Asymmetric commodity cycles: Evidence from an experimental market

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ABSTRACT

Laboratory experiments of commodity markets have used the Cobweb design to investigate market dynamics. The predicted cycles of the Cobweb theory did not occur. Arango (2006) adds complexity and realism to the Cobweb model and observes stronger fluctuations and autocorrelation. He shows that these fluctuations are quite symmetric and similar to the behaviour observed in one category of markets. However the fluctuations are different from the asymmetric price behaviour observed in other commodity markets. We hypothesise that asymmetries could be caused by non-linear demand, different from the linear demand curve used by Arango. Consequently we replicate his experiment using a demand structure with constant price elasticity and dynamic adjustment. Similar to Arango, the supply side is complicated by capacity lifetimes and investment delays across treatments. Compared to the previous results, this experiment gives rise to larger fluctuations and stronger asymmetries.

KEY WORDS: *Commodity cycles, Cournot markets, cobweb markets, bounded rationality, complexity, experimental economics.*

JEL classification: *C9 - Design of Experiments; D01 - Microeconomic Behaviour: Underlying Principles; D43 - Oligopoly and Other Forms of Market Imperfection; D84 - Expectations; Speculations; L10 - Market Structure, Firm Strategy, and Market Performance.*

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1 INTRODUCTION

It is well known that commodity markets fluctuate with certain regularities (Spraos 1990; Cuddington & Urzua, 1989; Cashin *et al* 2002, Deaton & Laroque, 1992, 1996, and 2003), and that fluctuations have significant negative effects for consumers, producers and developing countries (Deaton, 1999; Akiyama *et al* 2001; Akiyama *et al* 2003). Cycles in commodity prices represent a major problem for both microeconomic and macroeconomic policies, particularly in countries where the economy depends largely on exports of one or two commodities (Deaton & Laroque, 1992). Therefore, the understanding of cycles is essential for policies of national savings and consumption, monetary policy, internal inside-country pricing policies, and for the design of risk-sharing mechanisms (Deaton & Laroque, 1992). In addition, better market knowledge is of course of interest to producers, investors and the banking system.

Despite the importance of the problem, most modern introductory textbooks in economics either ignore commodity cycles (e.g. Mankiw, 2004; Sloman, 2002; Samuelson & Nordhaus, 2001; and Case & Fair, 1996) or they deal with the phenomenon using the highly simplified cobweb model (e.g. Lipsey & Chrystal, 2003). Even though the properties of the world commodity prices are well known (Deaton and Laroque, 1992, Deaton, 1999, Cashin et al 2002), there is not agreement between economists regarding the causes of commodity price movements (Cashin et al 2002; Deaton & Laroque, 1992; 2003; Deaton, 1999); thus, the behaviour of commodity prices is poorly understood (Cashin et al, 2002). Journal articles dealing with commodity cycles also resort to models (e.x. Deaton & Laroque, 1992; 2003) that have not been able to reflect the empirical evidence (Deaton & Laroque, 2003; Gilbert, 2004). Thus, the lack of consensus and models is a problem to the extent that different models prescribe different policies. For instance, according to Deaton (1999) some African countries have got misleading advice based on improper models (Deaton, 1999).

Traditional economic literature attributes fluctuations in commodity prices to external shocks confronting inelastic demand, and to the behaviour of speculators (Deaton & Laroque, 1992), factors that move the price away from rational equilibrium and produce variability. Supply shocks normally causes temporary shortfall in production, and they are normally thought to be large; for instance, wars, pestilence, disease, weather, and political upheaval (Deaton, 1999). If demand is price inelastic, then variance of prices could be a number of times the variance of the supply shock (Deaton, 1999). For instance, Brunner (2000) presents the effect of the macroclimatic phenomenon ENSO (El Niño South Oscillation) on some commodities in South America. Deaton (1999) presents the case of rice in Japan, the poor harvest during 1993 lead the country to increase imports from zero in 1992 to 2.2 million tons in 1993, rice prices doubled and fell sharply after the recovery of Japanese production in 1994. Other commodity prices that have boomed due to external shocks are maize crop because of the flooding in the Midwest of the United States, and coffee because of frost and drought in Brazil.

The use of laboratory experiments of commodity markets has been limited to very simple designs. Most experimental markets do not include dynamic structures and are reset each period (e.g. Plott, 1982; Smith 1982). Dynamics have been considered in studies of speculative bubbles. First, Miller *et al* (1977) took the simplest intertemporal possible market based on the Williams´ two season model, where carryovers were allowed only from one season to the next one They found that the markets worked very efficiently with no signs of instability (Miller, 2002). Following, Smith *et al* (1988) considered asset markets lasting 15 periods. These markets regularly produced bubbles followed by crashes under a variety of market parameters. For commodity markets, dynamics have been introduced by lagged supply models (Carlson, 1967; Sonnemans *et al* 2004; Holt and Villamil, 1986; Sutan & Willinger, 2004) and by repeated play Cournot models (Rassenti *et al* 2000; and Huck *et al* 2004). The predicted cycles of the Cobweb theory did not materialize in these experiments, while some random fluctuations were sustained (Miller, 2002). These market designs may be relevant for certain seasonal agricultural products, but it rules out the capacity vintages problem. In particular, tree crop or mineral commodities require the analysis of costly investment where several years are needed to have production from investments, and this aspect seems to be ignored in most of commodity cycles models (Gilbert, 2006). Therefore, the obvious extension of the Cobweb market experiment is to introduce vintages of production capacity including capacity under construction; Arango and Moxnes (2007), step by step, introduced both vintages and capacity under construction where cyclical tendencies and instabilities where observed.

We repeat Arango's experiment with the following differences in the design: linear demand is replaced by a non-linear demand curve (constant price elasticity) and the price effect on demand is lagged. As a result (in the most complex treatment) we get stronger fluctuations than in Arango (2006), more periodic cycles, and asymmetries characterised by sharp upward price peaks (positive skewness). Both cyclicality and efficiency are considered.

In this experiment, we alter the demand side and observe the effects of: *i.* introducing a constant elasticity demand, and *ii.* introducing dynamics in the demand function. This is in line with other authors who assume constant elasticity demand and dynamic adjustment (Nerlove, 1958), for aggregate farm input in the US (Yeh, 1976), for household driving demand (Hill, 1986), and for other economic dynamic problems se examples in (Lewbel, 1994). We ask, will this demand formulation lead to asymmetric price oscillations in our experiment? Will the experiment generate price cycles like the ones observed for instance in sugar and coffee with positive skewness?

Our experiment has four treatments. Each new treatment adds complexity to the previous one. The first experimental treatment (T1) involves a simple lagged supply model with symmetric constant marginal costs as in Arango (2006); however we introduce a constant price elasticity of demand instead of a linear demand function. In treatment T2 we introduce a lag in demand. In treatment T3 we introduce vintages to reflect industries where capital lasts many years. The fourth treatment, T4, keeps the vintages and adds an extra delivery delay for investments. Typically, capacity additions require a sequence of operations: planning, choice of suppliers, production of parts, transportation, constructions, and testing, or time for gestation and growth in biological production systems. In total, capacity additions take several years in most commodity markets. In our case, the lag is such that one new investment decisions will be made before an ordered investment is in place.

The null hypothesis is based on the rational expectations hypothesis and the standard assumption about optimal decision making. The expected behaviour is convergence to a stable Cournot Nash equilibrium. Minor and seemingly random variations around the equilibrium value will be consistent with this hypothesis, but systematic cyclical tendencies will not. The alternative hypothesis is based on bounded rationality theory. Assuming adaptive expectations and that the investment decision is approached with a simple heuristic (Tversky & Kahneman, 1987), T4 will show cycles and possibly also T3. The alternative hypothesis is inspired by observations of cycles in real markets and by the results of previous experiments[1]. In section two we present the design and the hypotheses of the experiment. Section three presents the results which include a general overview, hypothesis testing and comparison with relevant empirical evidence from real markets. We observe oscillatory behaviour when complexity is increased. The price series show sharp peaks in treatments T3 and T4 different from the more symmetric fluctuations observed in Arango (2006). Finally, we present the conclusions.

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[1] More evidence of cyclical tendencies is presented in a number of one player experiments (Sterman, 1987a; Sterman, 1989; Diehl & Sterman, 1993, and Barlas & Günhan, 2004). Sterman (1989) and Diehl & Sterman (1995) show oscillatory behaviour as a result of ignorance of the supply line of pending production and this is important in all these studies. In a market setting, Kampmann (1992) observed cycles for pricing institutions with fixed and posted prices. Using a market clearing institution, prices tended towards equilibrium over time. Different from our experiment, Kampmann's experiment did not include vintages, had some extra complexity and used a different market clearing mechanism than that implied by the Cournot model

The next two sections present the experimental design and the hypotheses to be tested. In the last two sections we present results and discussions. Cyclical tendencies and implications for real markets are discussed, as well as the asymmetry in the price distribution.

2 EXPERIMENTAL DESIGN

The experiment consists of four treatments. Each new treatment builds on the preceding one. Treatments T1 and T2 have the same supply structure as the traditional Cobweb market or Cournot Nash game. All four treatments here have constant price elasticity while Arango uses linear demand. Furthermore, in T2, T3 and T4 demand is lagged. Thus, T3 and T4 mimic a market where it takes some time to build new capacity and capacity lasts for long periods. We have selected an electricity market ad hoc. The number of periods is large enough to allow learning and eventually convergence (40 periods in all but four markets). Following, we describe the treatments in detail, the procedures, and the hypotheses.

2.1 TREATMENT T1: STANDARD FIVE PLAYERS COURNOT MARKET

The first treatment corresponds to a computerized experiment of a Cournot market with constant marginal cost, under Huck's standard conditions[2]. There are five symmetric firms in each market, each represented by one player. Each subject chooses production between 0 and 6 units each period. Information about the realized price and profits is given in the next period. Thus, there is a one period production lag which makes the experiment dynamically identical to the traditional Cobweb design or the Cournot Nash game. The constant price elasticity of demand function is

$$D_t = D_0\left(\frac{P_t}{P_0}\right)^{\varepsilon} \qquad (1)$$

Where D_t and P_t are demand and price at time *t*, D_0 and P_0 are reference points of demand and price, and ε represents the price elasticity. Total production or supply is,

$$S_t = \sum_{i=1}^{5} q_{i,t} \qquad (2)$$

Where $q_{i,t}$ is the nonnegative production of subject *i* in period *t*. Demand D_t is set equal to supply S_t, therefore the market price in period *t* is given by an inverted demand function

$$P_t = P_0\left(\frac{S_t}{D_0}\right)^{1/\varepsilon} \qquad (3)$$

where $q_{i,t}$ is the nonnegative production of subject *i* in period *t*. Note that $q_{i,t}$ is equal to the investment made by subject *i* in period *t-1* ($q_{i,t} = x_{i,t-1}$). There is a ceiling price of 500 Col $/Unit. The profit for subject *i* in period *t* is,

[2] Standard conditions (Huck, 2004, p.106): a. Interaction takes place in fixed groups; b. Interaction is repeated over a fixed number of periods; c. Products are perfect substitutes; d. Costs are symmetric; e. There is not communication between subjects; f. Subjects have complete information about their own payoff functions; g. Subjects receive feedback about aggregated supply, the resulting price, and band their own individual profits; h. The experimental instructions use an economic frame.

$\pi_{i,t} = (P_t - c)\, q_{i,t}$ (3)

where the marginal cost c=85 Col $/Unit. The time step is thought 20 years per period, so that it mimics electricity markets, where thermo generators have around 20 years of life time.

2.2 TREATMENT T2: T1 WITH DELAYED DEMAND ADJUSTMENTS

Treatment T2 is equal to treatment T1 except that demand adjusts gradually towards the long term equilibrium demand. The adjustment process is based on the well known stock-adjustment principle developed by Nerlove (1958) and also known as the Koyck model (1954). There is a desired level of demand given by the long term demand curve under certain price,

$$D_t^{Equilibrium} = D_0 \left(\frac{P_t}{P_0} \right)^{\varepsilon} \tag{4}$$

where $D_t^{Equilibrium}$ is the equilibrium demand for price P_t. The demand is adjusted partially by the process,

$$D_t - D_{t-1} = k(D_t^{Equilibrium} - D_{t-1)} \tag{5}$$

where the change from one period to the next is only a fraction k; k is known as the coefficient of stock adjustment. The market clearance mechanism implies that D_t is equal to the total production S_t. Solving equations (4) and (5), and including the same ceiling price, we set the market price as,

$$P_t = MIN\left(P_o \left[\frac{S_t - (1-k) \cdot D_{t-1}}{k \cdot D_o} \right]^{1/\varepsilon}, \quad P_{MAX} \right) \tag{6}$$

The coefficient of stock adjustment k is set such that the average adjustment time, τ, is 10 years or half a time period. Appendix 2 presents a comparison of parameter k across treatments, which the selections of the parameter is selected.

2.3 TREATMENT T3: T2 WITH PRODUCTION CAPACITY LASTING FOUR PERIODS

Treatment T3 is equal to treatment T2 except that we introduce production capacity that lasts for more than one period, resembling many production sectors of the economy. T1 and T2 represent the more special case of agricultural products that are planted in one season and harvested the next. Capacity lasts for four periods. Since we assume full capacity utilisation, investments can be measured in production units. This simplifies the task for the subjects. As in T1 and T2, it takes one period before new production capacity is in place. Thus, production is equal to the sum of capacities of all four vintages,

$$q_{i,t} = \sum_{j=t-4}^{j=t-1} x_{i,j} \tag{7}$$

where $x_{i,j}$ is the investment decision made in years $j=t-4$ to $j=t-1$. To be consistent with T1 and T2, the time step is reduced from 20 years in T1 and T2 to 5 years. Hence the lifetime of capacity is still 20 years.

The parameter *k* is chosen such that the treatments give the same demand adjustments over time. While *k* in T2 is 6.389, in T3 it is 0.649, see Appendix 2**.** Thus, if there is a sudden change in price, the change in demand in one step of 20 years in T2 will be equal to the change in demand in four steps of 5 years each in T3.

Appendix 2 presents a comparison of parameter *k* across treatments.

2.4 TREATMENT T4: T3 WITH A ONE PERIOD EXTRA INVESTMENT LAG

This treatment is the same as T3 except for an extra one period investment lag. In many industries the investment lag stretches over several years. This means that there will be a period after an investment decision has been made in which the firm is producing with the existing capacity and in which the firm make yet another investment decision. This is captured in treatment T4 by lagging capacity by one period such that production is given by,

$$q_{i,t} = \sum_{j=t-5}^{j=t-2} x_{i,j} \qquad (8)$$

where $x_{i,j}$ is the investment decision made in years $j=t-5$ to $j=t-2$.

2.5 EXPERIMENTAL PROCEDURE

The experiment follow the standard framework used in experimental economics, with the same procedures across treatments. Subjects were recruited from the same student population and during the same time period. The subjects were forth and fifth year students of Management Engineering, Industrial Engineering, Master of Systems, and Economics at the National University of Colombia, Medellín. In T4 there was also one group with professors from the same faculty and one with professionals of the electricity industry. The experiment was initially tested with System Dynamics Master students at the University of Bergen, Norway. Treatments T1 and T2 were run with 3 markets each and treatments T3 and T4 with 6 markets each. No subject had previous experience in any related experiment and none of them participated in more than one session. Subjects were told that they could earn between Col $ 15000 and Col $ 320000 (US$5 – US$12 at that time) in about one hour and a half (circa 1.5 to 2.5 times a typical hourly wage for students). They knew that rewards were contingent on performance, which was measured in cumulative profits.

Upon arrival subjects were seated behind computers. Groups were formed in a random way. There were two or three markets per session, and subjects could not identify rivals in the market. Instructions (in Spanish) were distributed and read aloud by the experimenter (see Appendix 1). An English translation of the instructions of treatment T4 and the user interface can also be found in Appendix 1. Subjects were allowed to ask questions and test out the computer interface. In all treatments, parameters of the experiment, including the symmetry across firms, were common knowledge to all subjects.

The measurement unit for production was Mill GWh (millions of GWh), and for price Col $/kWh, both units commonly known in electricity markets. A reference point to build the demand curve was taken from Ford (1999), and the long term price elasticity $\varepsilon = -0.6$. This value is also quite representative for other commodity markets such as sugar (-0.84), coffee (-0.39), or cocoa (-0.89) (Deaton & Laroque, 2003). There was a price ceiling of 500 Col $/kWh. The initial condition was a total industry production of 14,56 Mill GWh per 20 year period for treatment T1 and T2, and 3,64 Mill GWh per 5 year period for treatments T3 and T4. Thus, according to *eq. (6)* the price started out at 70 Col $/kWh. Each period the subjects received information about their own production, total production of the rest of the players, total production in the market, market price, marginal profits, and profits. For T3 and T4 they had a capacity vintage graph that helped them keep track of the age structure of their current capacity. The experiment did not include a profit calculator as did the experiment of Arango (2006).

The subjects were also asked to forecast the price for the next period, except in T4, where they were asked to forecast the price for the period after the next one. Extra reward was given for good forecasting, measured by the accumulated forecasting error. The rewards could vary from 0 for forecast errors above an upper limit to Col $ 8000 (around US$3) for perfect forecasts.

The experiments were run in a computer network using the simulation software Powersim Constructor 2.51. The experimental market was easily programmed; the software ran automatically and kept record of all variables including the subjects' decisions. Subjects were also asked to write down their decisions and key variables on a sheet of paper to keep a record of past data and to provide a backup of the experiment. The experiment's software is available upon request; the equations are shown in Appendix 1.

2.6 TESTABLE HYPOTHESIS

First, we formulate null hypotheses based on standard economic models with rational expectations. Thereafter, we present alternative hypotheses based on bounded rationality. We consider both equilibrium and cyclicality.

2.6.1 Rational Expectations Hypotheses

In all treatments there is a unique Cournot Nash equilibrium (CN). Table 1 shows the numbers characterizing the CN equilibrium. Note that in T3 and T4 investments are one fourth of the investment in T1 and T2 due to the introduction of capacity vintages. Given the market structure, the CN model leads to a corner solution at the maximum price of 500 Col $/kWh.

Hypothesis 1: *Average prices are equal across treatments and equal to Cournot Nash equilibrium*

Table 1. Equilibriums of the experimental markets

	Individual Investment [Mill GWh] T1-T2 / T3-T4	Total production [Mill GWh] T1-T2 / T3-T4	Price [Col $/kWh]
Cournot Nash/ Joint maxization	0.224 / 0.056	4.48 / 1.12	500
Competition	0.648 / 0.162	12.96 / 3.24	85

Previous experiments have shown biases toward competition (Huck, 2004; Huck, *et al* 2004, Arango, 2006). To judge our results in this regard, Table 1 also presents the equilibrium values for perfect competition. We can observe that the CN price is equal to the price to for joint maximization.

Neoclassical economic theory suggests stability and not cyclical behavior because market actors with perfect foresight will detect any cyclical tendency and prevent it by countercyclical investments. Accordingly, economic theory normally attributes cyclical behaviour to external shocks and particularly so in the case of commodity markets (e.g. Cuddington & Urzua, 1989; Cuddington, 1992; Cashin *et al* 2002; Reinhart & Wickham, 1994; and Cashin & Patillo, 2000). We consider random shocks generated within a market to be consistent with standard economic theory. Such random variations may occur for a number of reasons, such as discontinuous investments, learning, strategic moves, etc. Previously, experiments with Cournot markets have shown that outputs and prices are close to the CN equilibrium. Typically the deviation is less than one standard deviation of the price variation over time (Huck, 2004).

Hypothesis 2. *Market prices do not show cyclical tendencies in any of the treatments while random variations may occur.*

2.6.2 Bounded Rationality Hypotheses

Similar to Arango (2006), the alternative hypotheses are based on bounded rationality theory; where the individual investment decision is seen as consisting of two steps. First, the subjects form expectations about future prices, and next they deliberate on the size of their investment. For instance, Nerlove (1958) does this by assuming adaptive expectations and by using the inverted marginal cost curve to find the appropriate future supply (and implicit investment). Here we rely on the same assumption about adaptive expectations; however, we formulate an explicit investment function because we assume constant marginal costs.

Proposed heuristic

The proposed heuristic is similar to the heuristic presented in Arango (2006), which assumes that people are not able to follow the optimal strategy (rational behaviour). Instead, they adjust capacity towards a desired capacity. That is, we assume people use a feedback strategy, where the desired capital is indicated by expected return on capital. The investment function is,

$$x_t = Max\{0, C_t / \tau + \alpha_C (C_t^* - C_t) + \alpha_{SC} (kC_t^* - SC_t)\} \quad (9)$$

where the *max* function precludes negative investments, total capacity C_t divided by the life time τ denotes depreciation, α_C determines how fast capacity is adjusted towards the desired capacity C^*_t. Finally, α_{SC} determines how quickly the supply line is adjusted toward the desired supply line kC^*_t, where $k=1/4$ since the investment delay is one fourth of the lifetime. The latter term is only applicable in T4. The desired capital

$$C_t^* = Max\{0, a - \frac{q^e - a}{P^e} P_t^*\} \quad (10)$$

is a linear function of expected price P^*_t. When P^*_t equals the equilibrium price P^e, desired capacity C^*_t equals equilibrium production q^e. At the same time, the parameter a determines the intercept with the y-axis and the slope. The parameter a is restricted to $a < q^e$ to avoid negative slopes. Also note that C^*_t depends on the equilibrium price P^e and not on the marginal cost c. Hence, the formulation could be used to test different assumptions about equilibrium. Finally, the expected price is given by

$$P_{t+1}^* = \beta P_1 + (1-\beta) P_1^* \quad (11)$$

which represents adaptive expectations (Nerlove, 1958) previously considered in related economic experiments (e. g. Carlson, 1967; Sterman, 1987b and 1989; Frankel & Froot, 1987). The parameter β is called the coefficient of expectations. Note that the price forecasting in T4 is two periods instead of one larger in T4. Following, we provide a simulation analysis of the proposed heuristic.

Differences between treatments

We simulate all treatments with the proposed heuristic to observe the consequent behaviour of the market price. The initial conditions are similar to those used in the experimental design. The coefficient of expectations is an average of values estimated by Sterman (1989) and Carlson (1967), i.e., β=0.53. The factors for the adjustment of the supply line and the total capacity are taken from Sterman (1989), who estimates parameters in an analogous heuristic with data from an inventory management problem. Average values are α_{SC}=0.10 and α_C=0.26. Parameter a was chosen a=1.25; so that the standard deviation of simulated prices in T4 becomes equal to those observed in T4. P^e was chosen equal to the competitive equilibrium price, since this is more appropriate according to the experimental results.

Simulations of T1 and T2 show fast convergence to the competitive equilibrium. Figure 1 presents the simulations for T3 and T4. The simulations indicate damped oscillation for T3 and explosive oscillations for T4. The oscillations are irregular with sharp peaks. Note that there are no external shocks in this simulation.

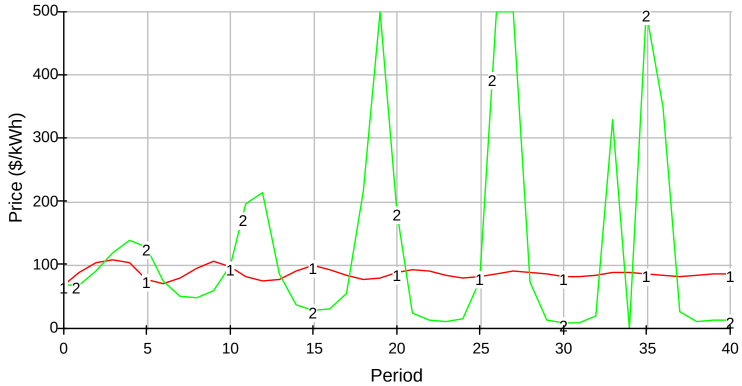

Figure 1**.** Simulated prices for T3 (line 1) and T4 (line 2).

Sensitivity Analysis[3]

T1 and T2 are not sensitive to changes in parameters. Sensitivity to α_C for T3 is presented in Figure 2, where we observe that explosive oscillations emerge when the value of parameter α_C is increased. A doubling of α_C or more (α_C>0.5) leads to unstable behaviour with explosive oscillations. The effect of the parameter a is similar to that of α_C. Instabilities occur for low values of a. Lower values of β leads to more stable behaviour.

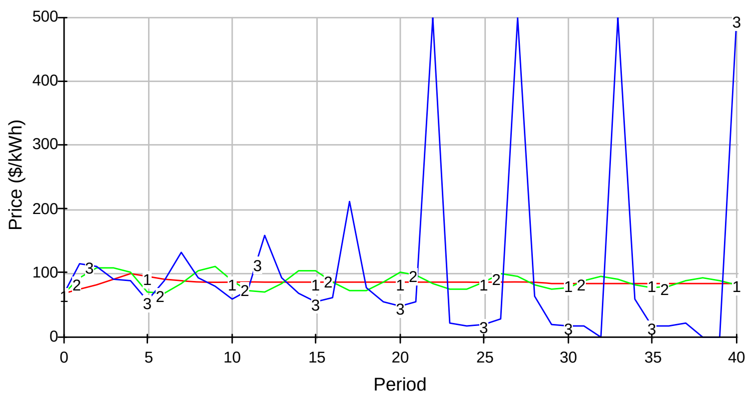

Figure 2. Sensitivity analysis of α_C for T3: line 1 for α_C=0.1; line 2 for α_C=0.3; line 3 for α_C=0.5.

Sensitivities in T4 are similar to those found in T3. However, explosive oscillations occur for lower values of α_C as shown in Figure 3. Additionally, T4 has the parameter α_{SC}, which could vary between 1 if there is a full account of the supply line of capacity and 0 if the supply line of capacity is completely ignored.

[3] Eigenvalue analysis could have provided insights about the stability properties of the treatments. Its use is complicated by the non linear demand curve. Here, simulations provide enough information about the potential for cyclical or unstable behaviour.

Simulations show that the larger α_{SC} is, the more stable the system becomes. To some extent, we expect that people will ignore the supply line of capacity, consistent with Sterman's observation (1989), which should result in stronger cyclical tendencies.

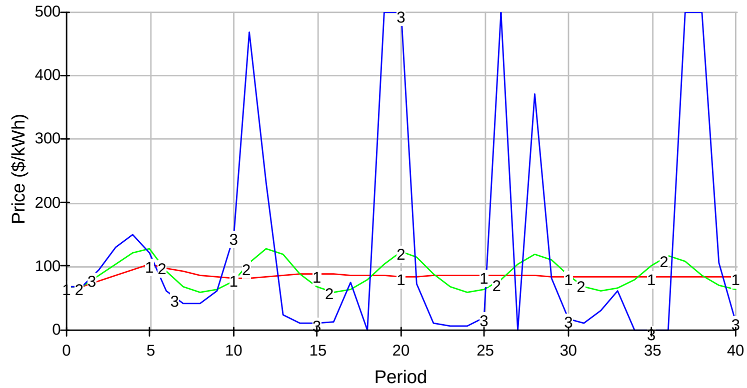

Figure 3. Sensitivity analysis of α_C for T4: line 1 for α_C=0.1; line 2 for α_C=0.2; line 1 for α_C=0.3.

To summarize, we present the formal hypothesis:

Hypothesis 3: *Cycles will not occur in treatments T1 and T2, while T3 may and T4 will show cycles with sharp peaks.*

We see that hypothesis 3 coincides with hypothesis 2 for treatments T1 and T2. The two hypotheses have different predictions for T4 and possibly for T3. We do not state an explicit hypothesis for the equilibrium or average price as we did in hypothesis 1. Rather we see the experiment as exploratory in this regard. The above simulations do not provide any hypothesis since the simulations simply assume competitive equilibrium.

3 EXPERIMENTAL RESULTS

We first present a general overview of the experimental results; next we test hypotheses and compare cyclical behaviour to behaviour obtained in other experiments. Finally, we evaluate the performance of the subjects.

3.1 GENERAL OVERVIEW

The main statistics for observed prices are presented in Table 2. Average prices are higher than the competitive equilibrium (85 Col \$/kWh) and far below the CN level (500 Col \$/kWh) in all treatments. Because of the large standard deviation ($S_{\overline{X}}$) and the limited number of markets, we cannot distinguish averages for the different treatments. Average standard deviations over time S increase considerable from T1 and T2 to T3 and T4 suggesting more unstable behaviour in the latter two treatments. The tendency is the same for autocorrelation. Statistical tests are presented in the next section.

Table 2. Summary statistics for the realized prices in the four treatments*

	All periods				First 20 periods			Remaining periods		
	$\overline{X}$	$S_{\overline{X}}$	S	α	$\overline{X}$	S	α	$\overline{X}$	S	α
T1	157	45	50	0.34	144	48	0.16	192	42	0.23
T2	107	12	25	0.24	105	30	0.21	111	16	0.18

T3	134	46	94	0.39	137	115	0.35	134	64	0.35
T4	127	31	103	0.48	123	113	0.50	134	88	0.35

* $\overline{X}$: mean sample of prices; $S_{\overline{X}}$ standard deviation of $\overline{X}$ across groups: S : average standard deviation over time; α : sample autocorrelation.

Table 2 also shows split results for the first 20 periods and the remaining ones, this enables us to look for signs of learning over time. The divided results do not show a clear pattern for average prices. We observe a reduction in the standard deviation from the first to the second period, especially in T3 and T4 where the reductions were 44% and 22% respectively. We observed a reduction in average autocorrelation of T4.

Then we look in more detail at the price development over time. Figure 4 shows the realized prices. Prices in treatments T1 and T2 are quite stable and hardly ever fall below the marginal cost (or competitive price). Prices in T3 and T4, reach high levels in very short periods separated by long periods with prices at or under the marginal cost. Thus, instability increases with complexity from T1 and T2 to T3 and T4. While prices never exceed 300 Col $/kWh in T1 and T2, there are incidents where the price hits the ceiling in 8 of the 12 markets in T3 and T4.

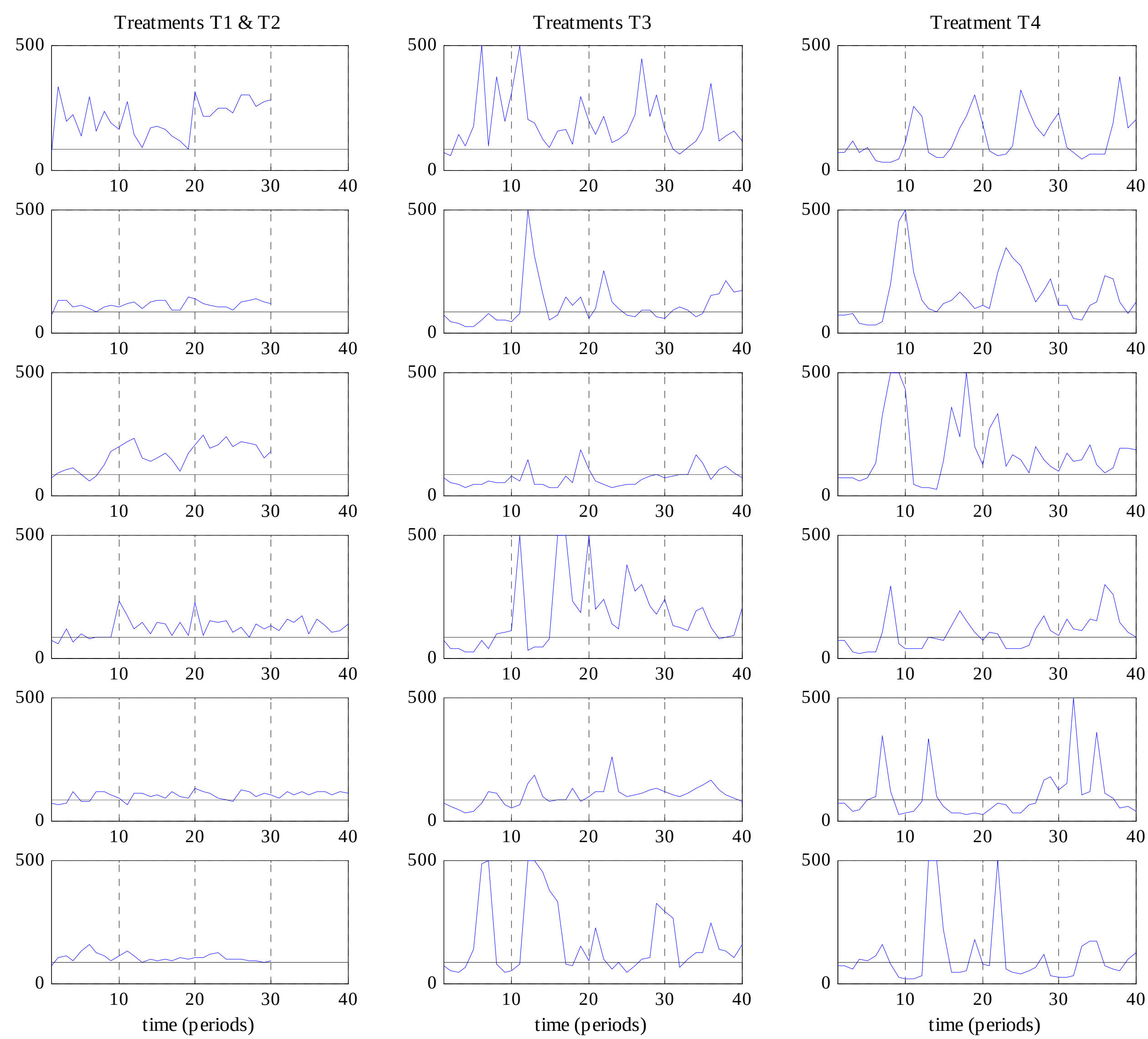

Figure 4. Time series for prices for all treatments together with marginal costs of 85 (all units in Col $/kWh). Left column presents T1 in the first three plots, the other three are for T2; the middle column presents T3; and the right column presents T4.

Note that, by design, all markets start up with overcapacity, with the corresponding price lower than the competitive equilibrium. Still, in all groups of treatments T3 and T4 the average player start out with investments above the equilibrium level, leading to lower prices after the delivery delay. As the subjects observe the low prices and realize that there have been over-investments, they reduce investments. Now they under-invest, and this leads to under-capacity and sharp price peaks due to the non-linear demand function. The cyclical phenomenon is repeated over time.

Visual inspections of the time series confirm previous evidence of cycles and/or instabilities. We observe that oscillations are stronger in T3 and T4 than in T1 and T2. Hence, the introduction of vintages in T3 and an extra investment lag in T4 seems to destabilise the market.

3.2 TESTING THE HYPOTHESES

Following, we perform the formal tests for the hypotheses of the experiments, first related to average prices and second to price variations.

Hypothesis 1: *Average prices are equal across treatments and equal to Cournot Nash equilibrium*

Table 3 presents the confidence intervals for all average prices. In all markets, the table shows that the predicted CN equilibrium (500 Col $/kWh) is not included in any of the 95% confidence intervals; therefore, hypothesis 1 is rejected. Instead, average prices are closer to the competitive equilibrium (85 Col $/kWh). In four markets, the competitive price falls in the confidence interval, in one market the average price is significantly lower.

Table 3. Confidence interval for average prices $\overline{X}$

	Lower bound	$\overline{X}$	Upper bound
Treatment T1			
G1	174	202	230
G2	105	111	118
G3	136	156	177
Treatment T2			
G1	108	120	133
G2	94	100	106
G3	94	100	108
Treatment T3			
G1	147	183	220
G2	80	108	136
G3	59	71	82
G3	123	168	212
G4	89	102	115
G6	125	171	218
Treatment T4			
G1	99	127	154
G2	117	150	184
G3	134	176	217
G3	80	101	123
G4	67	100	133
G6	69	108	147

Now, we turn to test cyclicality.

Hypothesis 2. *Market prices do not show cyclical tendencies in any of the treatments while random variations may occur.*
Hypothesis 3: *cycles will not occur in T1 and T2, while T3 may and T4 will show cycles with sharp peaks.*

The difference between hypotheses 2 and 3 pertains to treatments 3 and 4. If we observe cyclicality in T3 and T4, that favours hypothesis 3. No cyclicality favours hypothesis 2. We consider differences in variance and we investigate estimated investment heuristics. We also explore cyclicality with spectral analysis and autocorrelogram; however, we gave up this possibility because of the poor results.

Difference in variance across treatments

We pool T1 and T2 because the only difference is the delayed adjustment of demand and because both treatments represent traditional Cobweb markets on the supply side. Table 5 shows that the standard deviation for the pooled T1 and T2 is significantly different from the standard deviation for treatment T3 as well as from T4. There is no significant difference between the standard deviations for T3 and T4.

Table 4. Tests of differences between average standard deviations in different treatments

Ho	$\overline{S}$	S_S	t_{ratio}	$t_{critical, 0.05}$
$\overline{S}_{T1,T2} = \overline{S}_{T3}$	37.4 vs. 93.6	24.0 and 47.4	2.60	2.364
$\overline{S}_{T1,T2} = \overline{S}_{T4}$	37.4 vs. 102.5	24.0 and 22.7	-4.84	2.228
$\overline{S}_{T3} = \overline{S}_{T4}$	93.6 vs. 102.5	47.4 and 22.7	-0.42	2.364

$\overline{S}$ **is the average** standard deviation of prices.

Test of the adaptive expectation hypothesis

The adaptive expectations hypothesis presented in *eq. (11)* is formulated by a linear equation restricted to pass trough the origin of the 2D space ($P_{t-1} - P^{*}_{t-1}$, $P^{*}_{t} - P^{*}_{t-1}$). We relax this constraint by postulating a linear function of the form

$$(P^*_{t+1} - P^*_t) = \alpha + \beta (P_t - P^*_t) + \varepsilon_t \qquad (12)$$

where ε_t is *iid* random variable with zero mean and finite variance. The term α can be interpreted as a bias parameter. Thus, a subject might have adaptive expectations, but still retain either optimistic or pessimistic bias. The results of estimating α and β are presented in Table 5, for both individuals and aggregated markets. The table also includes the arithmetic mean of the coefficients α and β; and the r^2 for all the linear regressions. We define the expected price for an aggregated market to be the average of the expected prices of the individuals participating in the particular market.

Table 5. Parameter estimation for the adaptive expectations hypothesis for individuals and aggregated markets across treatments corresponding to *eq.(14)*.

*	α	β	r^2	α	β	r^2	α	β	r^2	α	β	r^2
	Individuals T1			**Individuals T2**			**Individuals T3**			**Individuals T4**		
1/1	2.54 (0.82)	0.47 (0.05)	0.14	9.21 (0.20)	-0.46 (0.06)	0.09	-4.29 (0.79)	0.25 (0.11)	0.07	2.13 (0.74)	-0.15 (0.09)	0.08
1/2	0.58 (0.97)	0.18 (0.67)	0.01	0.37 (0.92)	0.15 (0.16)	0.05	5.19 (0.68)	-0.07 (0.59)	0.01	5.63 (0.62)	0.23 (0.35)	0.02
1/3	4.21 (0.72)	0.24 (0.26)	0.05	-1.06 (0.73)	0.48 (0.00)	0.59	-3.32 (0.88)	0.26 (0.35)	0.02	-13.77 (0.26)	0.14 (0.15)	0.06
1/4	-21.86 (0.11)	-0.60 (0.04)	0.15	3.65 (0.34)	0.31 (0.01)	0.19	13.66 (0.52)	0.43 (0.06)	0.09	0.06 (0.98)	0.00 (0.94)	0.00
1/5	10.33 (0.56)	0.39 (0.06)	0.13	-1.43 (0.82)	0.23 (0.29)	0.03	-9.92 (0.14)	0.08 (0.05)	0.10	12.07 (0.45)	1.02 (0.02)	0.13
2/1	0.22 (0.94)	0.45 (0.05)	0.13	2.56 (0.32)	0.19 (0.31)	0.03	0.68 (0.80)	0.08 (0.02)	0.14	24.77 (0.27)	1.06 (0.00)	0.22
2/2	0.96 (0.77)	0.08 (0.57)	0.01	1.47 (0.30)	-0.17 (0.18)	0.05	1.21 (0.75)	-0.01 (0.78)	0.00	49.37 (0.02)	2.43 (0.00)	0.27
2/3	1.49 (0.41)	0.38 (0.00)	0.29	0.33 (0.84)	-0.11 (0.34)	0.03	4.40 (0.80)	1.04 (0.02)	0.15	-3.31 (0.83)	0.59 (0.05)	0.10
2/4	-2.73 (0.57)	0.09 (0.50)	0.02	-0.68 (0.68)	0.04 (0.48)	0.01	3.16 (0.76)	-0.13 (0.53)	0.01	14.49 (0.38)	0.70 (0.03)	0.13
2/5	-3.60 (0.42)	0.08 (0.38)	0.03	1.07 (0.55)	0.06 (0.61)	0.01	12.79 (0.23)	-0.64 (0.03)	0.13	5.71 (0.70)	0.65 (0.06)	0.10
3/1	-1.35 (0.88)	1.07 (0.00)	0.41	-1.87 (0.72)	0.29 (0.57)	0.01	0.95 (0.80)	-0.08 (0.62)	0.01	1.05 (0.22)	-0.01 (0.06)	0.09
3/2	1.83 (0.05)	-0.02 (0.07)	0.12	-6.59 (0.30)	0.08 (0.50)	0.02	2.32 (0.67)	-0.43 (0.25)	0.04	9.05 (0.51)	-0.35 (0.11)	0.07
3/3	-3.61 (0.55)	0.48 (0.04)	0.15	-2.22 (0.59)	0.28 (0.23)	0.06	-4.11 (0.05)	0.08 (0.04)	0.11	0.91 (0.96)	0.07 (0.87)	0.00
3/4	-1.88 (0.82)	0.23 (0.21)	0.06	-8.44 (0.11)	0.44 (0.12)	0.09	0.60 (0.84)	0.00 (0.96)	0.00	14.96 (0.61)	0.44 (0.02)	0.14
3/5	13.60 (0.21)	0.93 (0.10)	0.10	3.79 (0.64)	0.56 (0.10)	0.10	2.35 (0.68)	0.30 (0.16)	0.05	-4.58 (0.74)	0.13 (0.33)	0.03
4/1							-1.17 (0.97)	-0.06 (0.85)	0.00	6.25 (0.33)	-0.31 (0.05)	0.10
4/2							-5.00 (0.81)	0.53 (0.02)	0.14	0.00 (1.00)	0.00 (0.51)	0.01
4/3							12.05 (0.61)	0.45 (0.23)	0.04	0.02 (0.99)	0.02 (0.46)	0.02
4/4							0.06 (0.97)	0.00 (0.94)	0.00	-0.16 (0.97)	-0.03 (0.78)	0.00
4/5							10.55 (0.66)	0.88 (0.00)	0.22	6.25 (0.33)	-0.31 (0.05)	0.10
5/1							0.19 (0.96)	0.11 (0.48)	0.01	7.66 (0.64)	0.25 (0.09)	0.08
5/2							1.17 (0.47)	0.00 (0.99)	0.00	4.45 (0.86)	0.04 (0.80)	0.00
5/3							3.55 (0.48)	-0.14 (0.35)	0.02	-0.91 (0.97)	0.00 (0.99)	0.00
5/4							0.06 (0.99)	-0.14 (0.64)	0.01	-0.45 (0.97)	0.02 (0.84)	0.00
5/5							-0.16 (0.98)	-0.23 (0.66)	0.01	-12.56 (0.65)	1.08 (0.01)	0.19
6/1							1.11 (0.96)	0.03 (0.91)	0.00	-0.22 (0.99)	0.14 (0.25)	0.04
6/2							4.15 (0.84)	-0.06 (0.79)	0.00	-0.51 (0.89)	0.01 (0.85)	0.00
6/3							-4.34 (0.82)	0.56 (0.01)	0.16	18.45 (0.56)	0.62 (0.04)	0.11
6/4							2.69 (0.87)	-0.04 (0.82)	0.00	5.53 (0.73)	-0.25 (0.22)	0.04
6/5							-8.60 (0.45)	0.12 (0.14)	0.06	0.36 (0.98)	0.06 (0.79)	0.00
Avg	**0.05**	**0.30**		**0.01**	**0.16**		**1.88**	**0.10**		**5.16**	**0.31**	

	Markets T1			**Markets T2**			**Markets T3**			**Markets T4**		
1	11.18 (0.04)	0.64 (0.00)	0.69	-1.67 (0.36)	0.33 (0.00)	0.60	-15.21 (0.01)	0.45 (0.00)	0.74	-7.88 (0.12)	0.41 (0.00)	0.52
2	-5.36 (0.00)	0.35 (0.00)	0.61	-0.57 (0.39)	0.31 (0.00)	0.64	-8.16 (0.07)	0.48 (0.00)	0.70	12.07 (0.00)	1.00 (0.00)	0.95
3	-12.54 (0.00)	0.68 (0.00)	0.74	-3.86 (0.00)	0.48 (0.00)	0.76	-4.35 (0.02)	0.43 (0.00)	0.68	-14.65 (0.10)	0.47 (0.00)	0.57
4							-5.22 (0.44)	0.64 (0.00)	0.84	-3.53 (0.16)	0.19 (0.00)	0.39
5							-3.92 (0.02)	0.51 (0.00)	0.80	23.08 (0.00)	0.62 (0.00)	0.74
6							-16.91 (0.01)	0.52 (0.00)	0.76	-6.33 (0.35)	0.50 (0.00)	0.72
Avg	**-2.24**	**0.56**		**-2.04**	**0.37**		**-7.37**	**0.50**		**1.82**	**0.54**	

*: Market Number / Player

The coefficient of expectations β is postulated to be in a range from zero to one. All the β estimates from aggregate markets fall in this range, and all are significant. The estimate for β is similar across treatments and even the estimate for T2 is not significantly different from the others. Note the good fit for the aggregated markets with r^2 higher than 0.50 in all markets. The average β coefficients of the aggregated markets are all higher than the average coefficients for the individuals. Similarly, individuals present only few significant values of β and r^2 is considerable lower in almost all cases r^2 of the aggregated markets. Thus, the poor regressions may reflect different forecasting heuristics.

Now, we turn to make explicit tests of the proposed heuristics. The heuristic is constructed assuming that individuals form expectations about future prices first, and they next deliberate on the size of their investment. First we test the adaptive expectations and then the investment function.

Test of the heuristic

We explore the aggregated investment behaviour by performing regressions of the proposed heuristic. Here, we regress on time-series data the linear version of the hypothesised investment heuristic, which takes the form

$$x_t = m_3 P^*_t + m_2 P_t + m_1 SC_t + b + \varepsilon_t \qquad (13)$$

where m_i (i=1,2,3) and b are parameters to be estimated, and ε_t is *iid* random variable with zero mean and finite variance. The expected price P^* was taken as the average of individual expectations. There is no supply line of capacity, SC_t, in treatments T1, T2, and T3 and therefore we cannot estimate the coefficient m_1. Regressions are presented in Table 6 together with average values.

Table 6. Parameter estimation for the proposed heuristic for aggregated markets corresponding to *eq.(13)* (p-value in parenthesis).

	m_3 (*P)**	**m_2(*P*)**	**m_1 (*SC*)**	**b**	**r^2**
			Treatment T1		
Mkt 1	-0.025 (0.04)	0.012 (0.23)		11.01 (0.00)	0.19
Mkt 2	-0.010 (0.73)	-0.006 (0.70)		12.51 (0.00)	0.04
Mkt 3	0.006 (0.75)	-0.037 (0.03)		14.35 (0.00)	0.57
Average	**-0.010**	**-0.010**		**12.623**	
			Treatment T2		
Mkt 2	-0.057 (0.01)	0.012 (0.24)		16.04 (0.00)	0.20
Mkt 2	-0.067 (0.16)	-0.002 (0.91)		18.75 (0.00)	0.18
Mkt 2	0.029 (0.42)	-0.034 (0.07)		12.43 (0.00)	0.20
Average	**-0.032**	**-0.008**		**15.740**	
			Treatment T3		
Mkt 1	0.000 (0.92)	0.001 (0.38)		0.53 (0.00)	0.08
Mkt 2	-0.001 (0.70)	0.001 (0.42)		0.83 (0.00)	0.04
Mkt 3	0.001 (0.86)	0.001 (0.68)		0.90 (0.00)	0.03
Mkt 4	-0.002 (0.23)	0.002 (0.06)		0.74 (0.00)	0.12
Mkt 5	-0.006 (0.10)	0.004 (0.08)		1.01 (0.00)	0.08
Mkt 6	-0.004 (0.18)	0.003 (0.08)		0.74 (0.00)	0.14
Average	**-0.002**	**0.002**		**0.792**	
			Treatment T4		
Mkt 1	0.005 (0.09)	-0.002 (0.14)	-0.12 (0.46)	0.60 (0.02)	0.09
Mkt 2	0.000 (0.91)	0.000 (0.85)	0.18 (0.28)	0.59 (0.00)	0.04
Mkt 3	0.002 (0.11)	0.000 (0.94)	-0.08 (0.61)	0.44 (0.00)	0.22
Mkt 4	0.001 (0.77)	0.000 (0.81)	0.28 (0.05)	0.56 (0.05)	0.11
Mkt 5	0.003 (0.36)	-0.001 (0.48)	-0.14 (0.43)	0.81 (0.01)	0.03
Mkt 6	-0.005 (0.02)	-0.001 (0.19)	0.41 (0.00)	2.98 (0.00)	0.75
Average	**0.001**	**-0.001**	**0.088**	**0.997**	

Despite the potential meaning of the estimations from experiments, we should consider the poor results of the regressions, not only in terms of the r^2 (only 2 out of 18 where r^2 >0.25) but also in the significance of the estimated parameters. The analysis of results does not allow us to draw conclusions to neither accept nor reject the hypothesis. We also explore the individual investment behaviour. Even though the proposed heuristic is built for the aggregate market, we take a similar linear form for individuals. Appendix 3 shows the function and the results. The same puzzling and poor results dominates. Thus, the hypothesis did not receive much support; therefore, the search for other heuristics should follow up the research, e.g. non-linear investment functions.

Among the factors that complicate inferences about the investment decision rules are non linearity of demand, the potential number of alternative strategies, uncertainty about other's behaviour, etc. Since it has been difficult to explain individual behaviour, let's look at the other extreme, completely random investments, we explore this possibility through simulations. We assume investments distributes normally. Based on the experimental results, we estimate averages and standard deviations of investments for each of the treatments.[4] Then we simulate the markets assuming that investments are normally distributed (iid) with the estimated parameters. Figure 5 presents some typical behaviour. We observe that in all treatments the simulations are quite similar to the behaviours observed in the experiment (see Figure 4) with larger random variation in T1 compared with T2 and sharp upwards peaks in T3 and T4. Period lengths are clearly longer in T3 and T4 than in T1 and T2, as in the results of the experiment.

[4] Distributions for investments are: for T1 ~N(9.39, 2.16²), for T2 ~N(11.76,1.50²), for T3 ~N(0.18, 0.34²) and for T4 ~N(0.85, 0.46²).

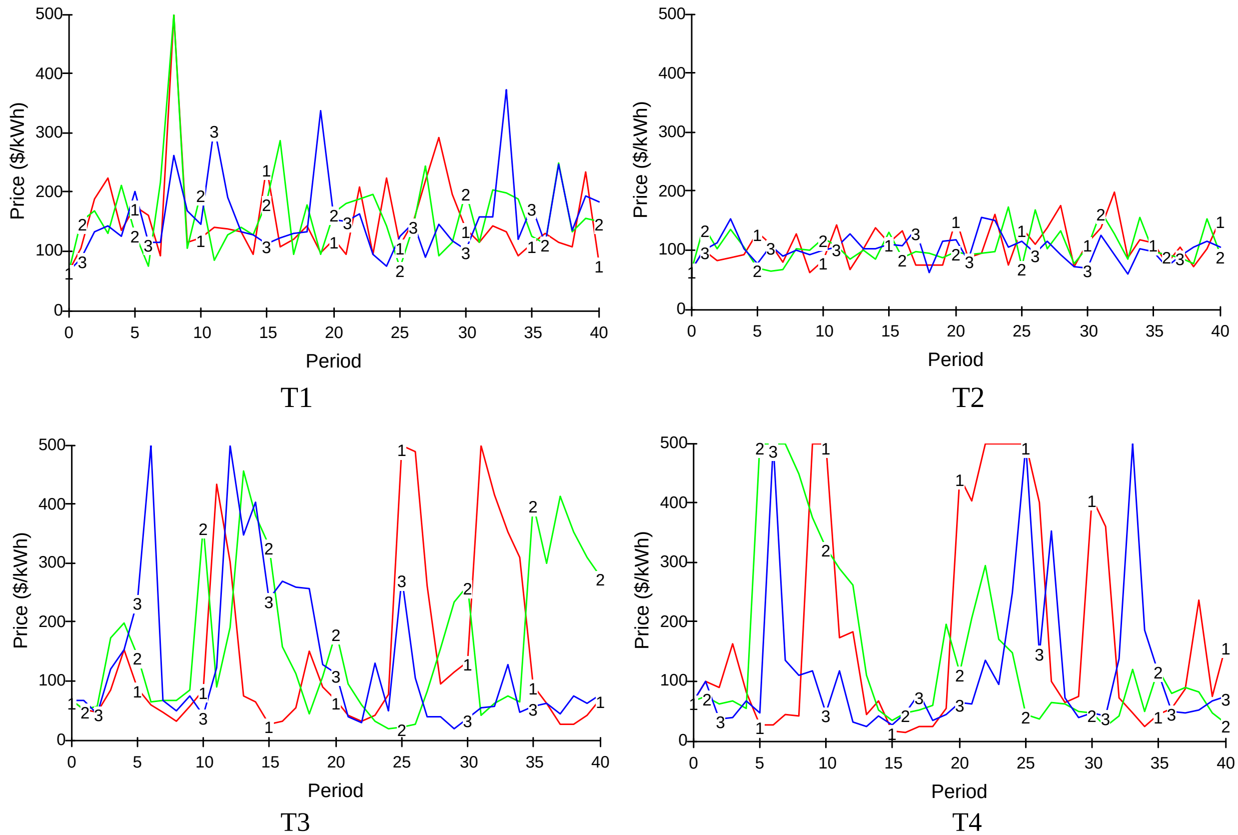

Figure 5. Stochastic simulations with normally distributed investments. Average and standard deviation from the experimental results.

The tests and analysis of the heuristics failed to reject or support the hypotheses of investment behaviour. Simulations have shown that a simple random investment could lead to cyclicality. Thus, systematic investment heuristics are not necessary to produce cycles in T3 and T4. Further research is needed to determine how investments are made. It is premature to conclude that investment decisions are not systematic at all.

In the next section we consider in more detail the effect of assuming demand with constant elasticity and lags.

3.3 COMPARISON WITH OTHER EXPERIMENTS AND REAL MARKETS

In this section, we compare the cyclical tendencies observed in T3 and T4 with previous experiments and real markets. We compare cycles in terms of period lengths, autocorrelation, and degree of asymmetry (skewness).

Visual inspection of the price time series in this experiment reveals average duration of 9.2 periods for T3 and 8.9 periods for T4, i. e., aprox. 45 years because the period length is 5 years, see Table 7. Long cycles of 27 years are also observed in Arango (2006). These period lengths seem too long for electricity markets, and much too long for many other commodities. For instance Cashin *et al* (2002) find period lengths of 63 months for bananas, 58 months for aluminium, 50 months for beef, 56 months for cocoa, and 70 for coffee. This suggests that our choice of 5 year intervals has an important and distorting effect on period lengths. Hence future experiments should consider using more frequent investment decisions, preferably yearly.

Table 7. Number of major peaks and corresponding troughs by visual inspection of price time series for T3 and T4. (Note: it was not possible to identify peaks for T1 and T2).

	T3	T4
Mkt 1	5	5
Mkt 2	4	5
Mkt 3	3	4
Mkt 4	5	4
Mkt 5	4	4
Mkt 6	5	5
Average	4.3	4.5
Average cycle duration	9.2	8.9

Cyclicality implies positive autocorrelation. Sample autocorrelation is reported positive in all the experimental markets in both Arango (2006) and this experiment. The one-lag coefficient of autocorrelation of our experiment is, on average, 0.39 and 0.48 for T3 and T4 respectively (see Table 2), while and Arango (2006) shows an average of 0.73. Similarly, real commodity markets are positively autocorrelated at yearly frequencies with autocorrelations higher than 0.8 (Cuddington & Urzua, 1989; Deaton, 1999; Cashin *et al* 2002). Again the 5 year intervals for T3 and T4 may have caused some distortion, and even more the 20 years of T1 and T2.

Table 8 presents the coefficient of skewness[5] for both Arango (2006) and this experiment. We observe clear price asymmetries in T3 and T4, but not in Arango. Skewness > 1 for all markets in T3 and T4, while in Arango, skewness takes both positive and negative values. This difference in the asymmetry of the distribution of prices around the mean implies that the demand has an important role in the price dynamics. The price distributions support this claim.

Table 8. Coefficient of skewness for the most complex treatment (T3) in Arango (2006) and for T3 and T4.

	Arango (2006)	T3	T4
Mkt 1	-0.29	1.47	1.01
Mkt 2	0.15	2.72	1.57
Mkt 3	-0.73	1.42	1.32
Mkt 4	0.22	1.32	1.26
Mkt 5	-1.13	1.19	2.37
Mkt 6		1.26	2.52
Lower limit	-1.07	0.96	1.02
Average	-0.36	1.58	1.81
Upper limit	0.36	2.17	2.33

We also compare the price distribution of T3 and T4 with that implicit in Arango (2006) (Figure 6). T3 in Arango has a near to uniform price distribution, while the shape of T3 and T4 is close to exponential. In T3 and T4 the highest concentration for prices is lower than the competitive equilibrium price, both cases around 50% of the time. In Arango, the prices are distributed over a wide range that includes both the competitive and CN equilibrium.

[5] The coefficient of skewness (or third moment) indicates the degree of asymmetry of the distribution around the mean. Positive coefficient of skewness implies that the distribution has a longer tail on the positive side of the mean, and vice versa. For example, the coefficient of skewness for a Normal distribution is zero and exponential distribution is positive.

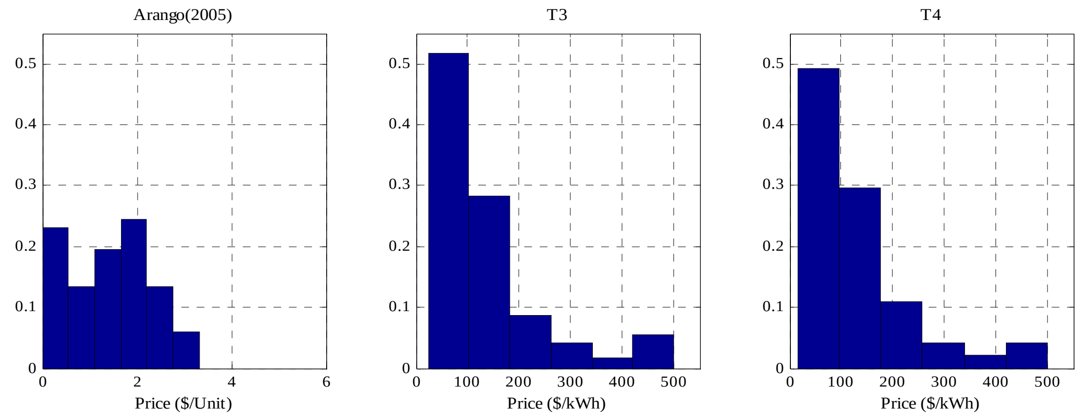

Figure 6. Histograms for the realized prices of the markets in the most complex treatment in Arango (2006) and for treatment T3 and T4.

Many commodity prices are asymmetric with positive values of skewness. For example, Deaton (1999) show that time series for cocoa and coffee prices are punctuated by sharp upward spikes. Deaton & Laroque (1992) find positive skewness for 13 commodities. For instance, from 1900 to 1981, sugar has yearly autocorrelation of 0.62, a coefficient of variation of 0.60, and skewness of 1.49. These statistics are comparable with the average observations in T3 with autocorrelation of 0.39, a coefficient of variation of 0.67, and skewness of 1.58; and they also compare with T4 with autocorrelation of 0.48, a coefficient of variation of 0.83, and skewness of 1.81. Arango (2006) observes values of autocorrelation of 0.73 and coefficient of variation of 0.5 on average; however, the skewness is not significantly different from zero. Thus, constant elasticity demand with dynamic adjustment is important for the skewness, less so for variance and not for autocorrelation.

3.4 MARKET PERFORMANCE

In this section, we are concerned with the effect of capacity lifetimes and investment lags on profits and market performance. In Table 9 we compare the average profits across groups and treatments with Competitive and CN equilibrium profits. We observe poor performance compared with the potential given by the CN equilibrium. All markets produce average profits above the competitive equilibrium with the exception of one group 3 in T3.

Table 9. Average profits across groups and treatments compared with the Competitive and CN equilibrium.

	Mkt 1	**Mkt 2**	**Mkt 3**	**Mkt 4**	**Mkt 5**	**Mkt 6**	**Average**	**Competition**	**CN**
T1	5057	1695	3462				3405	0	55720
T2	2677	1285	1090				1684	0	55720
T3	1968	400	-577	1569	352	1490	867	0	18573
T4	826	1328	1746	203	49	211	727	0	18573

3.5 OUTSMARTING THE MARKET

We have thus far shown that random investments lead to price behaviour that is quite similar to observed behaviour. Simulations with a simple heuristic also produced similar behaviour. However, regressions did not give much support to the hypothesised heuristics. Hence, we seem left with considerable uncertainty regarding the heuristics subjects use. As a final attempt to investigate the subjects' ability to handle the dynamics of the market, we introduce a micro investor, MI, i.e. an atomist. The MI will either invest nothing or a tiny amount each year, 0.046 GWh, on top of the actual investments in each of the experimental markets. Then we see if the MI performs better or worse than the average subject in the original experiments. The results indicate whether the original subjects could have improved at the margin by changing investment behaviour. We limit the analysis to T4. We propose three rules for the timing of the MI's investments, increasing in sophistication.

First we assume procyclical investments, not very different from the hypothesised heuristic:

Rule 1. Invest if the ratio of price to cost is greater than 1.

The we propose a neutral strategy:

Rule 2. Invest the same amount in all periods.

The third rule is countercyclical. We define a counter that is increased by 1 if the ratio of price over costs is less than 1, and that is reset to zero once it reaches the value 4. The rule is:

Rule 3. Invest if the counter is greater than or equal to 1.

The MI makes investment or production decisions in each of the six experimental markets for T4. The profitability of the original subjects and of the MI is measured with a "Performance Index", PI

$$PI^{j} = \frac{\sum_{t} EP_{t}^{j}}{IC^{j} + \sum_{t} ID_{t}^{j}} \qquad (14)$$

where EP^j_t is profits of subject j at time t, IC^j is the initial capacity of subject j, and ID^j_t is the investment made by subject j at time t. Table 10, shows the results.

The average PI of the MIs is greater than the average PI for the subjects in all cases except for three cases with rule 1. For rules 2 and 3 we find that the MIs outperform even the very best subjects in all cases but one with rule 2.

Table 10. Performance Indices –PI- in T4: average and highest for subjects in the experiment, and micro-investor MI with rules 1, 2 and 3.

Group	**Mkt 1**	**Mkt 2**	**Mkt 3**	**Mkt 4**	**Mkt 5**	**Mkt 6**
Average	101.3	185.1	269.9	13.6	7.3	26.1
Maximum	154.1	238.5	327.1	53.0	40.3	76.6
Micro-investor Rule 1	71.0	216.2	257.7	82.5	78.5	-37.0
Micro-investor Rule 2	151.5	238.6	330.6	59.8	55.3	83.1
Micro-investor Rule 3	164.9	262.1	339.7	65.8	58.9	96.6

When rule 1 performs just as good as the average subject, it indicates that the average subject tends to invest procyclically. The outstanding performance of the MIs with the countercyclical rule 3, suggest that the subjects would have benefited from using such a rule, at least at the margin.

4 CONCLUSIONS

This paper reports on a series of five players Cournot markets with groups of five seller subjects. Analogous to Arango (2006), step by step, we add complexity (and realism) to the supply side of the simple commodity market model: vintages in capacity and an extra investment lag. The two experiments differ in that we introduce a constant elasticity demand with gradual dynamic adjustment, instead of the linear static demand of Arango (2006).

Similar to previous experiments (e.g. Huck, 2004; Rassenti *et al* 2000; Arango, 2006) we find little evidence of cyclical behaviour before vintages and investment lags are introduced. Similar to Arango (2006) we find that the supply side additions lead to larger variance in price and to stronger autocorrelation. Our results differ from those of Arango (2006) in that fluctuations become asymmetrical measured by positive skewness. Similar to Arango (2006), average prices over all treatments are around 50 percent higher than the competitive equilibrium, respectively 45 percent and 54 percent for Arango (2006) and the current experiment. Since the constant price elasticity and the maximum price of the current experiment implies a much higher Cournout Nash equilibrium than the linear demand of Arango (2006), the current experiment shows a much larger downward bias relative to the Cournot Nash equilibrium.

Economic theory does not define any particular shape for the demand curve and leaves this as an empirical question. Depending on the availability of close substitutes, the demand curve could be close to linear or convex with close to constant price elasticity. Hence, one assumption is not necessarily more realistic than the other. It is however reassuring that our simulations and experimental results with a convex demand curve produce fluctuations similar to observations from real markets with positive autocorrelation, positive skewness and sharp upward peaks (Deaton, 1999; Cashin, 2002). This is an important result, given that previous models have not been able to clearly account for all of these features (He & Westerhoff, 2005; Deaton and Laroque, 1992). Moreover, our results could be extended to different commodities with similar market structure because, as Plott (1982) says, "*The theory takes advantage of the fact that principles of economics apply to all commodities which are valued independently of the source of individual values or the ultimate use to which the commodities are to be put*".

Traditionally, commodity cycles have been explained by external shocks. The dynamics observed in this experiment, by contrast, are generated endogenously by the internal structure of the market. Our experiment does not distinguish clearly between internally generated randomness and inappropriate investment heuristics. A test with a micro investor, however, suggests that, at the margin, subjects could benefit from heuristics that are countercyclical and thus are more appropriate for dynamic markets. Further analysis is needed to settle this very interesting issue.

Subjects in Arango (2006) were availed with a profit calculator to help identify the Cournot Nash equilibrium. Such a profit calculator was not available in this experiment. This may or may not have influenced average prices in the two experiments. The profit calculator may also have influenced the choice of heuristics in Arango (2006). Further research is needed to settle these issues.

Critics of experimental economics argue that real markets are inherently more complex than the markets analysed in laboratories. Behaviour in a very complex system may be governed by different laws than those used in simple systems (Gigerenzer *et al* 1999, Plott, 1982, p. 1522). We have responded to this criticism by adding complexity and realism step by step. Our results clearly suggest that complexity matters and that the subjects are not able to fully counteract the effects of complexity by altered behaviour.

Commodity cycles are known to cause problems for consumers, producers as well as nations that depend on a small number of commodities for their export earnings. Hence, price stabilisation is an important policy issue (Akiyama *et al* 2001). Our study suggests that commodity price fluctuations are not only caused by external shocks. Market actors may contribute considerably through seemingly random behaviour and through inappropriate investment heuristics. Thus, policy focus should not be exclusively on external events, policies should also consider the working of the market.

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Agricultural Commodity Markets And Trade

New Approaches to Analyzing Market Structure and Instability

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Appendix 1. Instructions (with translation for T4), User interface, and Code for T4 (The software and the rest of the material is available upon request).

INSTRUCTIONS

INSTRUCTIONES

PRECAUCIÓN: NO TOQUE EL COMPUTADOR HASTA LA INDICACIÓN PARA HACERLO

Este es un experimento en la economía de toma de decisiones, el caso es mercados eléctricos deregulados. Varias instituciones han soportado financieramente para realizar el experimento. Las instrucciones son simples, si usted las sigue cuidadosamente y toma buenas decisiones podrá ganar una considerable cantidad de dinero en efectivo después del experimento. En el experimento usted va a jugar el role de un productor de electricidad que vende la electricidad en un mercado. Cada período usted decidirá la producción futura. Su objetivo es maximizar las ganancias en todos los períodos del experimento. A mayores ganancias, mayor será el pago que usted recibirá.

Usted es uno entre 5 productores de electricidad en un mercado. Usted no sabe quienes son los otros jugadores en su mercado ni sobre su desempeño. Sus ganancias dependen de la producción y del precio de la electricidad menos el costo de producción. La producción no puede ser negativa y no puede ser mayor que 6 Mill GWh (**T3 y T4: 1.5 Mill GWh**), el cuál es un límite superior para asegurar un mínimo de competencia en el mercado. El costo unitario es 85 Col $/kWh para todos los productores. El costo incluye los operacionales y los costos de capital, y también el retorno normal al capital. Esto, si usted vende electricidad a 85 Col $/kWh su exceso de ganancias serán cero, lo que significa que usted está haciendo las ganancias normales en la economía.

El precio de la electricidad está dado para equilibrar la oferta y la demanda. La oferta es la suma de la producción de los 5 jugadores.
Para T1: La demanda es sensitiva al precio y presenta una reacción retardada a cambios en el precio. La curva de demanda se muestra en la Figura 1, y tiene una elasticidad constante al precio de –0.6. Note que hay un límite superior de 500 Col $/kWh para el precio. P
Para T2, T3 y T4: La demanda es sensitiva al precio y presenta una reacción retardada a cambios en el precio. La curva de demanda de largo plazo se muestra en la Figura 1, y tiene una elasticidad constante al precio de –0.6. Note que hay un límite superior de 500 Col $/kWh para el precio. La demanda tiene un tiempo promedio de ajuste de 10 años. Esto significa que si hay una variación en el precio, la demanda será gradualmente ajustada hacia la demanda indicada de largo plazo por la curva de demanda en la Figura 1. El proceso de ajuste es mostrado en la **¡Error! No se encuentra el origen de la referencia.**, donde usted puede ver como se ajusta la demanda después de un incremento súbito en el precio. Después de 10 años, aproximadamente el 63% del ajuste de largo plazo ha tenido lugar.

En resumen, a mayor producción total de electricidad, menor será el precio. Respectivamente, a menor producción total de electricidad, mayor será el precio. No hay crecimiento económico, lo que significa que la demanda sólo cambia por cambios en el precio. En el inicio del experimento, la producción total de electricidad es 14.56 Mill GWh (**T3 y T4: 3.64 Mill GWh**), el precio es 70 Col $/kWh, y su producción es 2.91 Mill GWh (**T3 y T4: 0.73 Mill GWh**).

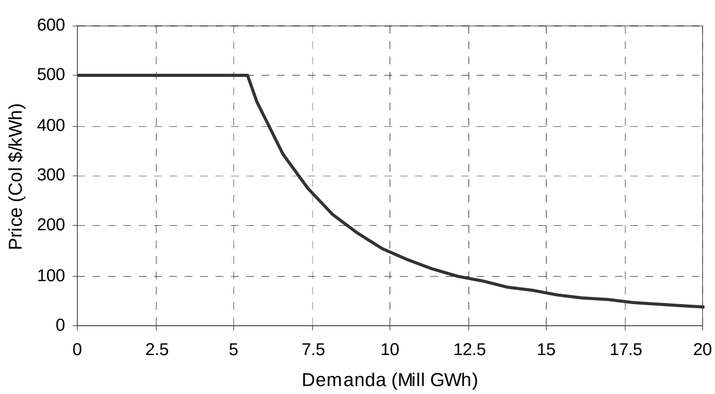


Figura 1. Curva de demanda.

Para T1 y T2:
Usted decide cada período la producción de electricidad para el próximo período. La longitud de cada período es 20 años. Antes de tomar decisiones, usted obtiene información acerca del precio de la electricidad y de los excedentes de ganancias del período actual. Cuando el próximo período comienza, este tendrá la producción que usted decidió en el período actual.

Para T3 y T4:
Usted decide cada período su producción adicional de electricidad para el futuro. La longitud de cada período es 5 años. Antes de tomar decisiones, usted obtiene información acerca del precio de la electricidad y de los excedentes de ganancias del período actual. Cuando el próximo período comienza, este tendrá la producción que usted ha decidido los últimos 3 períodos (**T4: 4 períodos**). Cada período usted decide la adición (inversión) de producción futura (capacidad). Estas adiciones (inversiones) permanecerán toda la vida útil de la capacidad de producción. La vida útil es de 4 períodos o 20 años. En todos los períodos futuros su producción será igual a la capacidad de producción, la utilización de la capacidad no puede ser reducida. También note que es necesario un período (T4: dos períodos) para construir nueva capacidad, esto es, la nueva capacidad no está disponible hasta el próximo período (**T4: período después del siguiente período**). La Figura 3 muestra la figura que se presenta en el experimento. Esta muestra las decisiones que usted ha tomado los 3 (**T4: 4**) anteriores períodos y la decisión que usted posiblemente tomará en el período actual. Cuando usted haya decidido la producción para el próximo período (**T4: período después del próximo período**), su decisión no puede ser cambiada cuando usted está en dicho período. En el primer período usted verá las decisiones iniciales hechas antes de usted tomar la compañía.

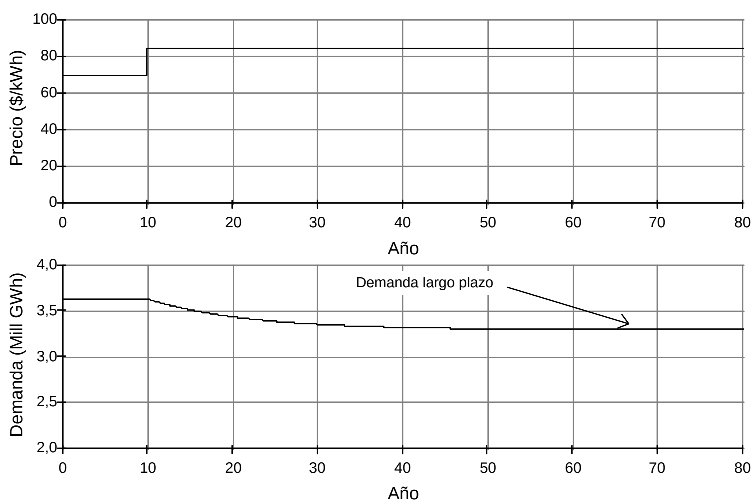
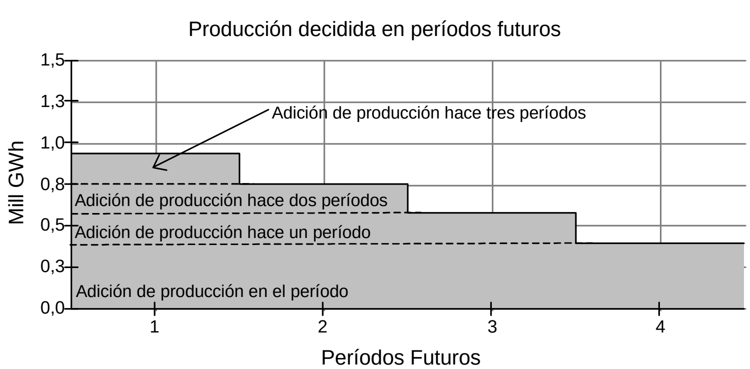


Figura 2. Reacción dinámica del precio ante un incremento en el precio de la electricidad (**T2, T3 y T4**).



T3

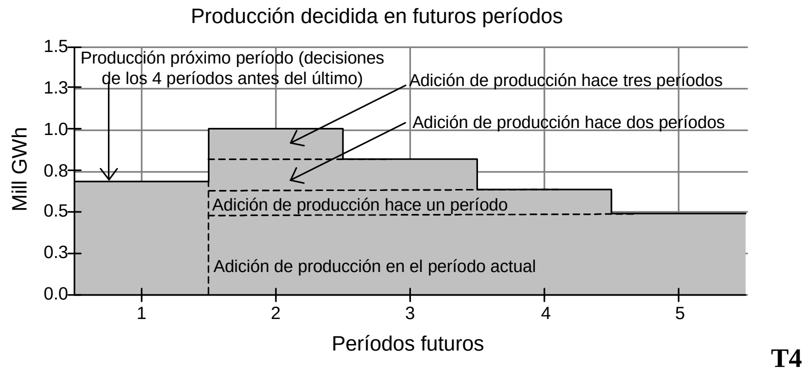


Figura 3. Producción futura decidida.

PAGOS

Usted recibirá un pago según sea su desempeño. Su desempeño es medido por la acumulación de excedentes de ganancias. Si usted obtiene cero excedente de ganancias, su pago será aprox. de Col $13 000. Si usted hace mas excedentes de ganancias recibirá un pago mayor, y si usted hace menos excedentes obtendrá menos. Esto, siempre habrá remuneración para hacer lo mejor.

En cada período, también se le solicita hacer el pronóstico del precio para el próximo período (**T4: período después del próximo**). Usted ganará pago extra dependiendo de la precisión del pronóstico que haga. Si usted hace un pronóstico perfecto en todos los períodos del experimento, usted obtendrá Col **$**6000.

CORRIENDO EL EXPERIMENTO

Todos los jugadores entran la decisión de producción y el precio pronosticado en el computador, escriben en la hoja de papel correspondiente, y presionan "Accept Decisions". Cuando todos han tomado sus decisiones, la ventana "Accept Decisions" aparece de nuevo, el juego ha avanzado un período. El tiempo avanza, y los jugadores obtienen los resultados del próximo período. Este es el momento de tomar decisiones de nuevo y así sucesivamente.
Después de 40 períodos, el juego termina. Usted escribe su pago en la hoja de papel y se aproxima al líder del experimento para obtener su pago.

TENGA CUIDADO DE NO PRESIONAR "Accept Decisions" A NO SER DE ESTAR SEGURO DE HACER ESTO. Una vez presione "Accept Decisions" su decisión no puede ser cambiada.

NOTA:
De acuerdo con el propósito de los experimentos, se requiere que no compartir ninguna clase de información entre los jugadores (verbal, escrita, gestual, etc.). Por favor, respete estas reglas porque son importantes para el valor científico de los experimento.

Gracias por participar del experimento y mucha suerte!!!

TREATMENT T4: Instructions (translation to English)

INSTRUCTIONS

WARNING: DO NOT TOUCH THE COMPUTER UNTIL YOU ARE TOLD TO!!!

This is an experiment in the economics of decision making, the case is a deregulated electricity market. Various foundations have provided funds for the conduct of this experiment. The instructions are simple, and if you follow them carefully and make good decisions you might earn a considerable amount of money which will be paid to you in cash after the experiment. In this experiment you are going to play the role of an electricity producer who sells electricity in a market. Each period you will make a decision regarding your future production. Your target is to maximize the profits over all periods of the experiment. The larger your total profits, the larger your payoff will be.

You are one among five electricity producers in a market. You do not know who the other players in your market are and how they perform. Your profit depends on your production, and the price of electricity minus the production cost. Production can not be negative and must be below 1,5 Mill GWh, which is an upper limit ensuring a minimum of competition in the market. The cost per unit is 85 Col $/kWh for all the producers. The cost includes the operational and capital costs, as well as a normal return to capital. Thus, if you sell electricity at85 Col $/kWh your excess profit will be zero, which means you are making the normal profits in the economy.

The electricity price is set to equilibrate the supply and the demand. The supply is the sum of the production of five the players. Demand is price sensitive and shows a delayed reaction to price changes. The long run demand curve is shown in the Figure 4, and has a constant price elasticity of –0,6. Note that there is an upper limit of 500 Col $/kWh for the price. The demand has an average adjustment delay of 10 years. This means that if the price is changed, the demand will gradually adjust towards the long run demand indicated by the demand curve in Figure 4. The adjustment process is illustrated in Figure 5, where you can see the demand adjustment after a step increase in the price. After 10 years, approximately 63% of the long run adjustment has taken place.

To summarize, the larger the total electricity production is, the lower the price will be. Respectively, the lower the total electricity production is, the higher the price will be. There is no economic growth, which means that demand only changes due to price changes. When the experiment starts, the total production is 3,64 Mill GWh, the price is 70 Col $/kWh, and your production is 0,73 Mill GWh.

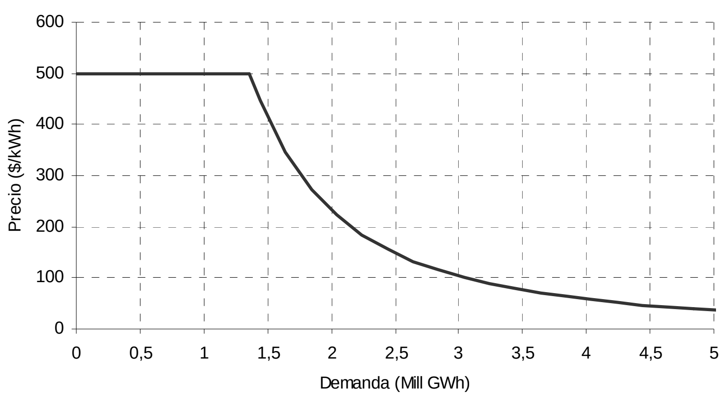


Figure 4. Long run demand curve for the experiment.

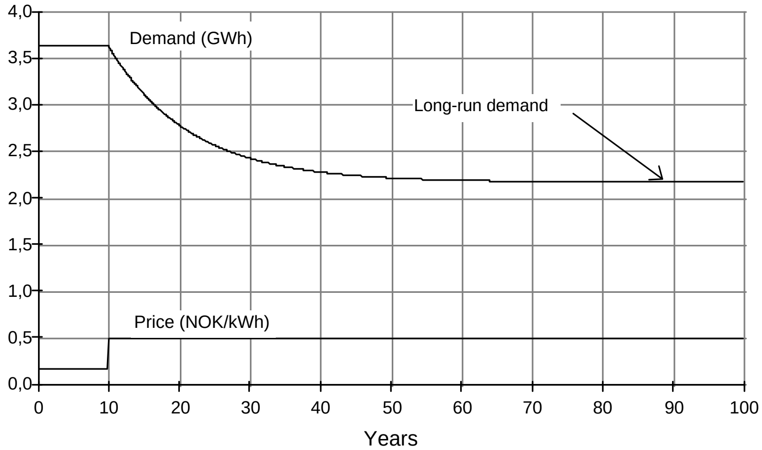


Figure 5. Dynamic reaction to a step increase in the electricity price.

Once each period you decide on your additions to your future electricity production. The length of each period is 5 years. Before you make your decision you get information about the electricity price and your profits for the period are currently in. When the next 5 year period starts it will be with the production you have decided in the current and in the last tree periods. Each year you decide an additions (investments) to future production (capacity).These additions (investments) will last the entire lifetime of the production capacity. The lifetime is four periods or 20 years. In all future periods your production will equal your production capacity, capacity utilization cannot be reduced. (Also note that it takes one period (5 years) to bu8ild new capacity, thus new capacity will not be available in the next period, rather the one after the next). Figure 7 explains the figure that is provided in the experiment. It shows the decisions you have made during the previous 3 periods and the decision you are about to make in the current one. When you have decided in the production for the period after the next period, your decision cannot be changed when you enter that period. In the first period you see the historical decision made before you take over the company.

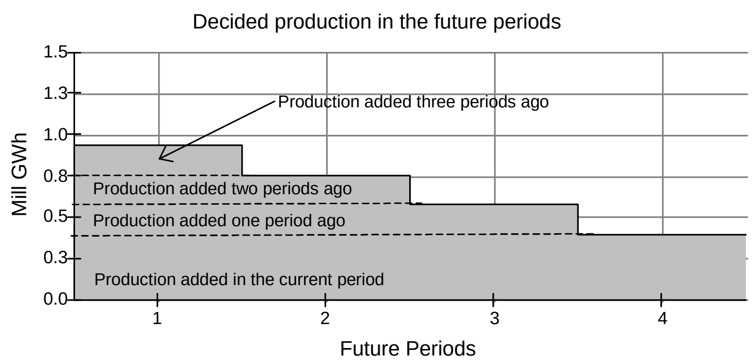


Figure 7. Decided future production.

PAYOFF

You will receive a payoff according to your performance. Your performance is measured by your accumulative excess profits. If you get zero excess profit your payment will be Col $ 15000. If you make more excess profits you get a higher payoff, and if you make less excess profits you get less. Thus, it will always pay off to do your best.

In each period, you are also asked to forecast the price of the next period (for the period after the next period). You will earn an extra payment depending on how precise forecasts you make. If you make a perfect forecast in each and every period you get Col $ 6000.

RUNNING THE EXPERIMENT:

All players enter their decided productions and their price forecasts in the computer, write them down in the given sheet of paper, and press “Accept Decisions”. When everyone has made their decisions, the window “Accept Decisions” appears again, the game has advanced to the next period and all players make new decisions, and so on.
The time advances, and the players get the results for the next period. It is time to make decisions again and so forth.
After YY periods, the game is over. You write down your payoff in the sheet of paper and approach the leader of the experiment to get your payment.

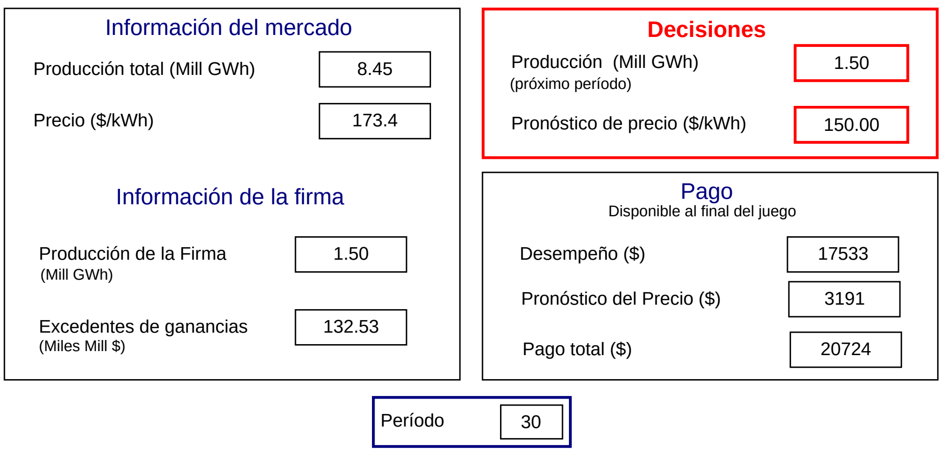
BE CAREFUL NOT TO PRESS “Accept Decisions” UNLESS YOU REALLY MEAN IT. After having pressed “Accept Decisions” your decision cannot be changed

NOTE:

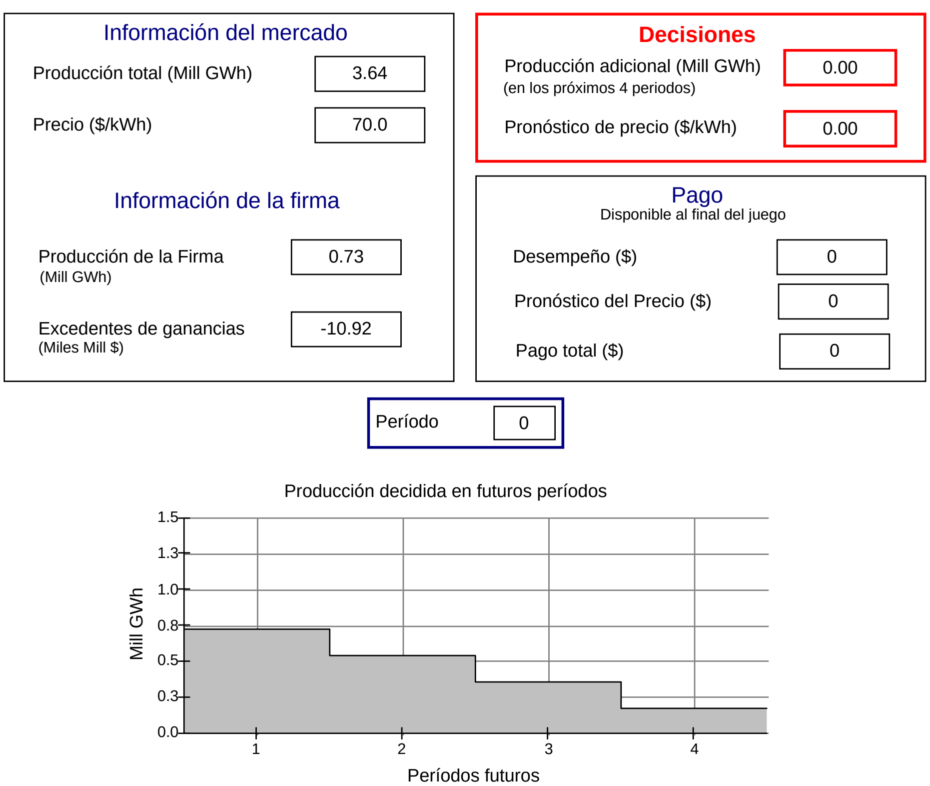
According to the purpose of the experiment it is required not to share any kind of information (verbal, written, gestures, etc.). Please, respect these rules because they are important for the scientific value of the experiment.

Thank you for joining this experiment and do your best!!!

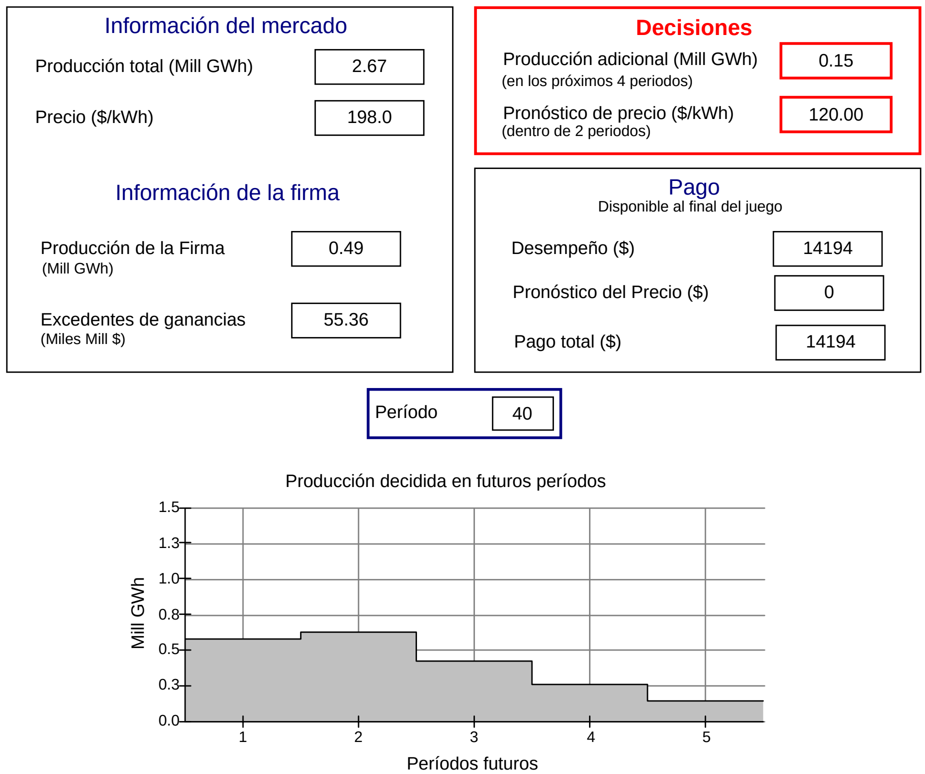
USER INTERFACE



T1 and T2



T3



T4

CODE OF THE BASE PROGRAM FOR T4 (EQUATION WRITTEN IN POWERSIM CONSTRUCTOR 2.51).

```
dim     Acum_Difference = (Players)
init    Acum_Difference = 0
flow    Acum_Difference = +dt*Difference
dim     Bank_account = (Players)
init    Bank_account = 0
flow    Bank_account = +dt*Net_profit
dim     Cap_last_0 = (Players)
init    Cap_last_0 = Initial_Capacity/4
flow    Cap_last_0 = -dt*Rate_16
        +dt*Rate_15
dim     Cap_last_1 = (Players)
init    Cap_last_1 = Initial_Capacity/4
flow    Cap_last_1 = -dt*Rate_15
        +dt*Rate_14
dim     Cap_last_2 = (Players)
init    Cap_last_2 = Initial_Capacity/4
flow    Cap_last_2 = -dt*Rate_14
        +dt*Rate_12
dim     Cap_last_3 = (Players)
init    Cap_last_3 = Initial_Capacity/4
flow    Cap_last_3 = +dt*Rate_13
        -dt*Rate_12
init    Deman_t_minus_1 = DemandReferenceX1
flow    Deman_t_minus_1 = +dt*Change_in_demand
dim     ordered_capacity = (Players)
init    ordered_capacity = Initial_Capacity/5
flow    ordered_capacity = -dt*Rate_13
        +dt*Investment
aux     Change_in_demand = (Consumption-Deman_t_minus_1)/Demand_Adjustment_Time
dim     Difference = (Players)
aux     Difference = ABS(Expected_Price-Precio_retardado)/Precio_retardado
dim     Investment = (p=Players)
```

```
aux	Investment =
SELECTDECISION(INDEX(p),Investment_Decisions,Simulated,Simulated,Simulated)+IF(TIME=0,Initial_Capacity/4,0)
doc	Investment =  AND INDEX(p)=p
dim	Net_profit = (Players)
aux	Net_profit = Revenues-Operational_Cost
dim	Rate_12 = (i=Players)
aux	Rate_12 = DELAYPPL(Rate_13(i),1,Rate_13(i))
dim	Rate_13 = (i=Players)
aux	Rate_13 = DELAYPPL(Investment(i),1,Investment(i))
dim	Rate_14 = (i=Players)
aux	Rate_14 = DELAYPPL(Rate_12(i),1,Rate_12(i))
dim	Rate_15 = (i=Players)
aux	Rate_15 = DELAYPPL(Rate_14(i),1,Rate_14(i))
dim	Rate_16 = (i=Players)
aux	Rate_16 = DELAYPPL(Rate_15(i),1,Rate_15(i))
dim	Auxiliary_100 = (i=Players, j=1..5)
aux	Auxiliary_100 = IF(INDEX(j)=1,Cap_last_1(i)+Cap_last_2(i)+Cap_last_3(i)+ordered_capacity(i),
IF(INDEX(j)=2,Cap_last_2(i)+Cap_last_3(i)+ordered_capacity(i)+Investment(i),
IF(INDEX(j)=3,Cap_last_3(i)+ordered_capacity(i)+Investment(i),
IF(INDEX(j)=4,ordered_capacity(i)+Investment(i),
IF(INDEX(j)=5,Investment(i),0)))))
dim	Capacity = (i=Players)
aux	Capacity = Cap_last_3(i)+Cap_last_2(i)+Cap_last_1(i)+Cap_last_0(i)
aux	Constant_71 = ARRSUM(Production)
aux	Consumption = MAX(ARRSUM(Production),2.5)-0.65*0
dim	Expected_Price = (p=Players)
aux	Expected_Price = SELECTDECISION(INDEX(p),
Decided_Expected_price,Simulated_Expected_price,Simulated_Expected_price,Simulated_Expected_price)
aux	fi = EXP(-years_per_period/Demand_Adjustment_Time)
dim	graph_payoff = (Players)
aux	graph_payoff = GRAPH(Bank_account,-
1000,1000,[8100,13000,15900,17200,18300,19200,19900,20300,21000,21600,22000"Min:8000;Max:22000;Zoom"])
dim	Operational_Cost = (Players)
aux	Operational_Cost = Production_Mill_kWh*1000000*Variable_O_and_M_costs/(1000000*1000000)
dim	Payoff = (Players)
aux	Payoff = IF(TIME<39,0,1)*graph_payoff
dim	Payoff_Price_Forecasting = (Players)
aux	Payoff_Price_Forecasting = GRAPH(Acum_Difference,0,10,[6000,2790,1130,0"Min:0;Max:6000;Zoom"])*IF(TIME<39,0,1)
aux	Precio_retardado = DELAYPPL(Price, 2,Price)
aux	Price = MIN(PriceReferenceY1*( (Consumption-fi*Deman_t_minus_1) / ((1-fi)*DemandReferenceX1))    ^(-
1/ElasticityReference),500)
dim	Production = (i=Players)
aux	Production = Capacity(i)
dim	Production_Mill_kWh = (Players)
aux	Production_Mill_kWh = Production*1000000
dim	Revenues = (Players)
aux	Revenues = Production_Mill_kWh*1000000*Price/(1000000*1000000)
dim	Simulated = (Players)
aux	Simulated = IF(TIME=0,0,.15)
aux	Total_Capacity = ARRSUM(Capacity)
dim	Total_payoff = (Players)
aux	Total_payoff = Payoff+Payoff_Price_Forecasting
dim	Warning = (i=Players)
aux	Warning = IF(Auxiliary_100(i,2)>Upper_limit_additional_production,1,0)
dim	Decided_Expected_price = (Players)
const	Decided_Expected_price = 0
const	Demand_Adjustment_Time = 10
const	DemandReferenceX1 = 3.64
const	ElasticityReference = 0.6
const	Initial_Capacity = 3.64/5
doc	Initial_Capacity = (0.9*90000/5)/1000
dim	Investment_Decisions = (Players)
const	Investment_Decisions = 0
const	PriceReferenceY1 = 70
dim	Simulated_Expected_price = (Players)
const	Simulated_Expected_price = 0
const	Upper_limit_additional_production = 1.5
const	Variable_O_and_M_costs = 85
const	years_per_period = 5
```

Appendix 2. Selection of parameter *k* such that there is equivalence across treatments.

The delayed adjustment process of demand implies that the demand should move from an initial condition $D_{t=t0}$ to the long term $D^{Equilibrium}$, by following equation:

$$D_t - D_{t-1} = k(D_t^{Equilibrium} - D_{t-1}) \tag{1}$$

which can be rewritten as,

$$D_t = \frac{1}{1+k} D_{t-1} + \frac{k}{1+k} D^{Equilibrium} \tag{2}$$

where and $D_t^{Equilibrium}$ is the equilibrium demand for price P_t. In continuous time, eq. (1) follows the differential equation

$$\frac{dD}{dt} = \frac{\left(D^{Equilibrium} - D(t)\right)}{\tau} \tag{3}$$

where τ, and τ is known as the average adjustment time and it was chosen equal to 10 years. The general solution for this differential equation is:

$$\mathrm{D(t)} = \mathrm{e}^{-t/\tau} \cdot \mathrm{D(0)} + \left(1 - \mathrm{e}^{-t/\tau}\right) \cdot \mathrm{D}^{\mathrm{Equilibrium}} \tag{4}$$

The eq (4) is analogous to eq. (2). If we introduce the variable $\phi = 1/(1+k)$, hence, from equation parameter $\phi = \mathrm{e}^{-t/\tau}$. In T2 the time step is 20 years, while in T3 ant T4 the time step is 5 years. To make experimental results comparable across treatments, it is required to choose an appropriate ϕ such that a change on demand in T2 made in only one step of 20 years is the same as the change on demand in T3 and T4 made in four steps of 5 years each.

Let's call ϕ_{20} the parameter ϕ for treatment T2 and ϕ_5 the parameter ϕ for treatments T3 and T4. In T2, the change in demand from period *T* to period *T+1* (or from time t to time *t* + 20 years) is given by eq. (2), hence,

$$D_{T+1} = \phi_{20} D_T + (1 - \phi_{20}) D^{Equilibrium} \tag{5}$$

which should be equivalent to the change in demand in T3 and T4 from period T' to period T'+4 (or from time t to time t + 20 years). Thus, from the same initial demand and the same change in price, $D_{T+1} = D_{T'+4}$. For T3 and T4, the adjust on demand in the first period is

$$D_{T'+1} = \phi_5 D_{T'} + (1 - \phi_5) D^{Equilibrium} \tag{6}$$

The adjust in the second period is

$$D_{T'+2} = \phi_5 D_{T'+1} + (1 - \phi_5) D^{Equilibrium} \tag{7}$$
$$D_{T'+2} = \phi_5 (\phi_5 D_{T'} + (1 - \phi_5) D^{Equilibrium}) + (1 - \phi_5) D^{Equilibrium} \tag{8}$$
$$D_{T'+2} = \phi_5^2 D_{T'} + (1 - \phi_5^2) D^{Equilibrium} \tag{9}$$

The adjust in the third period is

$$D_{T'+3} = \phi_5 D_{T'+2} + (1 - \phi_5) D^{Equilibrium} \quad (10)$$
$$D_{T'+3} = \phi_5 (\phi_5 D_{T'+1} + (1 - \phi_5) D^{Equilibrium}) + (1 - \phi_5) D^{Equilibrium} \quad (11)$$
$$D_{T'+3} = \phi_5^3 D_{T'} + (1 - \phi_5^3) D^{Equilibrium} \quad (12)$$

Finally, the adjust after four periods is

$$D_{T'+4} = \phi_5 D_{T'+3} + (1 - \phi_5) D^{Equilibrium} \quad (13)$$
$$D_{T'+4} = \phi_5 (\phi_5 D_{T'+2} + (1 - \phi_5) D^{Equilibrium}) + (1 - \phi_5) D^{Equilibrium} \quad (14)$$
$$D_{T'+4} = \phi_5^4 D_{T'} + (1 - \phi_5^4) D^{Equilibrium} \quad (15)$$

Since it is required that $D_{T+1} = D_{T'+4}$, the equivalence for treatments impose that $\phi_5^4 = \phi_{20}$, which implies that $\phi_5^4 = (e^{-2})^{1/4} = e^{-0.5} = e^{-5/10}$. Thus, for treatment T2 we have $\phi = e^{-2}$ or $k = 6.389$; and for treatment T3 and T4 we have $\phi = e^{-0.5}$ or $k = 0.649$.

Appendix 3. Parameter estimation for the proposed heuristic for individuals.

We explore individual behaviour with the following linear investment function

$$x^i_t = m_4 P^{*i}_{t}, + m_3 P_t + m_2 SC^i_{t}, + m_1 C^i_t + b + \varepsilon_t \qquad (16)$$

where m_j (j=1, … ,4) and b are parameters to be estimated, and ε_t is *iid* random variable with zero mean and finite variance. The index i represents individuals and the variables conserve the previous names.

Parameter estimation for the proposed heuristic for individuals corresponding to *eq.(16)* for treatments T1 and T2. The p-value of each coefficient is presented in parenthesis.

Mkt/Player	m_4 (*P**)	m_3 (*P*)	m_1 (*C*)	b	r^2
		T1			
1/1	-0.002 (0.01)	0.002 (0.01)	0.47 (0.00)	0.75 (0.00)	0.55
1/2	-0.015 (0.01)	0.016 (0.03)	0.73 (0.00)	0.66 (0.48)	0.48
1/3	-0.002 (0.19)	0.001 (0.64)	0.23 (0.17)	1.56 (0.00)	0.19
1/4	-0.003 (0.03)	0.003 (0.03)	0.07 (0.66)	0.87 (0.00)	0.18
1/5	-0.006 (0.00)	0.004 (0.06)	0.07 (0.65)	2.66 (0.00)	0.31
2/1	-0.014 (0.00)	0.005 (0.00)	0.09 (0.13)	2.84 (0.00)	0.67
2/2	0.000 (0.35)	0.000 (0.49)	0.00 (0.90)	2.92 (0.00)	0.04
2/3	0.008 (0.25)	0.001 (0.88)	0.59 (0.00)	-0.42 (0.46)	0.59
2/4	-0.012 (0.17)	0.005 (0.38)	0.22 (0.12)	2.18 (0.01)	0.21
2/5	-0.006 (0.72)	-0.007 (0.48)	0.33 (0.06)	2.99 (0.10)	0.19
3/1	-0.001 (0.53)	-0.005 (0.00)	-0.02 (0.82)	2.65 (0.00)	0.63
3/2	-0.055 (0.00)	0.003 (0.03)	0.52 (0.00)	4.81 (0.00)	0.58
3/3	0.008 (0.44)	-0.005 (0.63)	0.38 (0.06)	0.90 (0.24)	0.24
3/4	-0.007 (0.01)	0.000 (0.98)	0.31 (0.02)	2.33 (0.00)	0.67
3/5	-0.002 (0.82)	-0.011 (0.31)	0.23 (0.13)	4.47 (0.00)	0.58
Average	**-0.007**	**0.001**	**0.28**	**2.14**	
		T2			
1/1	0.003 (0.69)	0.006 (0.14)	0.18 (0.09)	1.88 (0.00)	0.30
1/2	-0.006 (0.08)	-0.003 (0.24)	-0.28 (0.03)	3.99 (0.00)	0.22
1/3	-0.014 (0.00)	-0.011 (0.00)	0.21 (0.04)	5.10 (0.00)	0.69
1/4	-0.003 (0.33)	0.003 (0.13)	-0.01 (0.96)	0.88 (0.03)	0.07
1/5	-0.017 (0.04)	0.013 (0.10)	0.23 (0.25)	1.52 (0.10)	0.12
2/1	-0.012 (0.03)	-0.002 (0.63)	-0.15 (0.14)	3.99 (0.00)	0.33
2/2	-0.014 (0.27)	0.011 (0.18)	0.10 (0.53)	1.95 (0.00)	0.05
2/3	-0.008 (0.45)	-0.005 (0.30)	0.06 (0.72)	2.25 (0.03)	0.11
2/4	0.034 (0.13)	-0.018 (0.03)	0.33 (0.01)	2.31 (0.27)	0.35
2/5	0.005 (0.52)	0.007 (0.12)	0.41 (0.00)	0.07 (0.91)	0.43
3/1	-0.035 (0.03)	0.019 (0.07)	0.46 (0.00)	2.33 (0.01)	0.44
3/2	0.001 (0.87)	-0.013 (0.00)	0.11 (0.15)	3.68 (0.00)	0.59
3/3	0.007 (0.41)	0.008 (0.03)	0.40 (0.00)	0.27 (0.74)	0.64
3/4	0.016 (0.19)	-0.022 (0.01)	0.29 (0.08)	2.29 (0.08)	0.42
3/5	0.006 (0.01)	0.004 (0.24)	-0.22 (0.00)	2.62 (0.00)	0.56
Average	**-0.003**	**0.000**	**0.17**	**2.32**	

Parameter estimation for the proposed heuristic for individuals corresponding to *eq.(16)* for treatment T3. The p-value of each coefficient is presented in parenthesis.

Mkt/Player	m_4 (*P**)	m_3 (*P*)	m_1 (*C*)	b	r^2
1/1	0.000 (0.29)	0.001 (0.00)	0.06 (0.42)	0.07 (0.36)	0.27
1/2	0.000 (0.46)	0.000 (0.47)	-0.17 (0.23)	0.24 (0.01)	0.06
1/3	0.000 (1.00)	0.000 (0.87)	-0.32 (0.02)	0.35 (0.00)	0.15
1/4	0.000 (0.18)	0.000 (0.16)	0.02 (0.77)	0.06 (0.32)	0.08
1/5	0.000 (0.78)	0.000 (0.00)	0.01 (0.92)	0.08 (0.04)	0.26
2/1	0.001 (0.26)	0.001 (0.11)	-0.20 (0.09)	0.15 (0.08)	0.30
2/2	0.000 (0.78)	0.000 (0.90)	0.19 (0.00)	0.00 (0.96)	0.33
2/3	-0.001 (0.21)	0.000 (0.84)	0.00 (0.96)	0.24 (0.00)	0.14
2/4	0.000 (0.74)	0.000 (0.73)	-0.42 (0.02)	0.53 (0.00)	0.22
2/5	0.000 (0.73)	0.000 (0.86)	-0.04 (0.66)	0.29 (0.01)	0.01
3/1	0.000 (0.66)	0.001 (0.01)	0.15 (0.01)	-0.09 (0.10)	0.40
3/2	0.000 (0.99)	0.000 (0.96)	0.10 (0.37)	0.10 (0.40)	0.04
3/3	-0.003 (0.01)	0.000 (0.22)	-0.24 (0.01)	0.74 (0.00)	0.22
3/4	0.001 (0.76)	0.000 (0.91)	0.06 (0.60)	0.12 (0.47)	0.01
3/5	0.000 (0.81)	0.001 (0.18)	0.26 (0.00)	-0.10 (0.32)	0.29
4/1	-0.001 (0.14)	0.001 (0.06)	0.02 (0.85)	0.10 (0.21)	0.09
4/2	-0.001 (0.17)	0.001 (0.01)	-0.18 (0.06)	0.36 (0.00)	0.27
4/3	-0.001 (0.24)	0.001 (0.12)	0.01 (0.90)	0.06 (0.55)	0.07
4/4	-0.007 (0.00)	0.000 (0.26)	-0.14 (0.08)	0.88 (0.00)	0.38
4/5	0.000 (0.28)	0.000 (0.22)	0.29 (0.01)	0.00 (0.99)	0.20
5/1	0.000 (0.84)	0.000 (0.50)	-0.15 (0.18)	0.48 (0.00)	0.08
5/2	-0.004 (0.00)	0.000 (0.06)	-0.02 (0.79)	0.51 (0.00)	0.44
5/3	0.000 (0.86)	0.000 (0.08)	-0.04 (0.59)	0.09 (0.00)	0.21
5/4	-0.001 (0.67)	0.001 (0.38)	0.07 (0.61)	0.05 (0.75)	0.03
5/5	0.001 (0.18)	-0.001 (0.39)	0.20 (0.00)	-0.02 (0.53)	0.42
6/1	-0.002 (0.00)	0.001 (0.00)	0.11 (0.19)	0.07 (0.16)	0.29
6/2	0.000 (0.42)	0.001 (0.16)	-0.07 (0.51)	0.13 (0.15)	0.12
6/3	-0.001 (0.03)	0.000 (0.05)	0.12 (0.26)	0.17 (0.11)	0.12
6/4	-0.001 (0.18)	0.001 (0.20)	-0.02 (0.85)	0.13 (0.07)	0.06
6/5	0.000 (0.91)	0.000 (0.95)	-0.10 (0.29)	0.18 (0.03)	0.04
Average	**-0.001**	**0.000**	**-0.015**	**0.199**	

Parameter estimation for the proposed heuristic for individuals corresponding to *eq.(16)* for treatment T4. The p-value of each coefficient is presented in parenthesis.

Mkt/Player	m_4 (*P**)	m_3 (*P*)	m_2 (*SL*)	m_1 (*C*)	b	r^2
1/1	0.000 (0.77)	0.000 (0.27)	0.22 (0.18)	-0.06 (0.63)	0.13 (0.35)	0.16
1/2	0.000 (0.19)	0.000 (0.16)	0.12 (0.49)	0.13 (0.03)	0.02 (0.51)	0.30
1/3	0.000 (0.72)	0.000 (0.83)	-0.25 (0.16)	0.06 (0.79)	0.29 (0.36)	0.09
1/4	0.003 (0.44)	0.000 (0.76)	-0.23 (0.18)	-0.05 (0.90)	0.03 (0.94)	0.08
1/5	0.000 (0.77)	0.000 (0.70)	0.06 (0.72)	-0.19 (0.12)	0.21 (0.04)	0.13
2/1	0.001 (0.06)	-0.001 (0.07)	0.05 (0.78)	-0.14 (0.18)	0.41 (0.01)	0.14
2/2	0.000 (0.22)	0.000 (0.14)	0.63 (0.00)	0.03 (0.41)	0.00 (0.86)	0.60
2/3	-0.001 (0.20)	0.000 (0.44)	-0.22 (0.21)	-0.03 (0.79)	0.29 (0.01)	0.08
2/4	-0.001 (0.05)	0.001 (0.11)	0.35 (0.03)	0.07 (0.34)	0.08 (0.12)	0.27
2/5	0.000 (0.81)	0.000 (0.39)	0.18 (0.22)	-0.10 (0.19)	0.12 (0.03)	0.28
3/1	0.005 (0.01)	0.000 (0.55)	0.19 (0.26)	0.05 (0.35)	-0.23 (0.08)	0.32
3/2	0.000 (0.78)	0.000 (0.97)	0.00 (0.99)	0.00 (1.00)	0.07 (0.08)	0.02
3/3	0.000 (0.72)	0.000 (0.98)	-0.17 (0.30)	-0.32 (0.01)	0.46 (0.00)	0.35
3/4	0.000 (0.92)	0.000 (0.54)	-0.36 (0.05)	-0.09 (0.69)	0.21 (0.29)	0.13
3/5	0.000 (0.06)	0.000 (0.31)	0.14 (0.45)	0.10 (0.11)	-0.04 (0.33)	0.40
4/1	0.002 (0.07)	-0.001 (0.06)	0.19 (0.24)	-0.04 (0.63)	0.03 (0.73)	0.17
4/2	-0.024 (0.26)	-0.001 (0.05)	0.28 (0.06)	-0.03 (0.64)	2.35 (0.20)	0.27
4/3	0.000 (0.81)	0.000 (0.31)	0.35 (0.01)	-0.22 (0.00)	0.33 (0.00)	0.53
4/4	0.001 (0.64)	0.000 (0.48)	-0.08 (0.64)	-0.10 (0.51)	0.21 (0.31)	0.12
4/5	-0.002 (0.28)	0.001 (0.29)	-0.10 (0.56)	-0.24 (0.05)	0.36 (0.01)	0.16
5/1	0.000 (0.74)	0.000 (0.48)	0.28 (0.11)	0.02 (0.85)	0.10 (0.28)	0.10
5/2	0.000 (0.90)	0.000 (0.59)	0.35 (0.03)	0.16 (0.00)	-0.02 (0.56)	0.64
5/3	0.000 (0.58)	0.000 (0.99)	-0.52 (0.00)	-0.36 (0.03)	0.61 (0.00)	0.28
5/4	0.003 (0.00)	0.000 (0.60)	0.12 (0.31)	0.01 (0.90)	-0.15 (0.25)	0.59
5/5	0.000 (0.94)	0.000 (0.95)	-0.27 (0.12)	0.18 (0.25)	0.15 (0.39)	0.10
6/1	0.000 (0.86)	-0.001 (0.04)	0.84 (0.00)	-0.03 (0.01)	0.32 (0.00)	0.90
6/2	0.000 (0.81)	-0.001 (0.01)	0.13 (0.39)	-0.01 (0.60)	1.31 (0.00)	0.28
6/3	0.001 (0.06)	-0.002 (0.00)	0.78 (0.00)	0.01 (0.75)	0.22 (0.06)	0.68
6/4	0.000 (0.70)	-0.001 (0.12)	0.52 (0.00)	0.02 (0.01)	0.11 (0.36)	0.65
6/5	0.000 (0.53)	0.000 (0.77)	0.86 (0.00)	0.00 (0.98)	0.10 (0.45)	0.73
Average	**0.000**	**0.000**	**0.148**	**-0.039**	**0.269**	