Experimental Economics and Political Decision Making

LINEEX Working Paper 12/00

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Mixture and distribution of different water qualities: An experiment on alternative scenarios concerning vertical structure in a complex market[†]

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[†] The authors would like to thank Santiago J. Rubio for helpful comments. The research whose results are reported here, was financed by the International Foundation For Research in Experimental Economics (IFREE), the Economis Science Laboratory of the University of Arizona and the TINKER Foundation. The authors are grateful for the support received by the three organizations. The results presented and the conclusions drawn do not necessarily express the opinion of the financing institutions. Any remaining errors are the authors' responsibility alone.

Abstract

We set up a model of water management, which is inspired by the possibility of mixing water of different qualities. Water is supplied to two types of consumers with different preferences for water quality and quantity. A distributional knot may exist which optimally distributes the supplied water in the downstream market. Different scenarios compare experimentally the advantages of a centralized *versus* a decentralized resource management. We conducted experiments with 14 markets in three different settings, labelled as “upstream monopoly”, “upstream duopoly” and “duopoly-monopsony”. We find that a two-product monopoly performs better than the duopoly regarding social welfare and volatility with respect to prices and production. Especially, the centralization of information enhances learning in the market considered. An interesting observation is that monopolistic subjects post much lower price offers at the outset of the experiment than duopolists do. However, in the course of the experiment production is lower and prices are higher in the monopolistic structure. In the duopoly-monopsony case, monopsonistic subjects failed to exercise market power and market prices did not reflect correctly the differences in qualities. Nevertheless, increased upstream competition and downstream market power helped to mitigate the waste of resources in the economy.

1 Introduction

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. in the equilibrium of an open access economy complete rent dissipation of the natural resource prevails while a sole owner of the resource would internalise externalities and thus conserve the resource better. 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 in a recent study; indeed, an increase of the industry size was observed to 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, also, 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. Gardner, Moore and Walker (1997) observed in an experiment with a static setting that with a lower number of extractors from a common basin higher efficiency results, though in any case below the expected non-cooperative equilibrium values. Herr, Gardner and Walker (1997) observed in a water pumping game experiment (with limited entry) that subjects in an intertemporal setting acted even more myopically and less successfully than in a (static) time-independent setting. From their results they suggested that the tragedy of the commons in a world with minimal institutional constraints on behaviour indeed existed and that myopic behaviour in a time-dependent setting exacerbated this problem.

In all of these papers, dynamic and static efficiencies relate to horizontal externalities due to competition in the extraction of a common resource. However, it is reasonable to assume that downstream competition (in distribution or in the final good market) competition among firms extracting from independent resources may also result in an inefficient outcome.

The experimental setting in this paper does not consider competition in the extraction of the resource in that property rights are assigned to a sole owner.[1] In the economy considered here, there are two sources of different qualities. Producers, who extract from their respective owned resource stock, have to take account of the intertemporal consequences of their decisions. Importance is also given to the demand side of the economy, which is represented by two different types of consumers, i.e., households and farmers. The resource may be subject to mixing and purification, since households demand a minimum resource quality.

The experimental design focuses on three different levels of complexity, which are characterised through the number of different types of (human) agents,[2] and their ignorance of the market conditions and demand shocks. Our interest in such a complex setting relates to some market features which are, on the one hand, rather specific to the case of water markets and which, on the other hand, have been studied in the experimental literature of industrial organisation. Several results in the literature indicate factors that may be responsible for observed shortcomings of human behaviour in complex environments. Among such factors, we mention misperception of feedback in complex environments (Paich and Sterman (1993) and Sterman (1994))

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[1] By defining property rights we concentrate on the effects which arise from the (alternative) institutional market designs and neglect the ‘public good’ nature of the resource. The public good component in water pumping games arises from the externality of individual extraction on the water table, and thus affects the pumping costs of all others that extract from the same basin.

and limitations in subjects' learning when exposed to strategic complexity (Richards and Hays (1998)), market- (García-Gallego and Georgantzís (2001)) and product-specific (García-Gallego et al. (2000)) asymmetries or multi-task problems. In fact, a number of factors favouring subjects' improvements of performance in the aforementioned cases have been identified in the literature, also. Trial-and-error algorithms have been shown to facilitate convergence of the strategies played by uninformed subjects towards symmetric, full-information equilibrium predictions (García-Gallego (1998) in a price-setting oligopoly and Rassenti et al. (2000) in a quantity-setting one).

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

2 Theoretical framework and the social optimum

Water differs from other natural resources in that it is essential to life such that all human activity is based on its usage. The multiplicity in the usage of the economic good water spreads from water 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 form and might be subject to irreversibility, to let alone the problems accruing to the resource's spatial and temporal dimensions.

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[2] Indeed, the here mentioned complexity induces different levels of market power.

Due to the aforementioned complexity, hydro-economic models in the literature, e.g. Burt (1964), Castro, Martinez and Rubio (1994), Rubio and Casino (1999), etc., usually involve a partial equilibrium analysis. Importance has been given to the definition of the property rights, since the optimal management policy depends crucially on it. Although in the case of surface water, exclusion from extraction may be hard to enforce, land ownership may restrict access to aquifers (dams of groundwater).

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 water resource stocks (aquifers) S_H and S_L from which 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, second derivatives are positive.

We consider the possibility that the resources differ in their respective water qualities. Quality of water in an aquifer may be lower due to marine intrusion or due to infiltration of fertiliser from agriculture production. 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:

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

Quality of potable water should weakly exceed the constant minimum quality standard Q_{min}, where $Q_H > Q_{min} > Q_L$. Mixed water 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 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 $C_{\Delta Q}(K, \Delta Q, Q_0)$, is assumed to satisfy the following conditions.

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

A centralised knot may exist which co-ordinates the resource flow between the sources and the consumers. The principal objective of the distribution knot is the centralisation of the decisions about quantity and quality supply and the distribution to the respective consumers.[3] More details about the peculiarities of the knot will be provided below in section 3.

Suppose there are many consumers in the economy who can either be represented by one of two types: i) the households *hh* 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 (*F*) prefer more quantity of each product to less. However, households (*hh*) demand a water quality, which exceeds weakly the 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 *hh* will be the maximum between the minimum quality and the mixed quality. Thus, $Q_0 = Q_M$ and

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

Let the *hh* take the purification cost into account in their utility function and assume the utility functions $U_{hh}=U_{hh}(K_{hh},Q_{Mhh})$ and $U_F=U_F(K_F,Q_{MF})$ (where $K_{hh}=K_{Hhh}+K_{Lhh}$, and $K_F=K_{HF}+K_{LF}$) of the respective consumer-types to be twice differentiable with respect to quantity and mixed quality. *F*s' utility is increasing in both arguments, while depending on the purification cost function, the utility function of *hh* 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, also. The indirect social welfare function $V(K_H,K_L)$ which maximises consumer surplus for a given quantity of water can be described as follows:

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[3] See distribution schemes in the Appendix A, in which M denotes the knot.

$$V(K_H, K_L) = \max_{K_{Hhh}, K_{Lhh}} U_{hh}(K_{Hhh}, K_{Lhh}, Q_{Mhh}; K_H, K_L) + U_F(K_{HF}, K_{LF}, Q_{MF}; K_H, K_L)$$

$$s.t.$$

$$(i) \quad K_H = K_{Hhh} + K_{HF}$$

$$(ii) \quad K_L = K_{Lhh} + K_{LF}$$

$$(iii) \quad Q_{Mhh} = \frac{Q_H K_{Hhh} + Q_L K_{Lhh}}{K_{Hhh} + K_{Lhh}}$$

$$(iv) \quad Q_{MF} = \frac{Q_H K_{HF} + Q_L K_{LF}}{K_{HF} + K_{LF}}$$

As a benchmark to our experimental results we may be interested in the socially optimal solution of water supply. Given the assumptions above, we are able to formulate the program that maximises social welfare. 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. 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 δ > 0 denote the social rate of discount, and t_0 the starting time of extraction. We can formulate the intertemporal objective function in the following way:

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

$$s.t.$$

$$(i) \quad \frac{dS_{Ht}}{dt} = \begin{cases} -K_{Ht} + a_H, & if\ S_H < S_H^{\max} \\ S_H^{\max}, & otherwise \end{cases}$$

$$(ii) \quad \frac{dS_{Lt}}{dt} = \begin{cases} -K_{Lt} + a_L, & if\ S_L < S_L^{\max} \\ S_L^{\max}, & otherwise \end{cases}$$

$$(iii) \quad S_{Ht_0} = S_H^{\max}$$

$$(iv) \quad S_{Lt_0} = S_L^{\max}$$

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

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

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

These equations (simultaneously) determine the steady-state standing-stocks of S_H and S_L. The equations 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. The first two of the three terms, which are all positive, represent the marginal costs which result from extracting a quantity of K_H (respectively K_L) from the stock S_H (S_L). The last term reflects the shadow price of the resource, i.e., the implied costs induced by a lower water table, which are imposed on all future extraction.

3 Experimental parameters and design of market institutions

The experiments whose results are reported here were conducted at the Laboratorio de Investigación en Economía Experimental (LINEEX) situated at the University of Valencia. Three treatments with 14 independent markets were studied in which a total of 82 subjects participated. They were recruited –following standard recruitment procedures- among undergraduate students of Economics at the University of Valencia. Urs Fischbacher's software *z-Tree 2011* was used for the design. An experimental session took 2 – 2.5 hours and subjects earned an average of 3500 ptas (20 $).

Given the above model, the following parameters were used in the experiment:

(i) For the recharge (a_H, a_L) = (*3, 3*);

(ii) For the initial and maximum stock sizes $(S_H, S_L) = (20, 20)$;

(iii) For the qualities of water, $(Q_H, Q_L) = (5, 1)$ and for the minimum quality standard demanded by the household $Q_{min} = 3$;

(iv) The utility and cost functions used are provided in Appendix A. For the sake of simplicity, the discount rate was taken equal to unity, $\delta = 1$. 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 $(K_{Hhh}, K_{Lhh}) = (2.55, 0)$ and $(K_{HF}, K_{LF}) = (0.45, 3)$ are assigned respectively to the *hh* and the *F*.

Subjects were told that sessions would last 45 periods. However, in order to avoid end game behaviour, we stopped sessions after the 35th period. For the last ten periods subjects received lump sum the highest payoff achieved by any subject in one period of the session.[4]

3.1 Experimental design

From the model there arise several problems of how to set it up in the laboratory. For instance, although one main characteristic of the resource may be that it can be supplied almost continuously, in the laboratory there exist clear restrictions to model continuity. Another non-trivial design problem arises from the institutional design question of how the resource should be allocated.

Table 1

In the experiment, we neglected the continuity property of water supply, and subjects were not introduced to the whole complexity of the problem they would face. No explicit reference was made to water in the instructions aiming at a no-label

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[4] When discussing the experimental results below, the 35th period, thus, will be paid most attention.

experiment. However, answers to subject questions were given on the basis of examples from the water market modelled here. Subjects who acted as producers knew their 'type' in the sense that they were conscious about consumers' preference of the one good over the other (high quality good versus low quality one). Moreover, they knew that their products were demand substitutes (though not identical) and that their production cost structures were identical as they received a table with their unit costs depending on the stock size (see Table 1 and the instructions in Appendix C). Consumers and producers were introduced separately to their tasks and did not know about the restrictions (see below) on the other side of the market. Consumers received specific information about the increases in their satisfaction from each additional unit bought. Producers received specific information about the unit costs of each unit that they were going to sell. This detailed information was provided at any instance on their computer screens. Obviously, it was private information and not accessible for the other market side; a history window would display all past outcomes regarding own decisions, quantities, payoffs and market prices. Both producers and consumers were asked to decide each period about their respective reservation prices. Each producer was able to sell up to five units of his resource in the market and had to post simultaneously five sealed offers which should equal the minimum price at which they were willing to sell the respective unit.[5] Subjects who would sell two products had to post five sealed offers for each product. The offers had to exceed weakly the cost for the corresponding unit and offers of subsequent units would have to be non-decreasing. On the *consumer* side, subjects would have to submit five sealed bids for each product, which had to be non-increasing for subsequent units and at most as high as the benefit that would arise from one unit extra. The bids should reflect the

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[5] The quantity limitation emerged from the time restrictions of experimental exposition.

maximum price at which subjects were willing to purchase an additional unit. Subjects knew that the units of the same product in a period would be sold at the same market price.

3.2 Experimental market institutions

As stated above, we wanted to study different market institutions and we were especially interested in how the existence of a distribution knot would influence in the described resource management problem. We distinguished the following market structures:[6]

Treatment 1 involved a (centralised) joint ownership of both sources on the upstream market, and a simulated distribution mechanism downstream. One subject was posting offers for both sources. Given these offers, the maximal consumer rent was determined in the simulated (centralised) downstream market: $V(K_H, K_L) - oK$, where o denotes the vector of sealed offers and K denotes the vector of quantities; $V(.)$ can be read from Table 1. Thus, the bundle of high quality and low quality resources which produced the highest consumer rent was allocated in the economy, and the corresponding offers of the subject would establish the clearing prices (subjects were not informed about this market clearing procedure).

Treatment 2 entailed separate (decentralised) ownership upstream and a simulated separate (decentralised) utility maximisation downstream. The subjects who were acting as producers did not receive information about how markets would clear and what influence the price of the competitor would have on the own demand. Although they posted their offers simultaneously, markets cleared in a random order

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[6] For the ease of exposition, Treatment 1 entails one subject, Treatment 2 and 3, two and three subjects, respectively.

determined by the computer.[7] However, a mechanism was introduced aiming at mitigating these random shocks and at avoiding inefficient outcomes in which consumers buy too much of the product which least fits their specific needs. 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: in the case that the low quality market opened first, the simulated farmers maximised their utility assuming not to make any deal in the other market, and vice-versa (the simulated households) if the high quality market opened first.[8] In the posterior market the demand of the preferred consumer and the residual demand of the other consumer would be served.

In Treatment 3, every market consisted of three experimental subjects. Two of them, the two owners of the sources, were on the (decentralised) supply side of the market; the third one, a consumer representative, would be on the (centralised) demand side.[9] The subject downstream acted as a monopsonist since she/he was awarded half the consumers' rent as a profit. She/he would distribute the resources optimally after having acquired them during the market day. A market day would comprise a sequence of two markets as in Treatment 2, in which the subject who acted as the consumer representative would subsequently buy in both markets which opened in a random order. In the second market the number of units, which were purchased in the first market, were taken into account.[10] The market-clearing price would be determined by means of comparison the unit offers and the unit bids. The highest

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[7] We introduced a chance move, because we were not interested in a systematic Stackelberg market structure. The chance move introduced demand shocks to the system, whose effects may be noticed in Figures 1-8 below.

[8] See Appendix A for the unit utilities of households and farmers.

[9] At the beginning of a session, both producers and the consumer representatives were randomly chosen between all experimental subjects to create the 14 experimental markets.

minimum price (coming from the producer's price offer) for some unit exceeded by the maximum price for the same unit which the consumer were willing to pay (coming from the consumer's bid) would determine the market clearing price. Thus, the quantity would be determined too.

4 Results

This section is organised in three subsections. The first subsection 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, welfare and efficiency comparisons of the three treatments are undertaken in the third subsection.

Figure 1

(i) Stock data

In Figure 1 the distribution of the end-period stock sizes is presented. Stock sizes below the socially optimal hydrological steady state stock size of (4.8; 5.0) 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 the different scenarios resulted in different resource-management. It can be seen from Figure 1 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 2

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[10] On subjects’ screens the maximal satisfaction level associated with the consumption of an additional unit would be displayed

Table 2 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.[11] Another common feature can be seen in Figure 2, in which we can observe a declining tendency in stocks during the course of the sessions. However, this tendency is much weaker in Treatment 1, in which it is only significant during the first 5 periods approximately. 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 producer-subjects 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 tendency is produced indicates that producer-subjects 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 it 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 underexploitation of the resource by firms who are competitors in the downstream market.

Figure 2

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[11] Throughout we use a α=.05-level of significance. We use standard tests from Siegel et al (1988).

(ii) 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.[12] That is, the high quality resource 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 means 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 the producers.

Figure 3

Figure 3 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 3 in the Appendix reports the posted offers for the first unit which were observed in the 1st and 35th periods of each treatment.

In the first period, the monopolistic subject in Treatment 1 never posted a higher offer for the first unit of low quality water than for the high quality one; in the same period, the rest of the units were also offered at prices which (qualitatively) reflect correctly the quality differences. Only three times (out of seventy possibilities)

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[12] 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.

an inverse order was observed. Along the 35 periods of the experiment, 155 times (out of 2450) low quality water was offered at a higher price than high quality one. The frequencies with which this event was observed in the 35 periods of each treatment are plotted in Figure 4. Given that excessively high price-offers for the last units (mainly, the 4th and 5th) were often posted by seller subjects as a means of controlling that their sales did not exceed the desired level, the frequency of the event of a higher price-offer for the low quality is highest for the fifth unit. In fact, in most of the occasions in which seller-subjects posted a higher price offer for low quality water than for high quality one, the corresponding unit of low quality was not sold. On the other hand, in some cases subjects were able to increase their sales of high quality water (and selling less low quality's) by raising low quality water's prices. The graph of Figure 4 peaks three times at four, i.e., four subjects posted (by chance) in the same period a fifth offer which was higher for the low quality unit than for the high quality unit. In all other cases there were significantly less observations of higher price-offers for low quality than for high quality water.[13]

Figure 4

Unlike the monopolist in Treatment 1, sellers of low quality water in treatments 2 and 3 lack any incentive to post higher prices 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)

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[13] The null-hypothesis of equal number of low and high offers of can be rejected by a one-tailed Binomial test at a α=.05-level of significance.

U-test in any of treatments 2 and 3. In Treatment 2, the low quality producer posted a higher price offer for the 1st (2nd, .., 5th) unit of his/her product in 8 (8, 7, 7, 6) out of the fourteen markets. In fact, price offers by the sellers of low quality water were on average higher than those posted by the seller of high quality water. In Treatment 3, the average price offer posted by the seller of low quality water was also higher than the average price offer posted by sellers of high quality water. Nevertheless, there are only 4 (5, 5, 4, 4, for the rest of the units) observations in which the price offer posted by the seller of low quality was higher than the corresponding offer posted by the seller of high quality.

Table 4

In the thirty-fifth period, the 1st (respectively, 2nd, .., 5th) price offer posted by the seller of low quality water 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(s) in Treatment 2. As can be seen from Figure 4, during the experiment, the number of times that the low quality producer posted higher offers (for any unit of his/her product) than the low 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 at the α=.05-level of significance (favouring a positive trend).

In few words, treatments 1 and 2 have produced a far more reliable representation of quality differences on price offers as compared to Treatment 3 in which a tendency towards equalisation of the offers across products exists. This somehow paradoxical result reminds us of what has been observed in different experimental settings in which subjects were faced with some relatively complex problem and in which some asymmetry existed yielding a theoretical prediction of asymmetric playing by subjects. A first observation is thus that the subjects who acted as monopsonistic distribution knots have influenced the market outcome in a sense that tends to distort over time the expected difference in prices as a result of the difference in qualities.

In Treatment 2 and 3, the average offers were lower in the 35th period than in the first period 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 the 35th period than in the first one. In the first period, the first unit of low quality water was offered at a higher price than the same unit of high quality water only in one observation. In all markets and in all three treatments it is observed that subjects who submitted in period 1 offers below 100 posted higher offers in the 35th period, and those who posted offers above 100 posted lower offers in the 35th period.

Table 5

The comparison of offer prices across treatments yields that, in the first period, the monopolistic subjects (Treatment 1) posted lower offers than the duopolistic ones (Treatment 2 and 3). The Mann-Whitney U-test rejects the null hypothesis of equal offer-prices in Treatment 1 and Treatment 2 in most occasions indicating lower offers in Treatment 1. A comparable result is obtained between Treatment 1 and Treatment 2 for some units (especially for the sellers of high quality water), as can be seen from Table 5. It is surprising that, in the duopoly, the offers are higher than in the monopoly, since static theory would predict the contrary. Considering the dynamic nature of the experiment, an interpretation for this apparently odd behavioural 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 the monopoly, subjects approach equilibrium prices from below as has been already pointed out in other experimental studies (see, especially, García-Gallego (1998)). To conclude, it seems that high first-period prices are rather specific to oligopolists' strategies aiming at establishing the collusive outcome. On the contrary, low first-period prices seem rather specific to monopolists' strategies aiming at reaching from below the initially unknown optimal strategy. A further factor which may favour this kind of behaviour observed in the case of monopolistic subjects may be found in the priors of our subjects, who may, initially, apply theories based on real world situations in every new situation they are faced with. In this sense, promotion of new products with low prices may be a strategy, which may be the aim of our subjects in Treatment 1, although it seems not reasonable in our context. On the other hand, the first-period price offers in Treatment 2 and those in Treatment 3 are not stochastically different from each other. However, 35th-period offers in 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 the offers posted by sellers of high quality water down.

Figure 5

The resulting prices reflect what has been stated above: In period 1, prices of high/low quality water across treatments are stochastically equivalent. Figure 5 presents a chart of the average prices in the experiment. In Treatment 1, the average prices increase significantly over time, which can be demonstrated 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 high quality price decreases and the low quality price increases. However, these observations are statistically insignificant at the $\alpha=.05$-level. 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 in the course of the experiment.

On the demand side of the market, in Treatment 3, monopsonistic subjects posted bids for high quality and low quality units. The average bids for the first unit are plotted in Figure 3. As would have been expected, subjects use their market power to influence market prices through their bids. As can be conjectured from the chart, average bids for units of high quality water decrease, while bids for low quality units remain stable over time. Nevertheless, based on individual data, we find that only in four markets a significant decrease of the bids (Table 6 in the Appendix) is observed, while, in one of these four markets, the decrease is only observed for the first unit. In the other three cases, market power has been exercised by downstream subjects who posted very similar bids (negatively correlated with time) for the units along the periods of each session. The volatility of the first unit average bids presented in Figure 3 stems from shock caused by the random order of market openings. Except from the three markets (7, 8, 11) mentioned above, the correlation between the satisfaction for one extra unit (displayed on subjects' screens) and the bids is usually positive and, in many cases, significant.

A non-negligible part of the subjects (10 out of 14) would post different offers depending on the order in which markets opened (see Table 7 in the Appendix). Some subjects (at least 3 out of 14: in markets 2, 10, 14) nearly copied 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 behaviour and were transmitted to upstream markets.

Figure 6

As a consequence of the observations above, the profits of the monopsonistic subjects in Treatment 3 decrease significantly over time (see Table 8 and 9 in the Appendix). Yet, in markets 7, 8, and 10 in which subjects exercised their monopsonistic market power consumers' surplus increased. In Treatment 1, average profits increased significantly over time. Figure 6 plots the average profits of consumers (Treatment 3) and of producers over the horizon of the experiment.

Figure 7

Figure 7 presents the average quantity of each quality, which was allocated in Treatments 1 to 3. Comparing the graphs in the 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 stabilising at the hydrological equilibrium (where extraction equals recharge (= 3 units)). 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 (the small numbers indicate the standard deviation). Table 11 exhibits the relative frequencies of the production in each treatment, and Table 12 (in the Appendix) reports the average quantities observed in the markets. We do not find any significant trend.

Table 11

(iii) Market Efficiency and Hydrological Equilibrium

We have compared the three treatments in terms of market efficiency. The averages of social welfare (i.e., aggregated utility *minus* production costs) are reported in Table 10 in the Appendix. Overall, Treatment 1 and Treatment 3 produced higher social welfare than Treatment 2, though insignificantly at the α=.05-level. In Treatment

3, the markets (7, 8, 10) in which monopsonistic power had been exercised produced below average social welfare. However, as indicated by the Spearman rank correlation coefficient, social welfare increased over time in these markets as compared to the other markets.

Figure 8

Figure 8 sketches average welfare in the 35 periods of the experiment. As in the above figures, we notice less volatility in the trajectory of the averages in Treatment 1 than in the other treatments. Since the monopsonistic subjects in Treatment 3 generally speaking failed to dictate the market, the introduction of an additional subject seemed to be responsible for more noise.

Table 13

An indicator for inefficiency in our hydrological model is the quantity of water recharge, which is lost because the stock is at its upper limit. Inefficiency arises since resources that flow into the economy are foregone. From Table 13, we perceive that the most economic usage in terms of water management prevailed under the conditions of Treatment 3. On the other hand, in Treatment 3, the recharge rate was more frequently exceeded by the production than in the other treatments.

5 Conclusions

In a series of experimental markets which were repeated over 35 periods each, we tested the performance of three alternative ways of administrating the flow and the market for two different qualities of water. Treatments 1, 2 and 3 were designed to simulate three scenarios concerning market power and (strategic) complexity. Each treatment consisted of 14 independent sessions. In the first treatment, a single subject acted as a multi-product monopolist selling two qualities of water to a computer simulated downstream representative of two consumer types labelled as “farmers” and “households”. In Treatment 2, the two sources (high quality and low quality) of water were owned by two competitors (two-subject treatment) selling to the same population of computer-simulated consumers who were assumed to act in an individually rational (decentralised or non coordinated) way. Finally, Treatment 3 combined (asymmetric) upstream competition (as in Treatment 2) and downstream coordination (as in Treatment 1), but all agents involved were human beings (three-subject treatment). Treatment 2 and 3 involved a randomly sequential market clearing mechanism.

Treatment 1 yielded much less volatility in most magnitudes like price-offers, sales, average market prices, private profits and stocks. Also, the evolution of stocks over time indicated that Treatment 1 yielded much more stability whereas the other two treatments produced stocks, which presented a declining time trend. However, this is not very surprising since subjects face a lower degree of strategic complexity (there is only one subject) and do not face downstream-market clearing shocks. Therefore, following the prediction by Paich and Sterman (1993) and Sterman (1994), feedback was more reliable in this treatment and subjects, over time, felt more and more confident about what they were learning from their strategies in the past. In treatments 2 and 3, the lack of any systematic time trend in the initial periods and the constant (over time) degree of volatility in all aforementioned magnitudes indicate that learning was poor.[14] Thus, we conclude that strategic complexity and (the ignorance of) demand shocks introduced an obstacle for learning and stability. In future work, hence, it will be a task to determine whether noise generated through acting human

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[14] A feature which would give some 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.

beings induces a more serious handicap to subjects' learning in unknown environments than moderate (binary) stochastic shocks.

Another phenomenon which is worth mentioning is that duopolistic markets start from higher first period offers than monopolistic markets, resulting from producer-subjects' willingness to signal a cooperative behaviour to their rivals. Monopolists' first period prices present the opposite pattern: initial period prices are low, which reminds us of "new product pricing" strategies dictated by our subjects' priors (although not applicable here).

In terms of static market efficiency, only in Treatment 1 prices reflected quality differences correctly from the first period on. Textbook theory claims that monopolistic pricing of differentiated products leads to lower price differences than a duopoly does. However, contrary to what would be expected, prices of low quality exceeded the ones of high quality in the early periods of the duopoly settings. In Treatment 2 in which the producers would sell directly to the simulated consumers this distortion of the quality-price offer relation was eliminated in the course of the experiment, but in Treatment 3 it even increased over some individual sessions. Hence, the product prices of both qualities in Treatment 3 tended to be equal. This somehow paradoxical result is due to the pursuit of the downstream market power whose consequence is that upstream firms have been forced to keep their price-offers as low as possible. Consequently, high quality prices were on average lower in Treatment 3 than in the other treatments.

In terms of social welfare, treatments 1 and 3 have outperformed the other treatment (Treatment 1 statistically significant). Comparing the water flow management between treatments, we find that less of the resource were wasted in Treatment 3 and that more units of both resources could be allocated than in the other treatments. In fact, 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 subjects have tried to keep the system close to its hydrological equilibrium (inflow = sales). This indicates that the dynamic factor has dominated static market features in influencing subjects' actions. The production of high quality water exceeded on average the production of low quality in all treatments.

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

Our results have two main implications for decision making in (complex) resource markets:

First, centralisation of consumption strategies is socially desirable. We saw that even a market with ideally behaving decentralised buyers may be dominated in terms of social efficiency by a market with human (imperfect) agents acting as downstream cartels (coordinators).

Second, considering that the dynamic aspects of water resource management are important, upstream centralisation is also desirable because it is more likely to guarantee the sustainable exploitation of the resource, and avoid market (price, quantity, profit) volatility.

6 Appendix

6.1 The distribution schemes

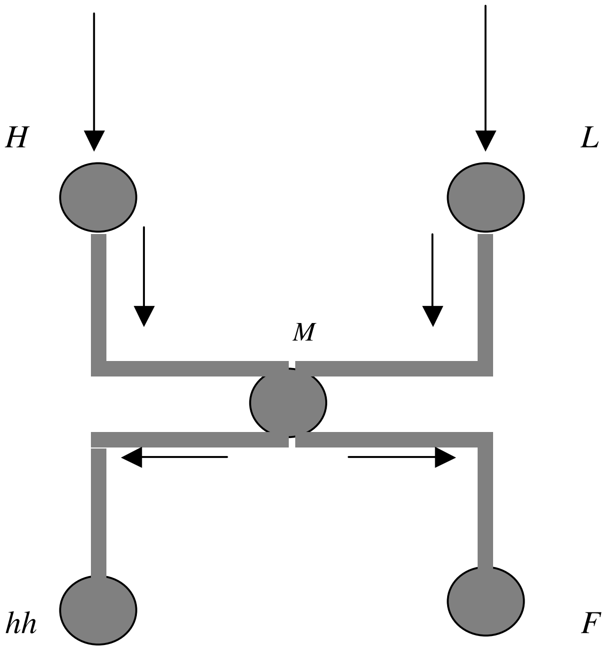


Figure A1: Distribution Scheme ***I*** (Treatment 1 and Treatment 3).

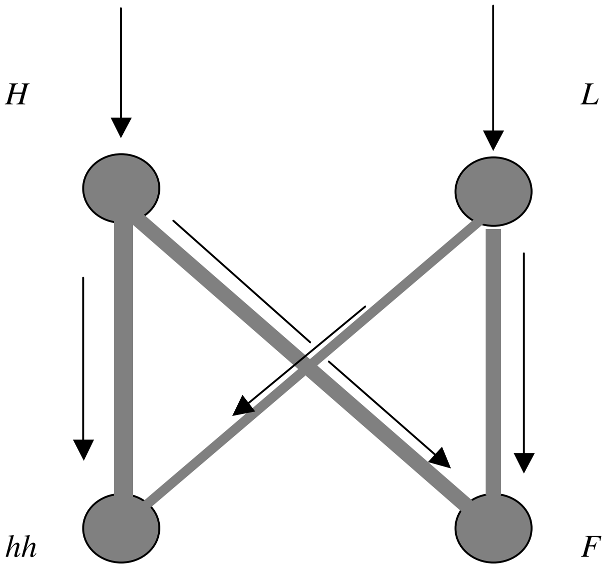


Figure A1: Distribution Scheme ***II*** (Treatment 2).

6.2 Utility and cost functions

The household’s utility was calculated by the following function:

$$U^{hh}(K_{Hhh}, K_{Lhh}, Q_{Mhh}) =$$
$$20{,}5\ \ln(1+(\max\{Q_{\min}, Q_{Mhh}\}+(K_{Lhh}+K_{Hhh})).(K_{Lhh}+K_{Hhh})-C_{\Delta Q_{hh}})\text{'}$$

where the last term in brackets denotes the purification costs,

$$C_{\Delta Q_{hh}}(K_{Hhh}, K_{Lhh}, Q_{Mhh}) = \begin{cases} \dfrac{\Delta Q_{hh}{}^{2}}{3}(Q_{Mhh}{}^{2}+(K_{Hhh}+K_{Lhh})^{2}),\ if\ Q_{\min} > Q_{Mh} \\ 0, \qquad\qquad\qquad\qquad otherwise \end{cases}$$

The farmer’s utility function was:

$$U^{F}(K_{HF}, K_{LF}, Q_{MF}) = 17.\ \ln(1+0{,}5.(Q_{MF}+3.(K_{LF}+K_{HF})).(K_{LF}+K_{HF}))$$

The cost function of producer *i* (*i* = *H, L*) was given by

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

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

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

6.3 Tables and figures

Table 1. Tables of *(i)* unit production costs and of *(ii)* social welfare utils for combinations of high quality and low quality water

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

Welfare utils	Low 0	1	2	3	4	5
High 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

Table 2. 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	12,0	12,6	9,4	11,6	11,0

Table 3. First unit posted offers in periods 1 and 35 of Treatment 1-3; consumers' posted bids (Treatment 3)

Period	Session	oL1	oH1	oL2	oH2	oL3	oH3	bL3	bH3
1	1	2	3	30	5	1	10	55	300
1	2	300	300	11	5	4	10	82	380
1	3	20	25	450	100	3	25	40	300
1	4	8	18	975	300	5	10	40	260
1	5	20	30	5	450	15	20	65	270
1	6	2	5	900	10	12	400	125	200
1	7	10	60	25	10	330	500	186	375
1	8	3	4	2	350	15	300	150	250
1	9	3	5	50	5	1	75	70	300
1	10	3	4	6	400	300	125	115	350
1	11	1	3	20	10	1000	300	187	363
1	12	5	8	10	50	10	10	100	260
1	13	20	80	35	60	400	10	175	350
1	14	4	8	200	300	607	10	150	385
		oL1	oH1	oL2	oH2	oL3	oH3	bL3	bH3
35	1	72	92	90	150	30	65	117	399
35	2	165	385	60	65	60	95	84	396
35	3	65	150	60	75	65	80	47	350
35	4	80	100	65	100	60	100	65	250
35	5	95	110	60	99	120	65	85	388
35	6	75	95	100	130	30	75	80	215
35	7	70	86	80	150	77	51	89	79
35	8	50	80	86	100	50	49	80	100
35	9	82	93	85	90	50	99	105	200
35	10	66	81	115	395	68	40	180	341
35	11	85	90	75	100	25	18	25	25
35	12	79	94	25	50	110	140	65	340
35	13	85	90	75	120	70	74	50	325
35	14	85	100	100	99	55	50	82	391

Table 4. Spearman rank correlation coefficient r_s and t-test of time dependence of ‘disequilibrium’ offers (i.e., $o_L > o_H$)

	Treatment 1					Treatment 2					Treatment 3				
	o1	o2	o3	o4	o5	o1	o2	o3	o4	o5	o1	o2	o3	o4	o5
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*

H_0: $r_s(t,\#(o_L>o_H))=0$

*:rejection of H_0 at α=.05-level of significance (|t|>2.04)

-: the minus sign indicates negative correlation

Table 5. U statistics of pairwise comparison between posted offers in Treatment 1-3.

		period 1			period 35		
		T1-T2	T1-T3	T2-T3	T1-T2	T1-T3	T2-T3
Low	o1	40,5*	67,5	81	96,5	44**	81
	o2	43*	68	83	93,5	65	72,5
	o3	47*	44,5*	82	94	90	59
	o4	51*	78,5	82	89,5	86	83,5
	o5	43*	80,5	75	86	72	72
High	o1	52,5*	49,5*	93,5	81	40**	67,5
	o2	56,5	53*	92	80	38,5**	29**
	o3	56,5	61	87	47,5*	39**	14,5**
	o4	55*	57	87	45*	47**	10,5**
	o5	53*	61	85,5	46*	58,5	16,5**

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 6. Spearman rank correlation coefficient r_s and *t*-test of posted bids 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*
Agregate	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

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

*:rejection of H_0 at α=.05-level of significance ($|t|>2.04$)

-: the minus sign indicates negative correlation

Table 7. Spearman rank correlation coefficient r_s and *t*-test of posted bids with consumer’s unit satisfaction level (for one unit extra) 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*

H_0: r_s(b(.),”u’(.)”)=0

*:rejection of H_0 at α=.05-level of significance (|t|>2.04)

-: the minus sign indicates negative correlation

Table 8. Spearman rank correlation coefficient r_s and *t*-test of time dependence of subjects' profits

	Treat-ment1	Treatment 2		Treatment 3		
		L	H	L	H	C
r_s	0,9	0,2	0,1	0,22	0,12	-0,38
t	11,9*	1,19	0,57	1,28	0,72	-2,39*

H_0: $r_s(t,\pi(t))=0$

*:rejection of H_0 at α=.05-level of significance ($|t|>2.04$)

-: the minus sign indicates negative correlation

Table 9. Average profit; Spearman rank correlation coefficient r_s and t-test of time dependence of subjects's profits in Treatment 1-3

	market	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Treatment 1	$T1_{average}$	456	538	476	485	502	261	476	405	422	408	199	438	450	504
	r_s	0,18	0,68	0,15	0,51	0,51	0,03	-0,3	0,53	0,76	0,62	0,8	0,63	0,58	0,7
	t	1,06	5,28*	0,87	3,38*	3,39*	0,16	-1,5	3,59*	6,64*	4,48*	7,64*	4,63*	4,07*	5,63*
	“L1”$_{avg}$	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	-0,3	0,33	0,6	0,4	0,73	0,52	0,29	0,5
	t	0,69	9,31*	0,08	2,3*	1,68	-0,2	-1,5	2,03	4,35*	2,52*	6,07*	3,53*	1,74*	3,36*
	“H1”$_{avg}$	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	0,7	0,48	0,76	0,32	0,25	0,38
	t	1,3	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*
Treatment 2	$L2_{average}$	177	176	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	0,3
	t	0,69	1,74	1,12	0,72	0,95	0,83	1,73	0,4	-2,5*	4,42*	0,74	-1,6	0,38	1,82
	$H2_{average}$	321	170	347	355	325	380	315	347	195	298	282	156	338	309
	r_s	-0,2	-0	-0,4	-0,2	0,19	0,34	0,07	0,56	-0,2	0,61	0,65	-0,4	-0	-0
	t	-1,2	-0,2	-2,2*	-1,3	1,08	2,08*	0,4	3,83*	-1,1	4,39*	4,92*	-2,4	-0,1	-0,3
Treatment 3	$L3_{average}$	101	142	202	134	199	183	211	148	142	154	79,5	241	197	268
	r_s	0,34	0,2	0,21	0,27	0,19	0,24	0,1	0,43	-0,1	-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*	-0,5	-0,2	0,1	0,81	0,65	1,57
	$H3_{average}$	212	288	237	232	249	222	204	174	329	207	166	286	231	143
	r_s	-0,1	0,28	0,02	0,53	0,25	0,47	-0,1	-0,4	-0,3	-0,4	-0,7	0,57	0,28	0,63
	t	-0,3	1,7	0,12	3,57*	1,5	3,05*	-0,6	-2,4*	-1,7	-2,7*	-5,4*	4,02*	1,68	4,68*
	$C3_{average}$	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	0,2	-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*

H_0: $r_s(t, \pi_i(t))=0$

*:rejection of H_0 at α=.05-level of significance ($|t|>2.04$)

-: the minus sign indicates negative correlation

Table 10. Average social welfare *ASW* (individual and aggregate); Spearman rank correlation coefficient r_s and *t*-test of time dependence of social welfare in each market (Treatment 1 to 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

H_0: $r_s(t, SW(t))=0$

*:rejection of H_0 at α=.05-level of significance ($|t|>2.04$)

-: the minus sign indicates negative correlation

Table 11. Relative frequencies of allocated quantity (low|high quality) in Treatment 1-3

units	KL1	KH1	KL2	KH2	KL3	KH3
0	0,08	0,01	0,12	0,02	0,16	0,05
1	0,11	0,16	0,13	0,15	0,08	0,06
2	0,21	0,24	0,2	0,26	0,13	0,26
3	0,3	0,32	0,31	0,22	0,26	0,27
4	0,18	0,16	0,16	0,24	0,17	0,22
5	0,12	0,11	0,08	0,11	0,21	0,15

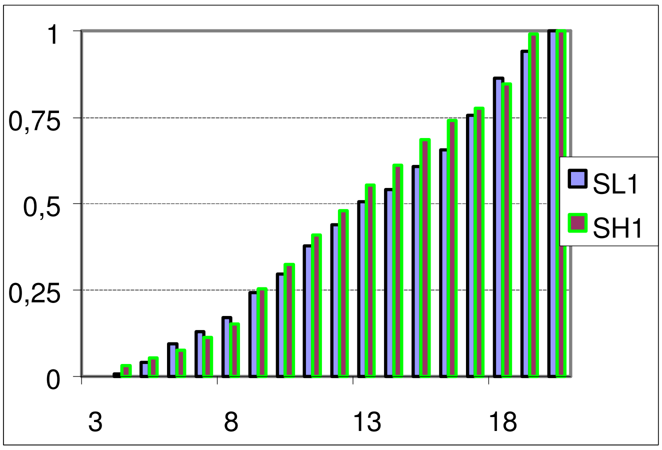
Table 12. Average allocated quantity (low|high quality) in Treatment 1-3

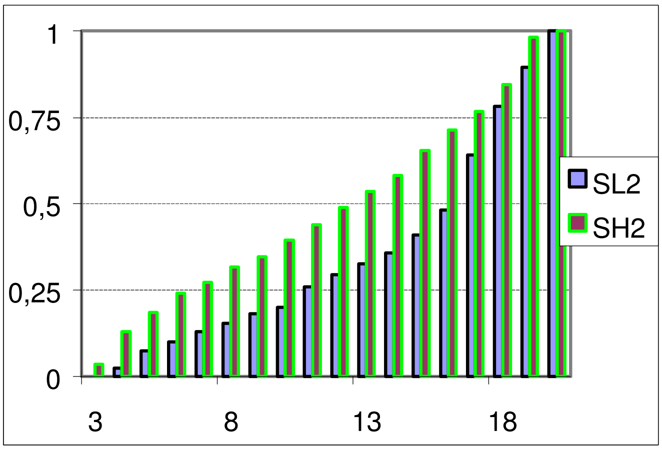
Market	qL1	qH1	qL2	qH2	qL3	qH3
1	2,23	2,26	1,71	3,17	3,23	3,17
2	1,49	1,09	2,09	3,34	3,23	3,14
3	2,77	2,91	1,89	3,29	2,91	3,03
4	3,23	3,17	2,89	3,03	3,23	2,83
5	2,6	2,8	2,69	2,8	1,94	3
6	1,46	1,4	1,77	2,91	3,29	3,09
7	3,14	3,06	1,74	3,29	2,86	2,94
8	3,26	3,23	2,94	1,31	2,57	3,11
9	3,2	3,23	3,26	3,34	3,37	3,26
10	2,8	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 13. Resource losses due to underexploitation (units of recharge which did not enter the respective bassin) in Treatment 1-3; observations in which the quantity felt short of the constant periodical recharge

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

Figure 1. End of period stock sizes: cummulative distribution in Treatment 1-3





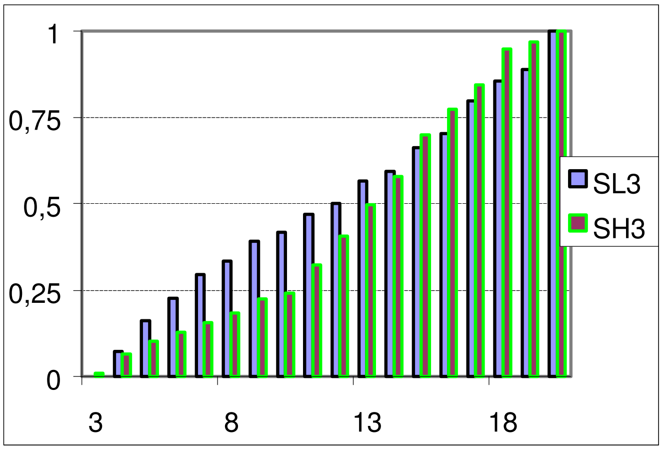


Figure 2. Evolution of average stock sizes in Treatment 1-3

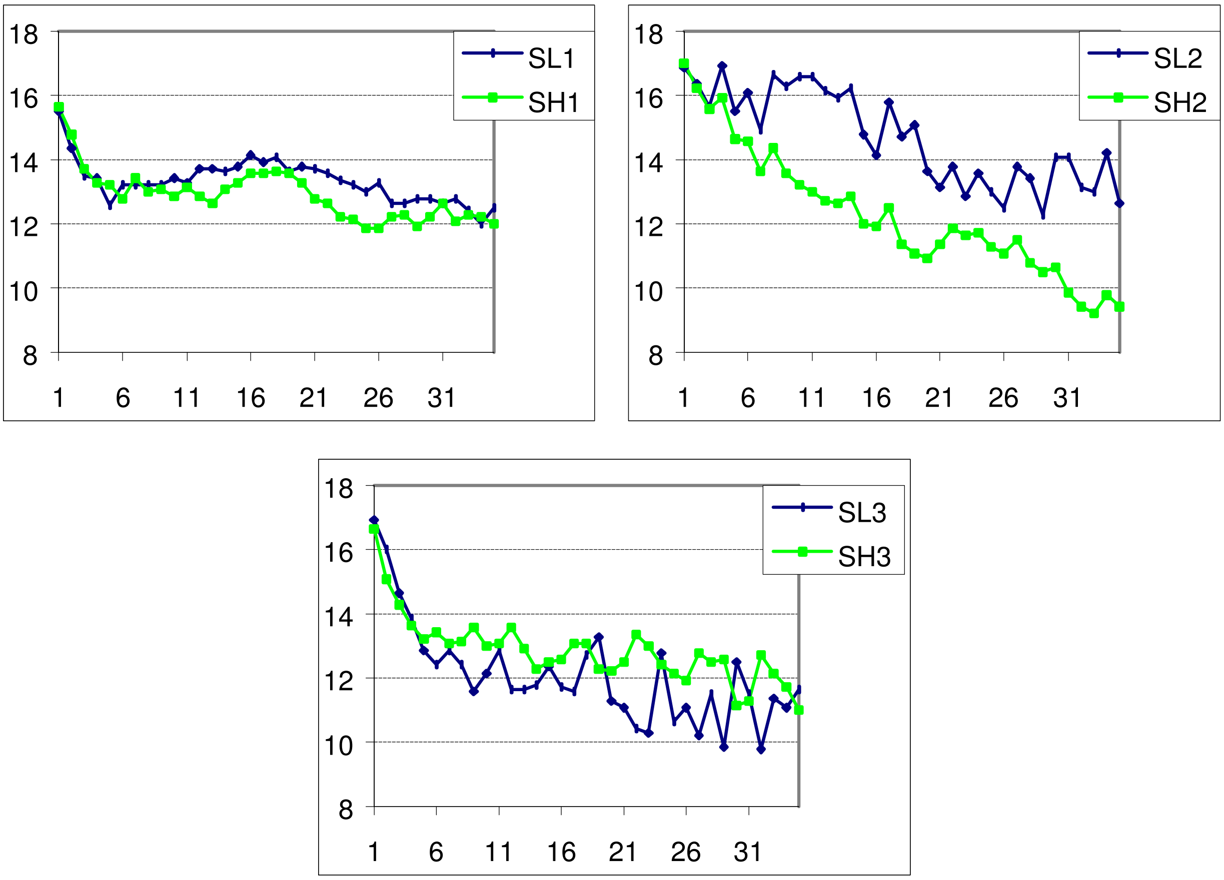


Figure 3. Evolution of average first unit price offers in Treatment 1-3; average first unit bids in Treatment 3

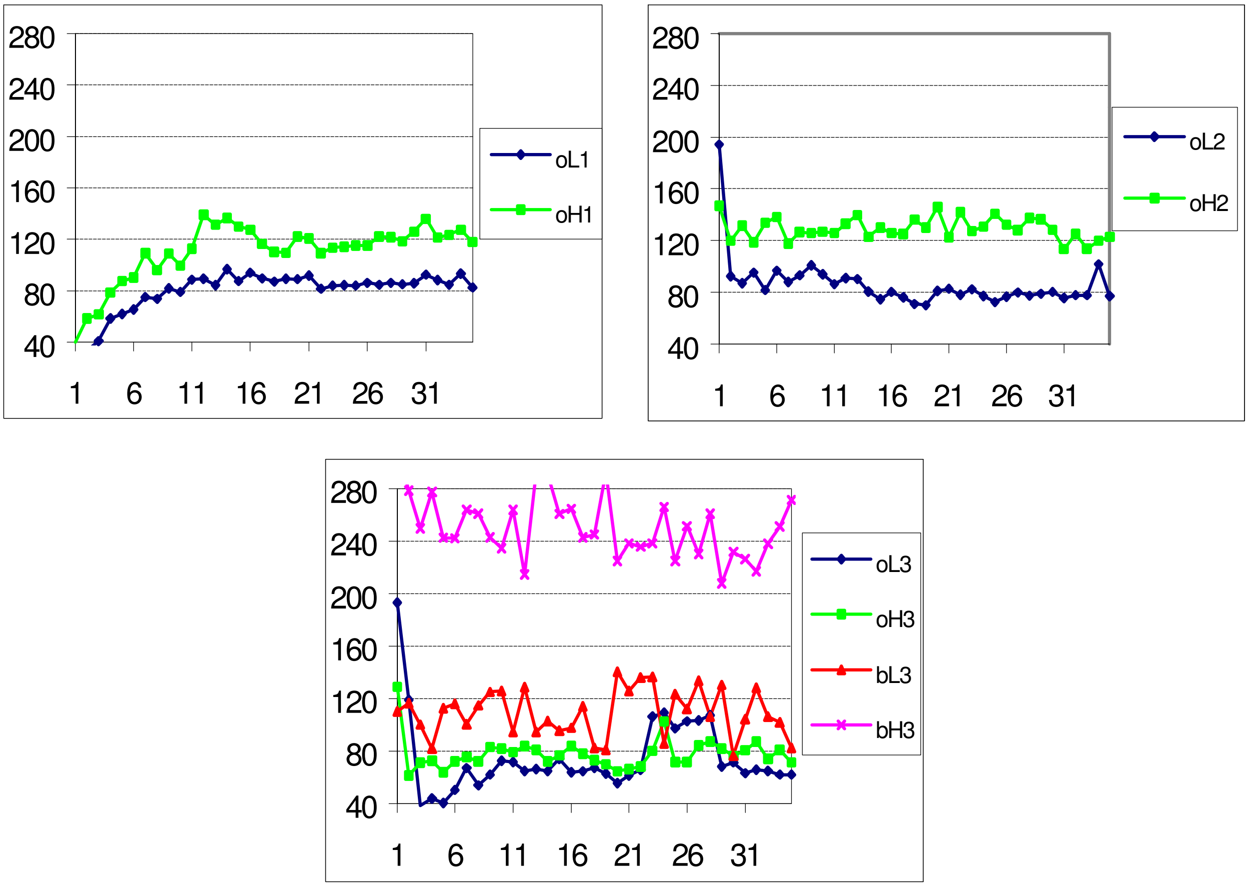


Figure 4. Evolution of frequencies of observations in which the offer *k (k =1, .., 5)* of the low quality product exceeds the offer *k* of the high quality product; Treatment 1-3

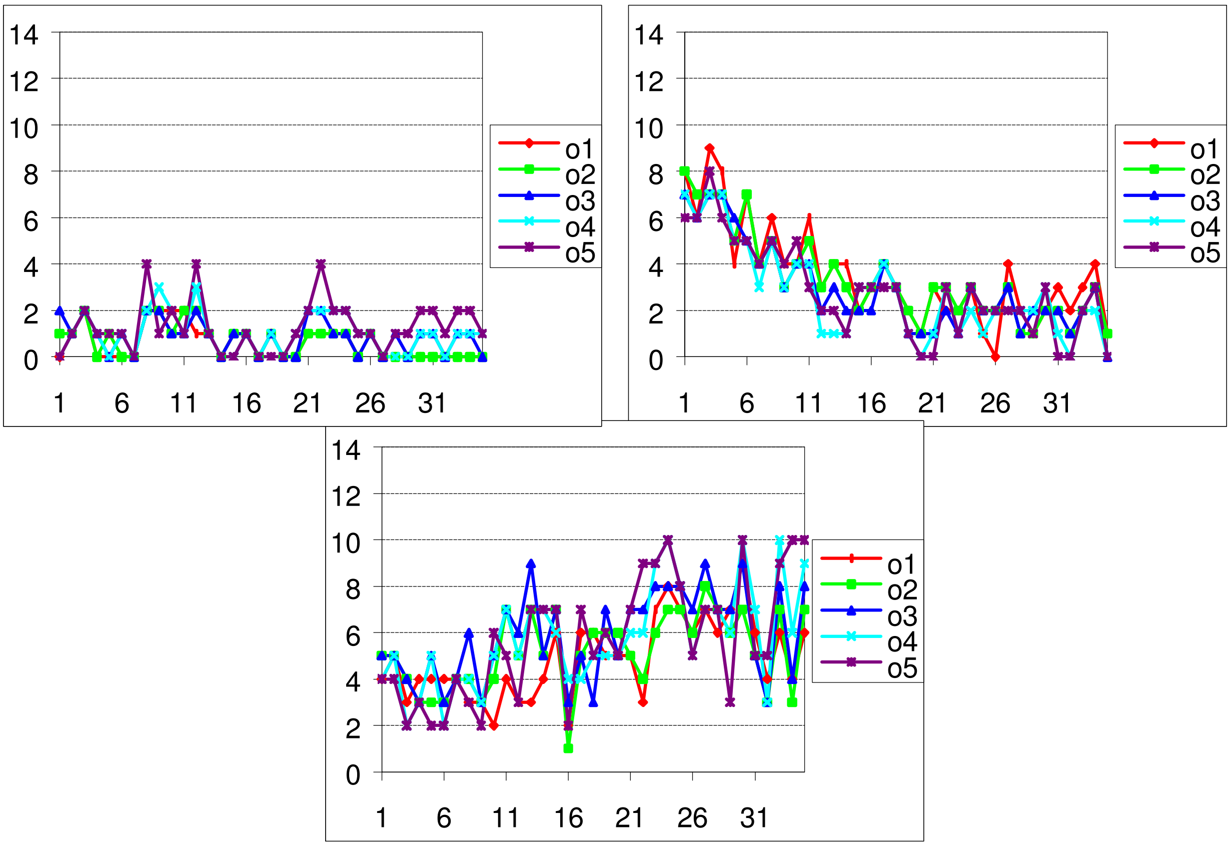


Figure 5. Evolution of average clearing prices for low|high quality in Treatment 1-3

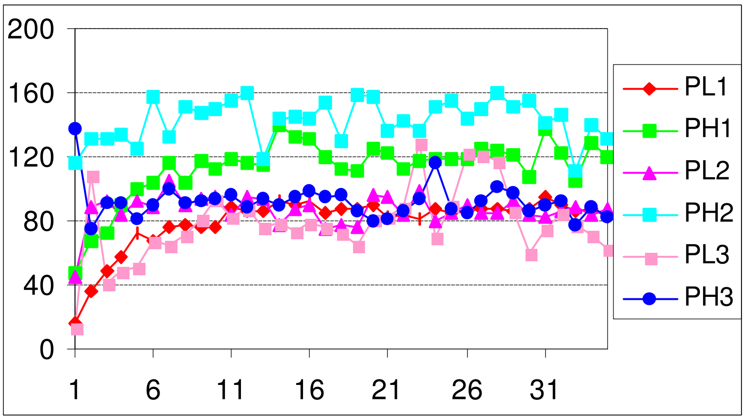


Figure 6. Evolution of average payoff in Treatment 1-3

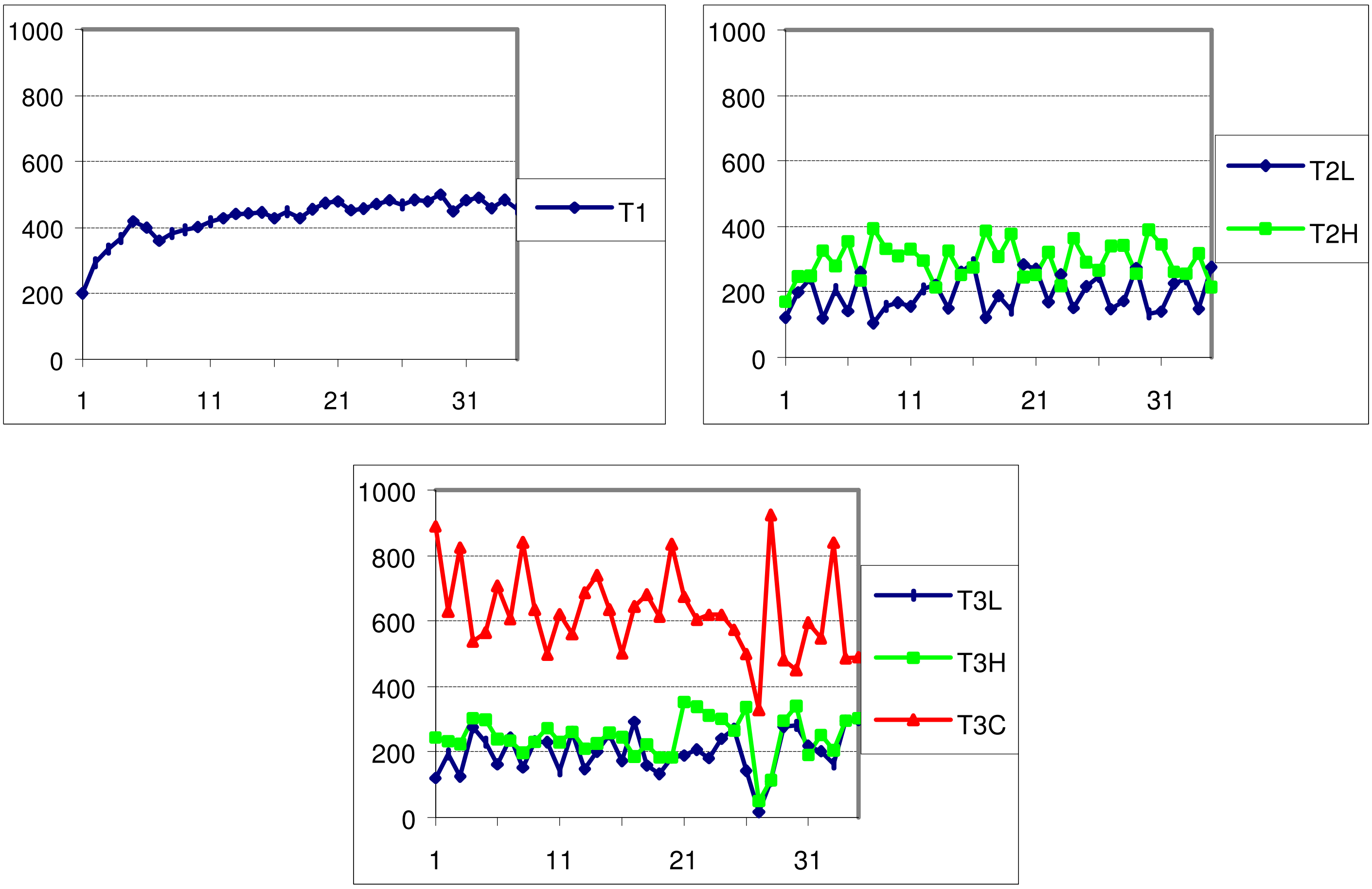


Figure 7. Evolution of average quantity sold of each quality in Treatment 1-3

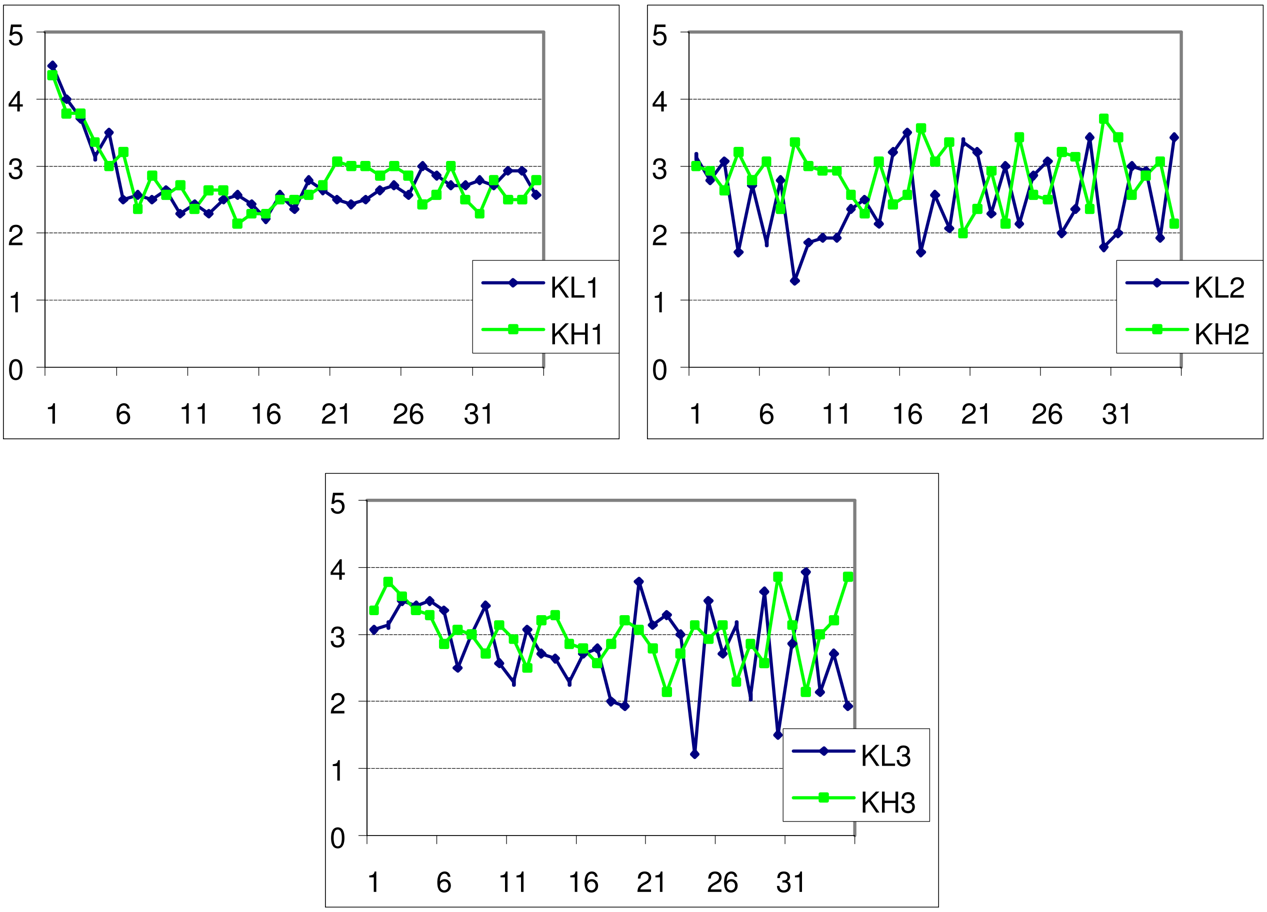
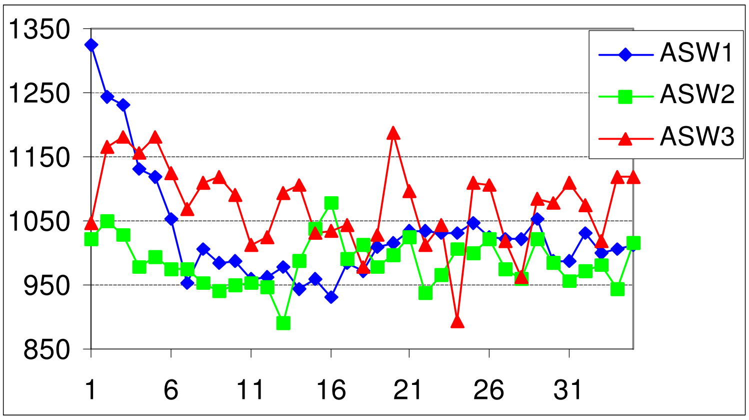


Figure 8. Evolution of Average Social Welfare in Treatment 1-3



6.4 Instructions

A4.1. Producers

The goal of this Experiment is the study of decision-making in experimental markets. You will make some decisions directly related to your monetary reward. You will be privately paid on cash at the end of the experiment. You can make any questions regarding this instructions raising a hand first. 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 basic characteristics:

1. There are two consumers (represented by one single agent in Treatment 2) and two producers in the market. Producers compete to sell their production and you are one of them.
2. Two commodities which are demand substitutes (but not identical) are supplied in the market ("Good 1" and "Good 2"), each one supplied by one producer. Both producers have similar costs functions. The computer will tell you which producer type you are.
3. Consumers have different tastes but they both prefer Good 2 to Good 1.

You have to decide about the minimum selling price for each product unit, knowing that

1. The following table shows your unit production costs (using ECUs as an experimental monetary unit).
2. Using this information you have to announce the five minimum prices at which you are willing to sell your production (maximum 5 units).
3. Pricing schemes for the 5-unit bundle cannot be decreasing: the first unit price must not be higher than the second unit price; the second unit price must not be higher than the third unit price, etc.
4. The unit cost decreases with the stock size. Your initial stock size is 20 units and every Round you will get three more units. Your stock can never exceed 20 units, so you will loose all additional (those exceeding 20) units you may receive.

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 and you get your additional 3 units (as you will at the beginning of each round), so your stock is now 13. Your unit costs for the unit you produce are the following:
The cost of the first unit you produce is 2 ECUs
The cost of the second unit you produce is 2 ECUs
The cost of the third unit you produce is 4 ECUs
The cost of the fourth unit you produce is 7 ECUs
And the cost of the fifth unit you produce 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 your reservation price for the second unit. These rules also apply for the third, fourth and fifth units.

If you sell 5 units, in the following Round your stock size would be 11 units (8 you kept with you plus 3 you get in the new round). If you do not sell any unit with your announced prices, your stock would be 16 units (13 you had plus 3 you get).

Your choices and your earnings

1. During the experiment, you have to fill the correspondent boxes in the computer with the minimum prices at which you are willing to sell your goods. In each box, you will also get information about each unit cost.
2. Both producers make decisions on prices at the same time, so you will not receive any information regarding the other producer's prices until 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 proposed selling price for any unit (by a producer) exceeded by the correspondent proposed buyer bid (reflecting a consumer's willingness to pay). 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. You will be privately paid at the end of the experiment. Your entire payment will be the sum of the payments you get in each round. The exchange rate is 10 ECU = 3 ptas.

A4. 2. Consumers' representive (only Treatment 3)

The goal of this Experiment is the study of decision-making in experimental markets. Your decisions will be directly related to your monetary reward as we will explain afterwards. You will be privately paid on cash at the end of the experiment. You can make any questions regarding this instructions raising your hand first. Any communication is strictly forbidden and will be penalized with the immediate exclusion of the experiment.

The Experiment

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

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

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

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

4. In the following table you get a picture of consumer 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 these ones minus your expenditure.

Prod1|Prod2	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 (the highest amount you are willing to pay in the market for each product unit up to a maximum of 5 per product), knowing that:

1. The reservation price schedule you are submitting in each round should not be 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 this same product. This carries over to the third, fourth and fifth units.
2. Your demand is restricted each round to 5 units of each product.

Your choices and your earnings

You have to introduce your reservation prices in the computer using the appropriate boxes. All units of the same product will have the same price in each Round. This price will be the highest minimum price (coming from a producer's willingness to accept) which lies below some highest price (coming from your willingness to pay). This way the number of units sold is also determined.

.Products are sold sequentially, one after another, in a random order determined (in each round) by the computer. Depending on this order, you will have to state first the price you are willing to pay for each unit of one good and then the price you are willing to pay for each unit of the other good.

.Every time you have to choose the highest price you are willing to pay for each product unit, you will get precise information about the incremental value the consumers you represent enjoy.

.Although, in each round, you may propose five different reservation prices, all units of the same product are sold to you at the same market price: the highest price offer exceeded by your corresponding reservation price. As this unit is the last one which the producer is willing to sell and you to buy, we also know that this is the last unit sold.

.Consumer net earnings are the difference between the value they get from the consumption (the value you see in the first table) and the price they pay for the purchase of the products.

5. Check the previous table. If you have previously bought 2 units of Good 1, your potential earnings as a function of the units of Good 2 you buy (see the correspondent column) are:

If you buy no units of Good 2: Consumers get a 361 ECUs value
If you buy 1 unit of Good 2: Consumers get a 753 ECUs value
If you buy 2 units of Good 2: Consumers get a 909 ECUs value
If you buy 3 units of Good 2: Consumers get a 1.046 ECUs value
If you buy 4 units of Good 2: Consumers get a 1.151 ECUs value
If you buy 5 units of Good 2: Consumers get a 1.244 ECUs value

6. In the simple interface you will find boxes where you have to fix the price your are willing to pay and you will also find the value consumers get with the purchase. For example, if you prefer to buy one unit of product 2 rather than none, consumers get a value increase of 392 ECUs (the difference between 753 and 361).

Your net payments will be half of consumer earnings. At the end of the experiment you will be paid privately. The exchange rate is 10 ECUs=3 ptas.

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