92*	-2.89*	-0.83	1.46	-2.22*	1.19	-3.17*

Note: The null hypothesis is H_0: $r_s[t, \pi_i(t)]=0$. The asterisk (*) represents a rejection of H_0 at α=.05 level of significance (|t|>2.04). The sign (-) indicates negative correlation

Table 8. Average allocated quantity of each water quality (treatments 1-3)

Market	KL1	KH1	KL2	KH2	KL3	KH3
1	2.23	2.26	1.71	3.17	3.23	3.17
2	1.49	1.09	2.09	3.34	3.23	3.14
3	2.77	2.91	1.89	3.29	2.91	3.03
4	3.23	3.17	2.89	3.03	3.23	2.83
5	2.60	2.80	2.69	2.80	1.94	3
6	1.46	1.40	1.77	2.91	3.29	3.09
7	3.14	3.06	1.74	3.29	2.86	2.94
8	3.26	3.23	2.94	1.31	2.57	3.11
9	3.20	3.23	3.26	3.34	3.37	3.26
10	2.80	3.29	3.14	0.86	3.11	3.26
11	3.34	3.37	3.17	3.14	1.66	2.23
12	3.17	3.17	3.34	3.37	2.89	2.94
13	2.77	2.91	2.43	3	2.14	2.71
14	3.23	3.23	2.11	2.97	2.97	3.37
Average	2.76	2.79	2.51	2.84	2.81	3.01
median	2.97	3.11	2.56	3.09	2.94	3.06

Table 9. Average social welfare (*ASW*) in each market and on aggregate. Spearman-rank correlation coefficient (r_s) and t-test of time dependence of social welfare in each market (treatments 1-3)

Treat-ment	Market	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Av.
1	*ASW*	942	674	1053	1140	1070	692	1105	1115	1123	1117	1009	1146	1082	1164	1031
	r_s	0.50	0.54	0.05	-0.41	0.03	-0.36	0.16	-0.33	-0.03	-0.18	-0.68	-0.53	-0.53	-0.08	-0.1
	t	3.31*	3.68*	0.27	-2.61*	0.18	-2.23*	0.93	-1.98	-0.19	-1.06	-5.30*	-3.59*	-3.56*	-0.45	-0.59
2	*ASW*	995	923	1027	1058	1058	1006	994	839	1021	773	1102	919	1072	1014	986
	r_s	-0.02	-0.11	0.33	-0.01	0.77	-0.27	-0.20	0.16	-0.88	0.11	-0.06	-0.59	0.30	0.38	-0.07
	t	-0.10	-0.64	2.01	-0.08	6.96*	-1.64	-1.19	0.96	-10.39*	0.63	-0.34	-4.21*	1.78	2.33*	-0.4
3	*ASW*	1059	1061	1098	1022	1029	1122	994	1053	1100	969	762	1085	1016	1006	1075
	r_s	-0.56	-0.27	-0.03	-0.23	0.15	-0.17	0.16	0.40	-0.61	-0.37	0.01	-0.15	0.25	-0.28	-0.27
	t	-3.86*	-1.60	-0.18	-1.36	0.87	-0.98	0.94	2.51*	-4.37*	-2.26*	0.07	-0.85	1.48	-1.66	-1.63

Note: The null hypothesis is H_0: r_s[t, *SW*(t)]=0. The asterisk (*) represents a rejection of H_0 at α=.05 level of significance (|t|>2.04). The sign (-) indicates negative correlation

Table 10. Resource losses by each quality water (treatments 1-3) due to under-exploitation (units of recharge which did not enter the respective basin)

	Resource Loss L	Resource Loss H	#(KL < 3)	#(KH < 3)	#(KL = 3)	#(KH = 3)
T1	216	189	195	200	147	157
T2	334	199	218	210	153	110
T3	225	119	180	178	92	100

Note: Symbol # notes the number of observations in which the quantity felt short of the constant periodical recharge