CAPACITY UTILIZATION IN ELECTRICITY MARKET BEHAVIOR: AN EXPERIMENTAL ANALYSIS

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ABSTRACT

This paper describes a laboratory experiment of electricity markets to study the effect of variable capacity utilization over market dynamics. Previous experiments have left out a potential source of cyclical behavior by assuming full capacity utilization. We run 12 experimental markets of the power generation sector, involving two treatments: a first treatment with fixed (full) capacity utilization where subjects make investment decisions, and a second treatment where subjects make both investment and capacity utilization decisions. Visual inspections, basic statistics and simulation tests run with decision rules estimated from experimental data show that the markets run under full capacity utilization present a cyclical behavior in market development. Conversely, such tests show a non-cyclical market development for the markets run under variable capacity utilization, suggesting that varying capacity utilization favors stability rather than a cyclical behavior.

Keywords: Electricity Market, Capacity Utilization, Decision-Making, Experimental Economics, System Dynamics.

1. INTRODUCTION

The deregulation of the electricity industry took place in the late 80s. In general, positive and negative aspects have been observed (Sioshansi & Pfaffenberger, 2006). Several authors argue about the potentiality of a prejudicial cyclical behavior in the industry (Bunn & Larsen, 1992 and 1994; Ford, 1999 and 2001; IEA, 1999, 2002 and 2003; Larsen & Bunn, 1999; Lomi & Larsen, 1999; de Vries & Hakvoort, 2004; Kadoya *et al.*, 2005). Since the time series of deregulated electricity markets are still short to show evidence of a regular cyclical behavior (Ford, 1999; IEA, 1999 and 2003; Larsen & Bunn, 1999; de Vries & Hakvoort, 2004; Olsina *et al.*, 2006; Botterud & Doorman, 2008), the concerns are based on simulation models (Bunn & Larsen, 1992 and 1994; Ford, 1999 and 2001; Larsen & Bunn, 1999; Kadoya *et al.*, 2005; Olsina *et al.*, 2006) and experiments (Arango, 2006a and 2006b) of electricity markets.

These studies rely on simplifications that differ from reality. Rather than a disadvantage, the simplifications prevent the simulation model builder to lose control over her own model and help her to understand the structure responsible for the model's behavior (Randers & Göluke, 2007). This applies for experimenters as well, since the simplicity of the experiment allows them to have control over the variables, offering the best opportunity to learn something useful about the question that motivated the research (Friedman & Sunder, 1994; Friedman & Cassar, 2004). However, the assumption of full capacity utilization assumed on those studies is not a realistic supposition. One could develop a simulation model incorporating variable capacity utilization or, analogously, design an experiment allowing subjects to make capacity utilization decisions.

Many commodity industries suffer from persistent cyclical instability. Additionally, some of them show at least two distinct cycle periods: a short-term cycle in inventories, production and prices and a long-term cycle in capacity and/or prices (Sterman, 2000; Randers & Göluke, 2007). The classical economic theory of commodity cycles is the Cobweb Theorem (Ezekiel, 1938). As argued by Sterman (2000, p. 798), although Cobweb models do capture the core structure underlying commodity cycles, they are unsuitable for serious modeling of market dynamics because they do not distinguish between production capacity and capacity utilization and so cannot explain the multiple oscillatory periods observed in many industries. Some authors have already used a more realistic approach than the Cobweb Theorem developing System Dynamics models and have shown a pattern of interplay between a "4 year" capacity utilization cycle and a "20 year" capacity cycle. Meadows' (1970) and Randers & Göluke's (2007) models support this pattern of behavior in the context of livestock and oil tankers industries respectively. Moreover, Mass' (1975) model supports the same pattern of behavior in a macroeconomic context.

Although useful for understanding the interaction between capacity utilization cycles and capacity adjustment cycles in several contexts, these models include behavioral assumptions that we would like to test rather than induce. Under these circumstances, experimental economics provide a methodological framework to test the rationality of subjects making isolated investment and capacity utilization decisions in the context of a deregulated electricity market.

Previous experiments of electricity markets took as starting point the simplest Cobweb model (Arango, 2006a and 2006b)[1]. Arango added complexity and realism to the markets to respond to the critics of experimental economics who argue that real markets are

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[1] Other previous applications of experimental economics in electricity markets have focused mainly in market design (*e.g.*, Rassenti *et al.*, 2003; Vogstad *et al.*, 2005; Kiesling & Wilson, 2007).

inherently more complex than the markets analyzed in laboratories and so experimental results are not representative of real economic phenomena (Loewenstein, 1999; Fatás & Roig, 2004). Arango (2006a) showed cyclical tendencies in prices as market complexity increased, while the follow-up experiment of Arango (2006b) showed a well-defined oscillatory behavior in prices. The present experiment can be seen as a continuation of Arango's works. The main difference is that we are relaxing Arango's full capacity utilization assumption.

We formulate the null hypothesis based on rational choice classic theory (Muth, 1961; Lucas, 1981) and the standard assumption in neoclassical economics about optimal decision making. The null hypothesis is convergence to a stable Cournot Nash equilibrium; minor and seemingly random variations around the equilibrium value will be consistent with this hypothesis.

The alternative hypothesis is based on the bounded rationality (Simon, 1955 and 1979) and the use of very simple information-processing rules or heuristics (Tversky & Kahneman, 1974), which are consequence of bounded rationality (Kleinmuntz, 1993). There is experimental support for bounded rationality theory in dynamic experiments (*e.g.*, Sterman, 1989a and 1989b; Kampmann, 1992; Paich & Sterman, 1993; Diehl & Sterman, 1995; Duffy & Ochs, 1999; Lei *et al.*, 2001; Moxnes, 2004; Arango, 2006b). While heuristics could lead to near-to-optimal results for simple problems, the results are likely to deteriorate with complexity (Kampmann, 1992; Paich & Sterman, 1993; Diehl & Sterman, 1995; Moxnes, 2004; Arango, 2006a).

Regarding cycles, we propose two heuristics that express the intended rationality of agents. The first one, concerning investment behavior, is inspired on the investment function formulated in Senge (1980) and the investment dynamics of electricity markets reported in Stoft (2002). It assumes that agents use a feedback strategy to adjust their capacity towards a desired capacity. This rule is consistent with the anchoring and adjustment heuristic (Tverksy & Kahneman, 1974). Previous experimental support for similar heuristics is presented in dynamic experiments (*e.g.*, Sterman, 1989a and 1989b; Bakken, 1993; Paich & Sterman, 1993; Diehl & Sterman, 1995; Barlas & Özevin, 2004; Arango, 2006b). The strategy tends to underestimate the investment lag, which results in continuous investments even when there is a lot of capacity in the supply line (capacity still in construction phases), generating a pronounced raise in capacity when all these investments realize in installed capacity. This raise results in a dramatic fall in prices with the subsequent under-investment behavior to raise prices again. In theory, this behavior should produce the long-term capacity cycle (*e.g.*, Sterman, 1987 and 1989a; Bakken, 1993; Arango, 2006b). The second one, concerning capacity utilization behavior, is inspired on the capacity utilization function formulated in Randers & Göluke (2007) in an inventory management problem. The strategy tends towards full utilization when prices are high and to minor utilization rates when prices are low. In theory, this behavior should produce the short-term capacity utilization cycle. There is no previous experimental support for the capacity utilization heuristic. Thus, we consider the experiment exploratory in this regard.

Section 2 describes the experimental design. The design includes testable hypotheses based on rational choice and bounded rationality theories. Section 3 presents the experimental results. Section 4 tests the hypotheses. Finally, section 5 concludes.

2. EXPERIMENTAL DESIGN

2.1. Experimental economic model

We use a computerized experiment of a symmetrical Cournot five player market with linear demand. The design corresponds to a Cournot market experiment under standard conditions (Huck, 2004)[2], except for the investment and capacity utilization dynamic complexity as we explain later in the experimental treatments. We use five players in order to ensure a non-collusive behavior with outcomes expected to be about the Cournot Nash outcome or even about competitive levels (Huck *et al.*, 2004). We use the same experiment of Arango (2006b), with a time step of one year, with four years before new production capacity is in place and capacity lasts for sixteen years. Investment decisions are made yearly. Each subject decides freely on investments with the exceptions that its capacity must not exceed 20% of the total capacity (reflecting the maximum allowed market share) and that its investments must not be negative. The market price is determined by a linear inverse demand function with a non-negativity restriction. Information about the realized price and own profits is given each period. The market price in period *t* is:

$$P_t = Max\left(6 - 0.1\sum_{i=1}^{5} q_{i,t}, 0\right) \tag{1}$$

where $q_{i,t}$ is the production of subject *i* in period *t*. Production varies according with the experimental treatments. There are two experimental treatments. Treatment T1 is identical to Arango's (2006b) experiment except for the more disaggregated investment and capacity vintages while T2 introduces variable capacity utilization.

Following, we describe the treatments and the rest of the experimental design.

2.1.1. Treatment T1

We set up our first treatment, T1, equal to Arango (2006b), where subjects have fixed capacity utilization (*i.e.*, production equals installed capacity). Production equals the sum of the capacities of all players. Given the investment lags and the vintages of capacity, production of subject *i* in period *t* is:

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[2] Standard conditions (Huck, 2004, p. 106): *(i)* interaction takes place in fixed groups, *(ii)* interaction is repeated over a fixed number of periods, *(iii)* products are perfect substitutes, *(iv)* costs are symmetric, *(v)* there is not communication between subjects, *(vi)* subjects have complete information about their own payoff functions, *(vii)* subjects receive feedback about the aggregated behavior of the other subjects, and *(viii)* the experimental instructions use an economic framework.

$$q_{i,t} = \sum_{j=t-19}^{t-4} x_{i,j} \tag{2}$$

where $x_{i,j}$ is the investment decision made in years $j = t\text{-}19$ to $j = t\text{-}4$. The profit function in experimental pesos (E$) for subject *i* in period *t* is:

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

where *c* are the marginal costs, which include both capital and operational costs and are equal to 1 E$/Unit.

This treatment links the present work with the literature and is identical to Huck's standard conditions for Cournot markets, except for the longer lag in investment and the more disaggregated investment and capacity vintages showing explicitly information of the investment that is about to realize in capacity and the capacity that is about to depreciate in a given period. Thus, subjects receive information about: *(i)* their total investments, aggregate over three vintages, *(ii)* their capacities, aggregate over sixteen vintages, *(iii)* their productions, *(iv)* aggregate production of the other players, and *(v)* production of the market (see Appendix 1, in Spanish). This change in the information presented to subjects favors model transparency, which in general has a positive effect over subjects' performance (Rouwette *et al.*, 2004). Since T1 is run under such information conditions, T2 has to be run under the same information conditions as well and not under the conditions used in Arango (2006b). If we do not do it in such a way, the variations in the results of T1 with respect to the results of T2 could be due either to model transparency or to the variable capacity utilization (or both) and we might not know precisely which of them is the responsible for the variations. However, it is not an objective of this work to see if the transparency will have a positive effect over subjects' performance. If this was the case, we would have to compare the results we obtain in T1 against the results reported in Arango (2006b).

2.1.2. Treatment T2

Different from T1, the second treatment, T2, does not assume full capacity utilization since investors may adopt a strategic bidding behavior (Arango, 2006a and 2006b). In this treatment subjects have the possibility to make capacity utilization decisions in a yearly basis like the investment decisions. Given the time step that we are using, the shorter delay that we can use for capacity utilization decisions is one year. While it might look like a long lag, in real life situations not only do decision makers have to adjust the utilization but also have to assess the current status of several variables in order to make the wisest decisions, activity that in the case of corporate and economic environments may take up to a year (Sterman, 2000, p. 636) . Thus, it takes one year before a utilization decision realizes.

Most observers expect that competition increases capacity utilization rates in electric generation just as it has done in every other deregulated industry and it is conceivable that capacity utilization reaches rates above 70%, possible above 80% (Maloney, 2001). Thus, in this treatment capacity utilization decisions are restricted to values between 70% and 100%. This treatment is also identical to Huck's standard conditions for Cournot markets, except for the longer lag in investment and the more disaggregated investment and capacity vintages as well as for the distinction between production capacity and capacity utilization. Since it is possible that the installed capacity be not equal to production, information items *(iv)* and *(v)* of T1 become *(iv)* aggregate capacity and production of the other players and *(v)* capacity and production of the market for T2 (see Appendix 1, in Spanish).

Production equals the sum of the capacities of all players multiplied by their respective capacity utilizations. Given the investment lags, the vintages of capacity and the utilization lag, production of subject *i* in period *t* is:

$$q_{i,t} = \sum_{j=t-19}^{t-4} x_{i,j} \cdot CU_{i,t\text{-}1} \tag{4}$$

where $x_{i,j}$ is the investment decision made in years $j = t\text{-}19$ to $j = t\text{-}4$ and $CU_{i,t\text{-}1}$ is the capacity utilization decision of subject *i* in period *t-1*. The profit function in experimental pesos (E$) for subject *i* in period *t* is:

$$\pi_{i,t} = \left(P_t - \beta\right) \cdot q_{i,t} - \alpha \sum_{j=t-19}^{t-4} x_{i,j} \tag{5}$$

where β and α are the operational and capital costs respectively. As we just noticed, this extension of T1 implies a change in the cost function since now we have both capital and operational costs. The cost function for T1 is[3]:

$$c_i = C \cdot q_i \tag{6}$$

where *C* are the marginal costs which include both capital and operational costs and are equal to 1 E$/Unit, and q_i is the electricity production of subject *i*.

The cost function for T2 is:

$$c_i = \beta \cdot q_i + \alpha \cdot CI_i \tag{7}$$

where q_i and IC_i are the electricity production and the installed capacity of subject *i* respectively. As we mentioned previously, β and α are the operational and capital costs respectively.

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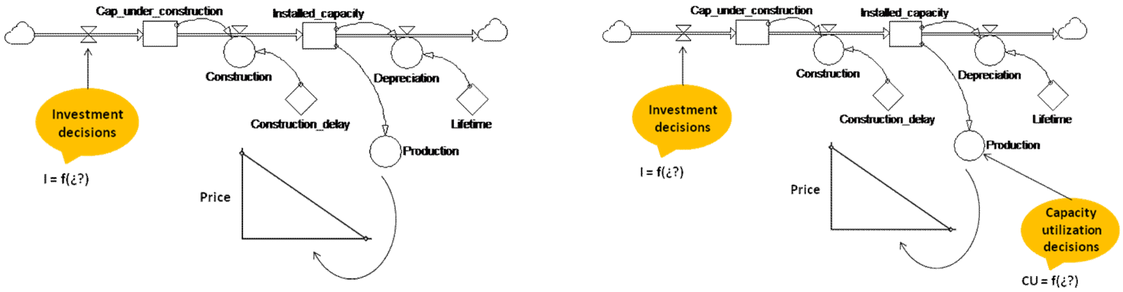
[3] The cost function for T1 is the same cost functions used in Arango (2006a and 2006b).

To link T2 with T1, the Cournot Nash equilibrium must be the same. This implies that the values of the capital (α) and operational (β) costs must be chosen in order to hold the expression that provides the first-order condition for the production, which is derived in Appendix 2.

We use a time horizon of 70 years which should be large enough to allow learning and eventual convergence towards some equilibrium.

The model underlying the experimental economic model is represented by System Dynamics methodology as shown in Figure 1. Notice that there are not feedback structures feeding the investment decisions for both T1 and T2, while for T2 there are not feedback structures feeding the capacity utilization decisions as well, *i.e.*, there are not behavioral assumptions since we want to test the rationality of those decisions rather than induce it.



T1 **T2**

Figure 1. Stock and flow diagram of the experimental markets.

2.2. Experimental procedure

The experiment follows the standard framework used in experimental economics (Friedman & Sunder, 1994; Friedman & Cassar, 2004). All subjects were recruited from the same population last year students in the undergraduate programs of Industrial Engineering, Management Engineering and Economics at the Universidad Nacional de Colombia, Medellín, Colombia in spring of 2009. There were 12 markets, 6 for each treatment. No subject had previous experience in any related experiment. Subjects were told they could earn between Col$10.000 and Col$50.000 (US$5 – US$25 at that time) in about one and a half hour, values that in general are greater than the opportunity cost of subjects. 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, such that subjects could not identify rivals in the market. Instructions (see Appendix 3, in Spanish) were distributed and they were read aloud by the experimenter. Subjects were allowed to ask questions and test the computer interface. All the experiment parameters were common knowledge to all subjects, including the symmetry across firms. The initial condition was a total industry production of 55 Units and individual productions of 11 Units (which implies a utilization of 1 or 100% for T2). Thus, the price started at 0.5 E$/Unit. These initial values were identical across groups.

Each simulated year, subjects were asked to make investment decisions in both treatments. In addition, subjects were asked to make capacity utilization decisions in T2. The experiment was run in a computer network using the simulation software Powersim Constructor version 2.51. The software ran automatically and kept record of all variables including subject's decisions. Still subjects were asked to write their decisions in a sheet of paper to keep a memory of past decisions and to provide a backup of the experiment. At the end of the session, subjects were asked to answer in written a question about the strategy they had followed during the experiment and an additional question about difficulties they might have experienced during the experiment. The software interfaces are presented in Appendix 1 (in Spanish) and the experiment is available upon request.

2.3. Testable hypotheses

2.3.1. Rational choice hypothesis: Cournot Nash equilibrium

The null hypothesis is based on rational choice classic theory (Muth, 1961; Lucas, 1981). Under this hypothesis, the economic model has a unique Cournot Nash equilibrium. Table 1 shows the numbers characterizing the Cournot Nash equilibrium. Previous experiments have shown some biases (*e.g.*, Arango, 2006a and 2006b). To judge our results in this regard, the table also presents the equilibrium values for perfect competition and joint maximization. Minor and random fluctuations around the Cournot Nash equilibrium are consistent with this hypothesis.

Table 1. Experimental markets equilibriums*.

	Individual investment (Units)	**Market production (Units)**	**Price (E$/Unit)**
Perfect competition	0.63	50.0	1.00
Cournot Nash	0.52	41.7	1.83
Joint maximization	0.31	25.0	3.50

* For T2 all equilibrium points are reached investing the amount specified in the table and making full capacity utilization decisions, *i.e.*, CU = 1 (100%) for all individuals.

Neoclassical economic theory suggests no cyclical behavior but stability. Any predictable cyclical tendency would lead to countercyclical investments and stabilization. In fact, if the economist can show that there is a negative feedback loop, there would be equilibrium and cyclical tendencies will be prevented by a countercyclical behavior (Stoft, 2002). Accordingly, economic theory normally attributes cyclical behavior to external shocks, particularly in commodity markets (Deaton & Laroque, 1992, 1996 and 2003; Deaton, 1999; Cashin *et al.*, 2002). We consider random shocks generated within a market to be consistent with standard economic theory. Previous experimental Cournot markets have found that outputs and prices are not exactly equal to the Cournot Nash equilibrium but close, typically closer than one standard deviation of the observed price fluctuations (Huck, 2004). To summarize, we present the next formal hypotheses:

Hypothesis 1: average prices are equal to Cournot Nash equilibrium predictions.
Hypothesis 2: market prices do not show cyclical behavior, while random variations may occur.

2.3.2. Bounded rationality hypothesis: heuristics and cycles

The alternative hypothesis is based on bounded rationality theory (Simon, 1955 and 1979). We propose that people use investment and capacity utilization heuristics.

The investment heuristic is inspired on the investment function formulated in Senge (1980) and the investment dynamics of electricity markets reported in Stoft (2002). This heuristic is similar to Arango's (2006a and 2006b) formulations and is consistent with the anchoring and adjustment heuristic (Tversky & Kahneman, 1974). The function assumes that people use a feedback strategy to adjust their capacity towards a desired capacity. The investment function is:

$$x_t = Max\left(\frac{C_t}{LT} + \alpha_{sl} \cdot \left(\frac{C_t^*}{ID} - SL_t\right) + \alpha_c \cdot \left(C_t^* - C_t\right), 0\right) \tag{8}$$

where the *Max* function precludes negative investments, capacity C_t divided by the lifetime *LT* denotes a normal level of investments to replace depreciated capacity, α_{sl} determines how quickly the supply line (capacity in construction) SL_t is adjusted towards the desired supply line C^*_t/ID, where *ID* corresponds to the investment delay. Finally, α_c determines how fast capacity is adjusted towards the desired capacity C^*_t. The desired capacity is:

$$C_t^* = Max\left(a + \left(\frac{q^e - a}{P^e}\right)P_t, 0\right) \tag{9}$$

which represents a linear function of actual price P_t. This is the same formulation used in Arango (2006a and 2006b) with the exception that since we do not have information about subjects' long run price expectations, we assume that the adjustment is based on the actual price P_t. When P_t equals the equilibrium price P^e, desired capacity C^*_t equals equilibrium production q^e. The parameter a is restricted to $a < q^e$ to avoid negative slopes.

The capacity utilization heuristic is inspired on the capacity utilization function formulated in Randers & Göluke (2007) in an inventory management problem. This heuristic assumes that subjects adjust his capacity utilization towards a desired capacity utilization. Such adjustment is given by the following expression

$$CU_t^{adjust} = \alpha_{cu}\left(CU_t^* - CU_t\right) \tag{10}$$

where α_{cu} determines how quickly the capacity utilization CU_t is adjusted towards the desired capacity utilization CU^*_t, which is also consistent with the anchoring and adjustment heuristic. Since we do not have information about subjects' short run price expectations, the desired capacity utilization is a function of the actual price P_t. and is inspired on the tabular function formulated in Randers & Göluke (2007). Figure 2 shows the desired capacity utilization function.

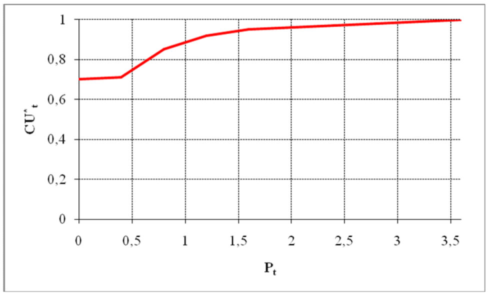
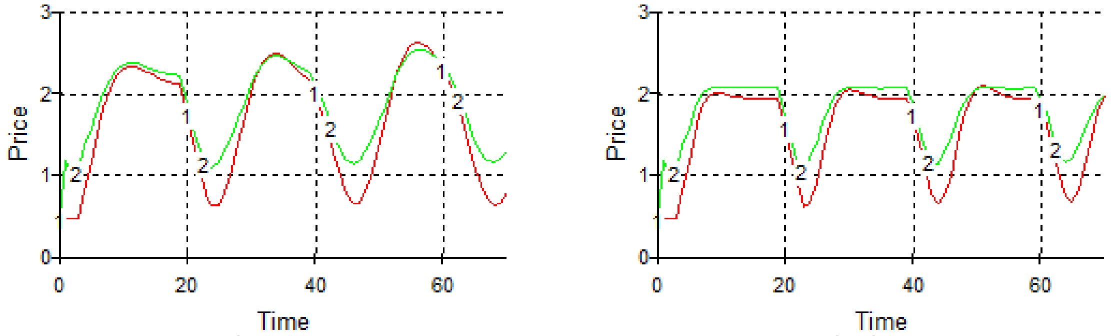


Figure 2. Desired capacity utilization function.

As we can observe in Figure 2, a desired full utilization realizes with prices closer to joint maximization levels than to the Cournot Nash equilibrium. This function is more realistic than a formulation that assumes a desired full utilization at the Cournot Nash equilibrium in the sense that there is a concern about price manipulation since in a deregulated environment theory suggests that generation owners could reduce output to raise the price (Montero & Sánchez, 2001; de Vries & Hakvoort, 2004; Puller, 2007). This function restricts the desired capacity utilization to values between 70% and 100% to hold consistency with the experimental conditions.

Initial conditions are the same as in the experiment. We choose $a = 38$ as in Arango (2006b). We use two sets of parameters and perform some sensitivity tests. Set 1 has $\alpha_{sl} = 0.1$ and $\alpha_c = 0.26$ and set 2 has $\alpha_{sl} = 0.5$ and $\alpha_c = 0.5$. For both parameter sets, we choose $\alpha_{cu} = 0.5$, which corresponds to a value used by Randers & Göluke (2007) in an analogous rule for capacity utilization decisions in an inventory management problem. Set 1 refers to values estimated by Sterman (1989b) in an analogous heuristic for an inventory management problem and set 2 refers to values studied by Arango (2006a and 2006b), which represent a more aggressive policy where half of the adjustments take place within one year.

Figure 3 shows simulated behavior for parameter sets 1 and 2 with full (line 1) and variable capacity utilization (line 2). As in Arango (2006b), we observe that the heuristic leads to oscillatory behavior in both cases. Set 1 produces one dominant cycle with an increasing amplitude over time. Set 2 shows a dominant cycle with a slightly shorter period than the observed with set 1. We also observe that the variable capacity utilization reduces the amplitude of the oscillations and does not allow prices to go below competitive levels, showing this way a more stable price behavior that allows having profits all the time.



Set 1 **Set 2**

Figure 3. Simulated prices of the experimental market with the heuristics of the literature with full (line 1) and variable capacity utilization (line 2).

Sensitivity analysis of the hypothesized parameters for both sets shows a tendency towards price stabilization when α_{sl} and α_c are reduced. Low values of α_{sl} in combination with increasing values of α_c lead to stronger instability, which indicates that ignoring the supply line and focusing primarily in capacity leads to greater oscillations. Behavior is not very sensitive to reasonable changes in α_{cu}.

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The simulations in Figure 3 are deterministic. To study the effects of internally generated disturbances, we introduce a normally distributed noise u_t to investment, $u_t \sim N(0, S^2{}_1)$ and to capacity utilization, $u_t \sim N(0, S^2{}_2)$[4]. Figure 4 shows simulated behavior for parameter sets 1 and 2 with full and variable capacity utilization, and without (line 1) and with noise (line 2)[5]. For set 1, we observe one dominant cycle period with some minor disturbances, *i.e.*, noise does not affect the underlying mode of behavior observed in deterministic simulations. For set 2, we also observe cycles, but the mode of behavior is different with respect to deterministic simulations since we observe a double-cycle behavior: cycles with relative high amplitudes followed by cycles of lower amplitudes.

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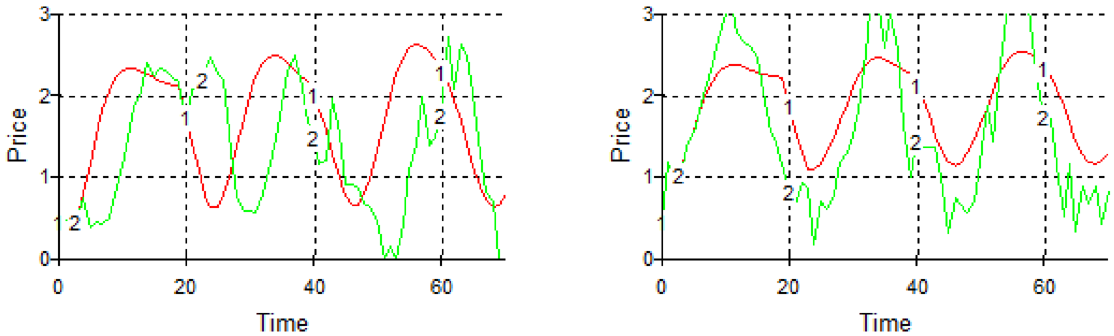
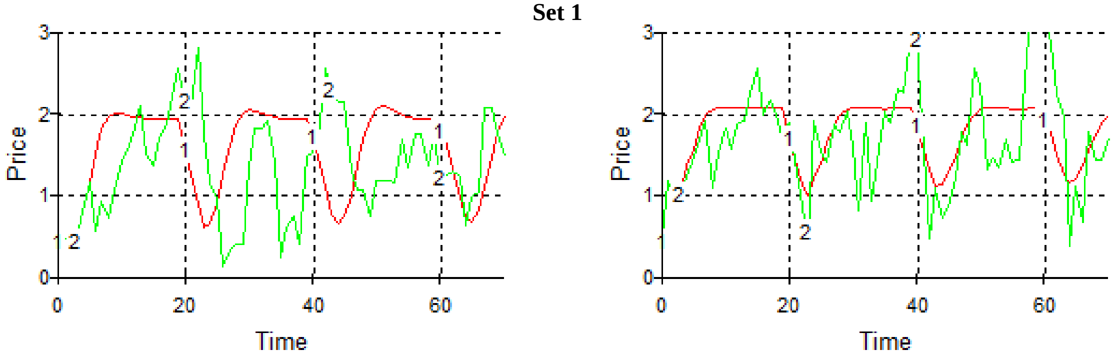
[4] S_1 is set as the average standard error for regressions of the investment heuristic, while S_2 is the analogous case for the capacity utilization heuristic.

[5] Given the inherent randomness in the process that introduces noise into the simulations, we run several simulations with noise. We show a representative simulation of each case.



Full capacity utilization **Variable capacity utilization**

Set 1



Full capacity utilization **Variable capacity utilization**

Set 2

Figure 4. Simulated prices of the experimental market with the heuristics of the literature for parameter sets 1 and 2 with full and variable capacity utilization, and without (line 1) and with noise (line 2).

To summarize, we present the next formal hypothesis:

Hypothesis 3: market prices show cyclical behavior.

2.4. Methods to test the occurrence of cycles

We run simulation tests with the proposed investment and capacity utilization adjustment heuristics. The simulations are run with estimated parameters for the linear forms of equations (8), (9) and (10) (see Appendix 4 for the derivation of the linear form of the decision rules).

The following simple linear form is an approximation of the aggregated investment behavior in equations (8) and (9):

$$x_t = m_2 SL_t + m_1 P_t + b \tag{11}$$

where m_2, m_1 and b are parameters to be estimated.

The following simple linear form is an approximation of the aggregated capacity utilization adjustment behavior in equation (10) and the tabular function of the desired capacity utilization in Figure 2:

$$CU_t^{adjust} = m_2 CU_t + m_1 Z_t + b \qquad (12)^6$$

where m_2, m_1 and b are parameters to be estimated.

Table 2 presents the theoretical values for these parameters, which will serve as references for comparison with the estimation results derived from the estimation process performed with the experimental results.

Table 2. Theoretical values of the parameters of the linear forms of the proposed heuristics.

	m_2	m_1	b
Investment			
Theoretical values set 1	-0,10	2,55	-1,02
Theoretical values set 2	-0,50	5,63	-2,50
Capacity utilization adjustment			
Theoretical values	-0,50	0,16	0,34

3. RESULTS

Figure 5 shows price development for the six markets of both treatments over time. The analysis could be performed with a focus on prices or capacities. We choose prices since they are easier to compare with real markets. In T1, prices vary from 0 E$/Unit to values close to 4 E$/Unit, suggesting a fluctuating price behavior. In T2, prices vary from 0 E$/Unit to values close to 4 E$/Unit, suggesting a fluctuating price behavior as well. In T1, visual inspection suggests tendencies towards regular price cycles for most of the markets with exploding oscillations in markets 1 and 2. Although market 4 has no apparent signs of cycles, it still shows great variations in prices. Regarding T2, visual inspection suggests a tendency towards regular price cycles in half of the markets (7, 9 and 11). Although the rest of the markets have no apparent signs of cycles, they still show great variations in prices. In general, the results for both treatments show no signs of a tendency towards stabilization in spite of the fact that the experiment was run over 70 periods (years).

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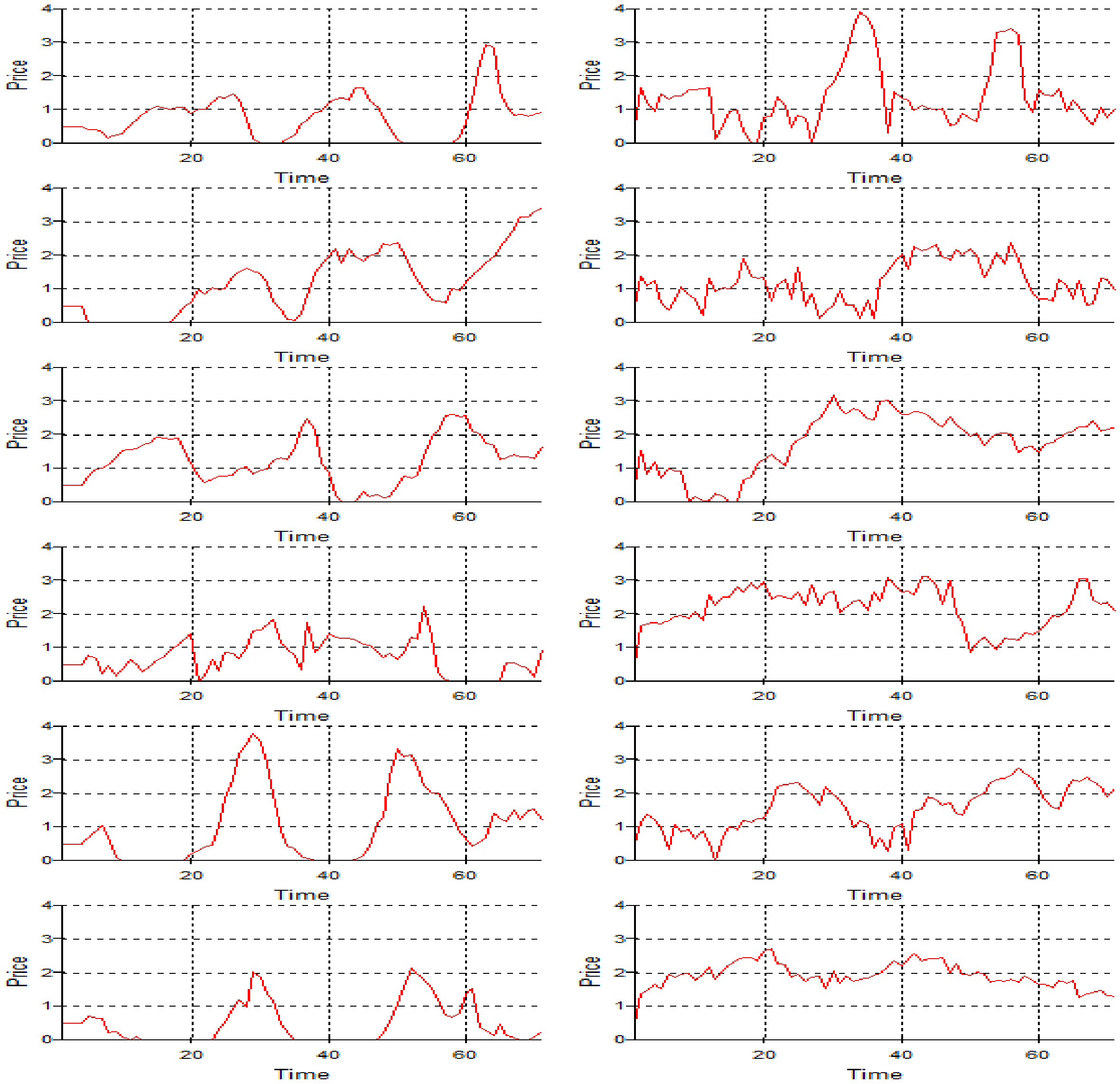
[6] Z refers to the price, but it is not the actual price. Since the desired capacity utilization function is a tabular function, we performed a curve fitting process to approximate $CU^*_t(P_t)$, which resulted in a non-linear component for P_t (see Appendix 4 for details on the derivation of equations (11) and (12)).



T1

T2

Figure 5. Observed prices for both treatments.

Table 3 shows a summary of price statistics for both treatments. In T1, we observe that all markets have average prices closer to perfect competition levels than to the Cournot Nash equilibrium. The average coefficient of variation shows that the average dispersion of prices is 86%, suggesting a fluctuating price behavior. Moreover, the table shows high one-lag autocorrelations, on average 0,87, which constitutes an indication of cycles. With respect to T2, we observe that markets 9, 10, 11 and 12 have average prices closer to the Cournot Nash equilibrium than to perfect competition levels, while for markets 7 and 8 is the opposite case, showing that varying capacity utilization allows generators having higher prices. The table also shows high one-lag autocorrelations for T2, on average 0,78, which constitutes an indication of cycles as in T1. However, the average coefficient of variation of T2 suggests a more stable price behavior than in T1.

Table 3. Summary statistics of the observed prices for both treatments[*].

	T1				T2			
	$\bar{P}$ (E$/Unit)	S (E$/Unit)	CV	α	$\bar{P}$ (E$/Unit)	S (E$/Unit)	CV	α
M1	0,79	0,65	0,83	0,89	1,38	0,93	0,67	0,78
M2	1,15	0,92	0,79	0,92	1,21	0,62	0,51	0,68
M3	1,21	0,70	0,57	0,92	1,75	0,88	0,50	0,92
M4	0,75	0,53	0,71	0,69	2,20	0,62	0,28	0,76
M5	1,05	1,09	1,05	0,94	1,55	0,68	0,44	0,84
M6	0,50	0,62	1,24	0,88	1,93	0,38	0,20	0,71
Average	**0,91**	**0,75**	**0,86**	**0,87**	**1,67**	**0,68**	**0,43**	**0,78**

[*] $\bar{P}$: mean price; S: standard deviation; CV: coefficient of variation; α: one-lag autocorrelation.

While the initial analyses we conducted in this section suggest a fluctuating behavior in prices for both T1 and T2, with a tendency towards a higher and a more stable price behavior in T2 than in T1, they can be misleading given that they correspond to basic tests and, hence, the conclusions derived from them may be not accurate, especially the conclusions derived from visual inspections. Thus, next section presents the formal hypothesis tests.

4. TESTING THE HYPOTHESES

Following, we perform the formal tests of the hypotheses presented in section 2.

4.1. Hypothesis 1

We present the limits for the 95% confidence intervals of the average prices in Table 4. We observe that hypothesis 1 is rejected for all markets of T1 since none of them has the average price in an interval that includes the Cournot Nash equilibrium value. Furthermore, all markets have average prices closer to perfect competition levels than to the Cournot Nash equilibrium. This bias towards competition was also observed in Arango (2006a and 2006b) and is consistent with previous experiments of Cournot markets (see summary in Huck, 2004 and Huck *et al.*, 2004). We observe similar results for T2 in the sense that hypothesis 1 is rejected for all markets, except for market 9. However, this time only markets 7 and 8 show a bias towards perfect competition levels, while markets 10, 11 and 12 show a bias towards the Cournot Nash equilibrium.

Table 4. Average prices and 95% confidence interval limits for both treatments.

	T1						T2					
E$/Unit	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**
Lower bound	0,63	0,94	1,04	0,62	0,78	0,35	1,16	1,06	1,55	2,05	1,39	1,84
Average	0,79	1,15	1,21	0,75	1,05	0,50	1,38	1,21	1,75	2,20	1,55	1,93
Upper bound	0,94	1,37	1,38	0,87	1,31	0,65	1,60	1,35	1,96	2,35	1,72	2,02

Next, we test the hypothesized cyclical behavior by performing regressions on the investment and capacity utilization heuristics and running simulations with the estimated rules, comparing those simulations against simulations run with the theoretical hypothesized behavior.

4.2. Hypotheses 2 and 3

4.2.1. Investment behavior

We explore the aggregated investment behavior for both treatments by performing regressions of equation (11) with the aggregated experimental results. Table 5 presents the regressions. In T1, we observe that two out of six markets have significant values for m_2 (SL) with a positive average contrary to theoretical values, m_1 (P) is significant in five out of six markets with a positive average, and *b* is always significant with a positive average contrary to theoretical values (significance at least at 10%). Thus, price drives investments, which is consistent with the view that decision-making in deregulated environments is guided by price (or profit) signals (Stoft, 2002; Olsina *et al.*, 2006). Moreover, these results are also consistent with other experiments on Dynamic Decision-Making in the sense that the supply line is ignored in the decision-making process, which is a source of instability (Sterman, 1989a and 1989b; Bakken, 1993; Diehl & Sterman, 1995; Barlas & Özevin, 2004; Arango, 2006a and 2006b). Regarding T2, m_2 (SL) is significant in four out of six markets with a positive average contrary to theoretical values, m_1 (P) is significant only in one market with a positive average, and *b* is significant only in half of the markets with a positive average contrary to theoretical values (significance at least at 10%). According to this, supply line drives investments, which is neither consistent with the behavior reported in the literature (Stoft, 2002; Olsina *et al.*, 2006) nor with the results reported in similar experiments (*e.g.*, Arango, 2006a and 2006b). We should consider the poor results of the regressions whenever the average R^2 is only 13,60 and it is mostly influenced by one market with an R^2 of 32,94.

The difference between T1 and T2 in the results of the regressions may be due to information availability. The available information is greater in T2 than in T1, which imply that subjects may have used more information besides price and supply line in the investment decision-making process. This indicates that subjects may use different mental models for decision-making according to the information available at the time they make decisions.

Table 5. Parameter estimates of the aggregated investment behavior for both treatments*.

		m_2 (SL)	m_1 (P)	b	R^2
T1	**M1**	-0,07 (0,32)	2,88 (0,00)	1,61 (0,00)	29,71
	M2	0,12 (0,02)	0,15 (0,58)	1,61 (0,01)	7,90
	M3	0,02 (0,74)	1,19 (0,01)	1,19 (0,02)	18,44
	M4	-0,01 (0,85)	2,23 (0,00)	1,57 (0,03)	15,37
	M5	0,08 (0,10)	1,23 (0,00)	1,08 (0,02)	36,32
	M6	0,02 (0,81)	1,44 (0,01)	2,60 (0,00)	13,00
	Average	**0,03**	**1,52**	**1,61**	**20,12**
T2	**M7**	-0,06 (0,26)	2,86 (0,00)	0,19 (0,80)	32,94
	M8	0,14 (0,02)	0,60 (0,22)	1,18 (0,12)	12,87
	M9	0,04 (0,56)	-0,32 (0,30)	3,28 (0,00)	2,70

	M10	0,17 (0,00)	0,22 (0,54)	0,99 (0,22)	15,69
	M11	0,12 (0,03)	0,51 (0,12)	1,34 (0,07)	10,44
	M12	0,12 (0,03)	-0,001 (0,99)	1,98 (0,00)	6,94
	Average	**0,09**	**0,64**	**1,49**	**13,60**
	Theoretical set 1[**]	-0,10	2,55	-1,02	
	Theoretical set 2[**]	-0,50	5,63	-2,50	

[*] P-values are presented in parentheses.
[**] Theoretical values from Table 2.

We also explore the individual investment behavior for both treatments. The proposed investment function for individuals is:

$$x_t^i = m_3 C_t^i + m_2 SL_t^i + m_1 P_t + b \qquad (13)^7$$

where m_3, m_2, m_1 and b are parameters to be estimated. The index i represents individuals and the variables conserve the previous names. Table 6 shows the regressions of equation (13) for all individuals across markets. In T1, we observe 13, 15, 10 and 13 significant values out of maximum of 30 for m_3 (C_i), m_2 (SL_i), m_1 (P) and b respectively (significance at least at 10%). The significant coefficients are not largely consistent with the coefficients for the aggregated markets in the sense that SL_i has more significant values than C_i and P. In addition, the low values of R^2 call for further research about individual investment heuristics whenever the average R^2 is 20,37. Regarding T2, we observe 18, 13, 11 and 21 significant values out of maximum of 30 for m_3 (C_i), m_2 (SL_i), m_1 (P) and b respectively (significance at least at 10%). While the significant coefficients are not largely consistent with the coefficients for the aggregated markets, they suggest a similar behavior to the one reported in analogous experiments in the sense that the supply line is ignored in the decision-making-process. Although this time the average R^2 for individuals is greater than in T1 (25,40 and 20,37 respectively), it is still low and calls for further research about individual investment heuristics.

Table 6. Parameter estimates of the individual investment behavior for both treatments[*].

			m_3 (C_i)	m_2 (SL_i)	m_1 (P)	b	R^2
T1	**M1**	p1	-0,03 (0,01)	0,20 (0,00)	0,02 (0,76)	0,20 (0,03)	39,83
		p2	-0,02 (0,29)	0,12 (0,01)	0,61 (0,00)	0,20 (0,56)	39,18
		p3	-0,16 (0,00)	-0,16 (0,03)	1,24 (0,01)	2,61 (0,00)	37,60
		p4	0,01 (0,67)	0,16 (0,00)	0,18 (0,09)	-0,02 (0,91)	18,26
		p5	-0,13 (0,01)	-0,02 (0,78)	0,14 (0,55)	3,21 (0,00)	12,01
	M2	p1	-0,14 (0,01)	-0,06 (0,43)	-0,02 (0,94)	3,34 (0,00)	12,48
		p2	-0,08 (0,01)	0,06 (0,26)	-0,07 (0,19)	1,08 (0,00)	17,17
		p3	-0,08 (0,00)	0,08 (0,07)	0,06 (0,15)	1,00 (0,00)	47,08
		p4	-0,04 (0,42)	0,15 (0,01)	-0,24 (0,34)	0,99 (0,23)	13,35
		p5	-0,003 (0,97)	0,01 (0,86)	-0,12 (0,54)	0,51 (0,33)	1,14
	M3	p1	0,06 (0,00)	-0,09 (0,27)	0,03 (0,39)	-0,05 (0,50)	38,31
		p2	-0,06 (0,23)	-0,05 (0,47)	0,30 (0,05)	0,78 (0,20)	13,66
		p3	-0,03 (0,47)	-0,10 (0,19)	0,62 (0,02)	0,94 (0,25)	11,36

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[7] Note that, unlike the aggregated investment behavior, the individual investment behavior includes capacity for individuals. This is so because for the aggregated investment behavior price is a function of the capacity, *.i.e.*, one must use price or capacity but not both, while for the individual investment behavior that is not the case.

		p4	-0,01 (0,88)	-0,16 (0,02)	-0,07 (0,24)	0,89 (0,02)	9,53
		p5	-0,05 (0,12)	0,11 (0,05)	-0,09 (0,75)	0,98 (0,11)	13,25
	M4	p1	-0,10 (0,27)	-0,07 (0,38)	0,17 (0,80)	1,81 (0,22)	3,53
		p2	-0,02 (0,44)	0,06 (0,38)	0,02 (0,85)	0,99 (0,03)	2,25
		p3	-0,09 (0,01)	0,03 (0,60)	0,91 (0,01)	1,14 (0,06)	24,19
		p4	0,02 (0,16)	0,20 (0,00)	0,44 (0,00)	-0,25 (0,13)	50,21
		p5	-0,004 (0,78)	0,19 (0,00)	0,11 (0,17)	0,05 (0,68)	21,11
	M5	p1	-0,07 (0,10)	-0,02 (0,80)	-0,03 (0,84)	0,62 (0,02)	4,36
		p2	0,09 (0,05)	-0,12 (0,05)	0,39 (0,00)	-0,44 (0,35)	30,25
		p3	-0,01 (0,86)	0,01 (0,86)	-0,05 (0,73)	0,76 (0,13)	0,24
		p4	-0,09 (0,11)	-0,01 (0,91)	0,45 (0,10)	1,66 (0,13)	37,99
		p5	-0,05 (0,40)	-0,04 (0,54)	0,45 (0,03)	0,87 (0,31)	24,29
	M6	p1	-0,02 (0,42)	0,12 (0,07)	0,16 (0,53)	0,39 (0,23)	10,27
		p2	0,001 (0,95)	0,12 (0,02)	0,10 (0,42)	0,27 (0,25)	8,33
		p3	-0,15 (0,04)	0,003 (0,96)	0,03 (0,96)	2,58 (0,03)	32,58
		p4	-0,03 (0,06)	0,19 (0,00)	0,02 (0,81)	0,99 (0,00)	29,70
		p5	-0,17 (0,09)	-0,18 (0,04)	-0,40 (0,45)	3,28 (0,03)	7,59
						Average	**20,37**
T2	**M7**	p1	-0,09 (0,00)	-0,01 (0,84)	0,17 (0,00)	0,93 (0,00)	41,77
		p2	-0,06 (0,11)	-0,05 (0,47)	-0,29 (0,20)	1,52 (0,02)	4,37
		p3	-0,06 (0,11)	-0,11 (0,06)	1,33 (0,00)	0,10 (0,91)	38,39
		p4	-0,07 (0,14)	-0,04 (0,58)	0,10 (0,56)	2,04 (0,03)	7,14
		p5	-0,24 (0,00)	-0,30 (0,00)	1,03 (0,00)	2,49 (0,00)	52,81
	M8	p1	-0,06 (0,01)	0,21 (0,00)	-0,17 (0,37)	1,03 (0,02)	44,43
		p2	-0,09 (0,01)	0,03 (0,57)	0,02 (0,92)	1,33 (0,01)	15,01
		p3	-0,15 (0,00)	-0,06 (0,41)	-0,20 (0,50)	3,22 (0,00)	18,21
		p4	-0,02 (0,20)	-0,03 (0,63)	-0,02 (0,78)	0,26 (0,05)	2,70
		p5	-0,21 (0,00)	-0,01 (0,85)	0,35 (0,12)	4,48 (0,00)	22,48
	M9	p1	-0,14 (0,03)	-0,12 (0,12)	0,02 (0,90)	2,14 (0,01)	8,08
		p2	-0,02 (0,12)	0,19 (0,00)	-0,02 (0,78)	0,23 (0,18)	25,58
		p3	-0,09 (0,09)	-0,13 (0,07)	-0,52 (0,01)	3,66 (0,00)	11,78
		p4	-0,01 (0,88)	0,02 (0,82)	-0,15 (0,64)	0,82 (0,53)	1,15
		p5	-0,07 (0,02)	0,12 (0,02)	-0,23 (0,12)	1,78 (0,01)	24,69
	M10	p1	-0,07 (0,17)	-0,01 (0,89)	0,11 (0,44)	0,82 (0,15)	3,84
		p2	-0,04 (0,00)	-0,02 (0,69)	0,02 (0,07)	0,81 (0,00)	40,93
		p3	0,02 (0,50)	0,03 (0,59)	0,31 (0,06)	-0,29 (0,67)	6,53
		p4	-0,05 (0,00)	0,20 (0,00)	0,08 (0,06)	0,34 (0,04)	74,28
		p5	-0,01 (0,75)	0,17 (0,00)	0,29 (0,40)	-0,18 (0,87)	25,59
	M11	p1	-0,13 (0,00)	0,12 (0,00)	-0,51 (0,00)	2,56 (0,00)	60,07
		p2	-0,08 (0,00)	0,11 (0,03)	-0,36 (0,09)	1,88 (0,00)	27,22
		p3	-0,02 (0,60)	0,12 (0,15)	-0,03 (0,86)	0,78 (0,22)	3,58
		p4	-0,17 (0,01)	-0,09 (0,20)	0,06 (0,63)	2,04 (0,00)	11,56
		p5	-0,11 (0,00)	0,02 (0,69)	0,54 (0,01)	0,99 (0,02)	33,36
	M12	p1	-0,02 (0,04)	0,23 (0,00)	-0,07 (0,34)	0,67 (0,00)	42,20
		p2	-0,13 (0,01)	0,12 (0,01)	-0,09 (0,29)	1,80 (0,00)	35,86
		p3	0,002 (0,83)	0,27 (0,00)	0,09 (0,37)	-0,10 (0,66)	46,58
		p4	-0,14 (0,00)	-0,01 (0,85)	0,12 (0,63)	2,95 (0,00)	18,66
		p5	0,01 (0,59)	0,004 (0,94)	0,18 (0,00)	-0,17 (0,22)	13,02
						Average	**25,40**

[*] P-values are presented in parentheses.

4.2.2. Capacity utilization adjustment behavior

Now we explore the aggregated capacity utilization adjustment behavior (this is only for T2) by performing regressions of equation (12) with the aggregated experimental results.

Table 7 presents the regressions. We observe that the coefficient m_2 (CU) is always significant with a positive average equal to the theoretical value, m_1 (Z) is always significant with a positive average, and *b* is always significant with a negative average contrary to theoretical values (significance at least at 10%). Thus, *CU* and *Z* (price) drive the adjustment process. Moreover, their average coefficients indicate consistency with the hypothesized non-full utilization behavior (Montero & Sánchez, 2001; de Vries & Hakvoort, 2004; Puller, 2007), similar to the behavior observed during the electricity crisis in California (Joskow & Kahn, 2002; Puller, 2007).

Table 7. Parameter estimates of the aggregated capacity utilization adjustment behavior[*].

	m_2 (CU)	m_1 (Z)	B	R^2
M7	-0,36 (0,00)	1,49 (0,01)	-1,20 (0,05)	28,62
M8	-0,68 (0,00)	2,99 (0,00)	-2,40 (0,01)	46,06
M9	-0,48 (0,00)	0,57 (0,08)	-0,17 (0,60)	33,99
M10	-0,62 (0,00)	14,34 (0,01)	-13,82 (0,01)	43,49
M11	-0,36 (0,00)	2,67 (0,00)	-2,35 (0,00)	43,62
M12	-0,53 (0,00)	0,03 (0,01)	0,39 (0,00)	44,26
Average	**-0,50**	**3,68**	**-3,26**	**40,01**
Theoretical[**]	**-0,50**	**0,16**	**0,34**	

[*] P-values are presented in parentheses.
[**] Theoretical values from Table 2.

We also explore the individual capacity utilization adjustment behavior. The proposed capacity utilization adjustment function for individuals is:

$$CU^{adjust}{}^{i}_{t} = m_2 CU^{i}_{t} + m_1 Z_t + b \qquad (14)$$

where m_2, m_1 and *b* are parameters to be estimated. The index *i* represents individuals and the variables conserve the previous names. Table 8 shows the regressions of equation (14) for all individuals across markets. We observe that the coefficient m_2 (CU_i) is always significant, except in one case, while m_1 (Z) and *b* have 7 and 6 significant values out of maximum of 30 respectively (significance at least at 10%). Thus, CU_i drives the adjustment process. According to the signs of the estimates, this implies that the higher the capacity utilization the lower the adjustment no matter the price, which is not consistent with the aggregated behavior. Moreover, the poor results of the regressions call for further research about individual capacity utilization heuristics whenever the average R^2 is 29,50.

Table 8. Parameter estimates of the individual capacity utilization adjustment behavior[*].

		m_2 (CU_i)	m_1 (Z)	b	R^2
M7	p1	-0,62 (0,00)	1,96 (0,13)	-1,39 (0,27)	31,29
	p2	-0,40 (0,00)	0,75 (0,49)	-0,42 (0,70)	20,96
	p3	-0,33 (0,00)	0,48 (0,60)	-0,22 (0,80)	16,50
	p4	-0,87 (0,00)	2,26 (0,02)	-1,56 (0,10)	47,29
	p5	-0,29 (0,00)	-2,50 (0,02)	2,73 (0,01)	21,72
M8	p1	-0,46 (0,00)	0,42 (0,81)	-0,02 (0,99)	22,62
	p2	-0,42 (0,00)	-0,20 (0,92)	0,56 (0,77)	21,27
	p3	-0,55 (0,00)	-1,82 (0,26)	2,24 (0,17)	28,17
	p4	-0,43 (0,00)	-0,18 (0,91)	0,55 (0,75)	21,56

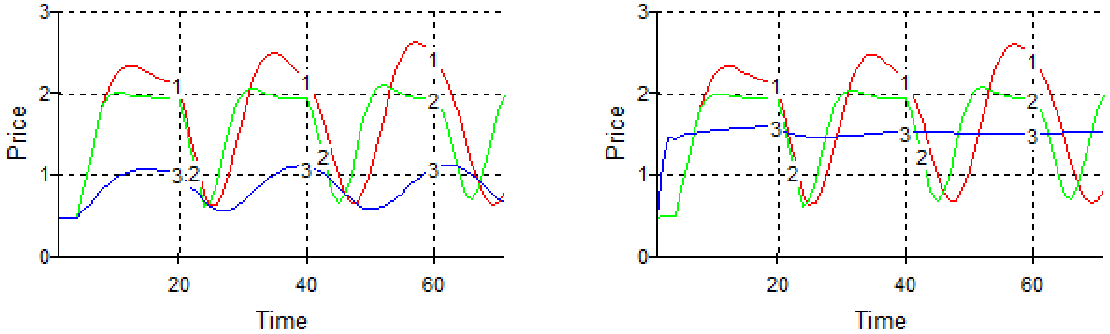
	p5	-0,78 (0,00)	2,33 (0,15)	-1,57 (0,33)	39,63
M9	p1	-0,26 (0,00)	0,85 (0,22)	-0,64 (0,35)	14,10
	p2	-0,61 (0,00)	1,44 (0,03)	-0,83 (0,16)	29,84
	p3	-0,80 (0,00)	0,09 (0,86)	0,49 (0,33)	40,00
	p4	-0,48 (0,00)	2,13 (0,02)	-1,69 (0,05)	24,97
	p5	-0,42 (0,00)	0,03 (0,97)	0,33 (0,64)	21,69
M10	p1	-0,66 (0,00)	14,48 (0,22)	-13,91 (0,24)	35,30
	p2	-0,96 (0,00)	2,15 (0,24)	-1,46 (0,42)	47,65
	p3	-0,73 (0,00)	1,26 (0,92)	-0,62 (0,96)	36,94
	p4	-0,10 (0,07)	3,94 (0,43)	-3,85 (0,44)	4,92
	p5	-0,06 (0,23)	1,76 (0,60)	-1,70 (0,61)	2,34
M11	p1	-0,20 (0,01)	1,32 (0,23)	-1,16 (0,29)	10,48
	p2	-0,56 (0,00)	3,31 (0,04)	-2,79 (0,07)	29,33
	p3	-1,00 (0,00)	0,05 (0,96)	0,67 (0,53)	55,15
	p4	-1,04 (0,00)	0,13 (0,88)	0,90 (0,27)	51,49
	p5	-0,25 (0,00)	-0,02 (0,99)	0,25 (0,83)	12,69
M12	p1	-0,56 (0,00)	2,93 (0,66)	-2,45 (0,71)	28,18
	p2	-0,26 (0,00)	7,43 (0,18)	-7,18 (0,19)	17,70
	p3	-1,06 (0,00)	-18,17 (0,02)	18,95 (0,01)	56,10
	p4	-0,72 (0,00)	-13,20 (0,09)	13,78 (0,07)	40,49
	p5	-1,08 (0,00)	1,60 (0,89)	-0,71 (0,95)	54,75
				Average	**29,50**

* P-values are presented in parentheses.

Next, we test the estimated heuristics by running simulation with them and comparing those simulations against simulations run with the theoretical hypothesized behavior of sections 2.3 and 2.4.

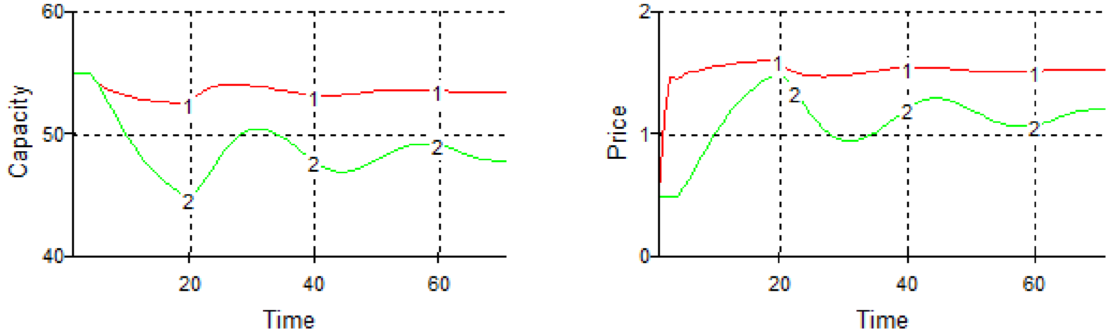
4.2.3. Behavioral implications of the estimated heuristics

Now, we compare simulations run with the aggregated linear regression model with the theoretical values from Table 2 against simulations run with the aggregated linear regression model with the averages of the estimated parameters in Table 5 (T1) and Tables 5 and 7 (T2). For T1, Figure 6 shows similar cycles, except that the simulation with the averages of the estimated parameters has a longer period and minor amplitude. For T2, Figure 6 shows similar cycles in capacities and prices for the simulations run with theoretical values, but it also shows a quite stable behavior in both capacity and price for the simulations run with the averages of the estimated parameters. This is an indication of capacity utilization leading to a more stable behavior as suggested in Arango (2006b). A clearer picture of this can be observed in Figure 7, where simulations run with the averages of the estimated parameters with full capacity utilization show dampened cycles, while simulations run with variable capacity utilization (the same simulations in line 3 of Figure 6 for T2) show a more stable behavior.



T1 **T2**

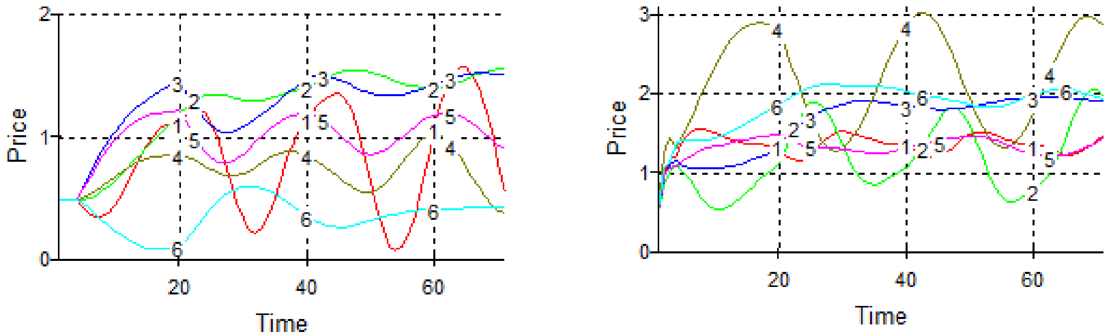
Figure 6. Simulation of the aggregated investment rule for T1 and the aggregated investment and capacity utilization adjustment rules for T2 with the theoretical values of investment set 1 (line 1) and set 2 (line 2) and theoretical values of capacity utilization adjustment (only for T2), and the average estimates from aggregated experimental results (line 3).



Capacity **Price**

Figure 7. Simulation of the aggregated investment and capacity utilization adjustment rules for T2 with average estimates from aggregated experimental results with variable (line 1) and full (line 2) capacity utilization.

We also run simulations with the estimated parameters for individuals in Table 6 (T1) and Tables 6 and 8 (T2), which can be observed in Figure 8. For T1, the results at individual level are largely consistent with the results at aggregated level. We observe that markets 1, 4 and 5 show a pattern of behavior similar to the behavior observed in Figure 7 at aggregated level with the averages of the estimated parameters, while markets 3 and 6 show dampened cycles. Thus, this test can be use to reject hypothesis 2, but it cannot be used to discard hypothesis 3. However, the accuracy of the test is reduced by the poor results of the regressions, where the average R^2 are 20,12 and 20,37 at aggregated and individual levels respectively. Regarding T2, the results at individual level are consistent with the results at aggregated level as well. We observe a more stable behavior in four out six markets. Thus, this test can be used to reject hypothesis 3, but it cannot be use to discard hypothesis 2. But as for T1, the accuracy of the test is reduced by the poor results of the regressions, where the average R^2 for investment are 13,60 and 25,40 and for capacity utilization adjustment are 40,01 and 29,50 at aggregated and individual levels respectively.



T1 **T2**

Figure 8. Simulation of the individual investment rule for T1 and the individual investment and capacity utilization adjustment rules for T2 with estimates from individual experimental results (line number and line number+6 represents the number of the market for T1 and T2 respectively).

5. CONCLUDING REMARKS

This thesis presented an experimental electricity market to study the effect of variable capacity utilization over market dynamics. We explored the potential occurrence of cycles (cycle hypothesis) in electricity markets in two experimental treatments: first we assumed full capacity utilization (T1) and second we relaxed this assumption allowing subjects to make capacity utilization decisions (T2). Previous simulation models (*e.g.*, Ford, 2001; Kadoya *et al.*, 2005; Olsina *et al.*, 2006) and experimental studies (*e.g.*, Arango, 2006b) of electricity markets have shown cyclical behavior; however, they assume full capacity utilization, leaving out a potential source of cyclical behavior (Meadows, 1970; Mass, 1975; Sterman, 2000; Randers & Göluke, 2007). Thus, we isolate investment and capacity utilization decisions to study the rationality in an experimental market

In T1, we found indications of cyclical tendencies in prices in five out of six markets by visual inspections, basic statistics and simulation tests. All observations are consistent with the cycle hypothesis, as suggested by behavioral simulation models (Bunn & Larsen, 1992 and 1994; Ford, 1999 and 2001; Larsen & Bunn, 1999; Kadoya *et al.*, 2005; Olsina *et al.*, 2006) and previous experiments (Arango, 2006a and 2006b) of electricity markets. In addition, we found, on average, a tendency towards a competitive behavior in prices in all markets. On the other hand, inT2, we found weaker indications of cyclical tendencies, where price cycles occurred only in two out of six markets as shown by visual inspections, basic statistics and simulation tests. In addition, we found, on average, a tendency towards a Cournot Nash behavior in prices in four out of six markets. Thus, these results indicate that varying capacity utilization allows having higher prices.

Since the main treatment difference between T1 and T2 is the variable capacity utilization, it is safe to conclude that varying capacity utilization leads stabilization. This is due to the shorter delay of capacity utilization decisions, which was only one period, compared against the delay of investment decisions, which was four periods, *i.e.*, subjects can have faster reaction and adjustment of production in T2 than in T1. It means that in T2, subjects had the possibility to influence market prices faster than in T1, where it took four periods to do so. In case there were periods with surplus capacity, it only took one year to cut production to help prices to rise. In fact, the average price of T2 (1,67 E$/Unit) is higher than that of T1 (0,91 E$/Unit). In addition, the lower bound used for capacity utilization decisions (70% of the installed capacity) did not allow subjects to raise price in dramatic ways, which could lead to over-investments and to an unstable behavior (Arango, 2006b). However, varying capacity utilization did not eliminate the possibility of cycles completely, as showed by the different tests we performed. Hence, our findings should serve as a motivation for further research of stabilizing policies in deregulated electricity markets

While our experiment represents an advance with respect to similar experiments (*e.g.*, Arango, 2006a and 2006b), the poor results of the regressions call for further investigation about decision-making heuristics at both aggregated and individual levels. In addition, more formal tests could be conducted to test cyclicality. For example, one could present autocorrelograms and autospectra, which are well-known statistical tests to look for evidence of cycles. Finally, our experiment still has assumptions that differ from reality. Further works should explore the analysis of those assumptions. For example, further experiments may explore decision-making under demand growth, bankruptcy, financing, hydrological uncertainty, etc.

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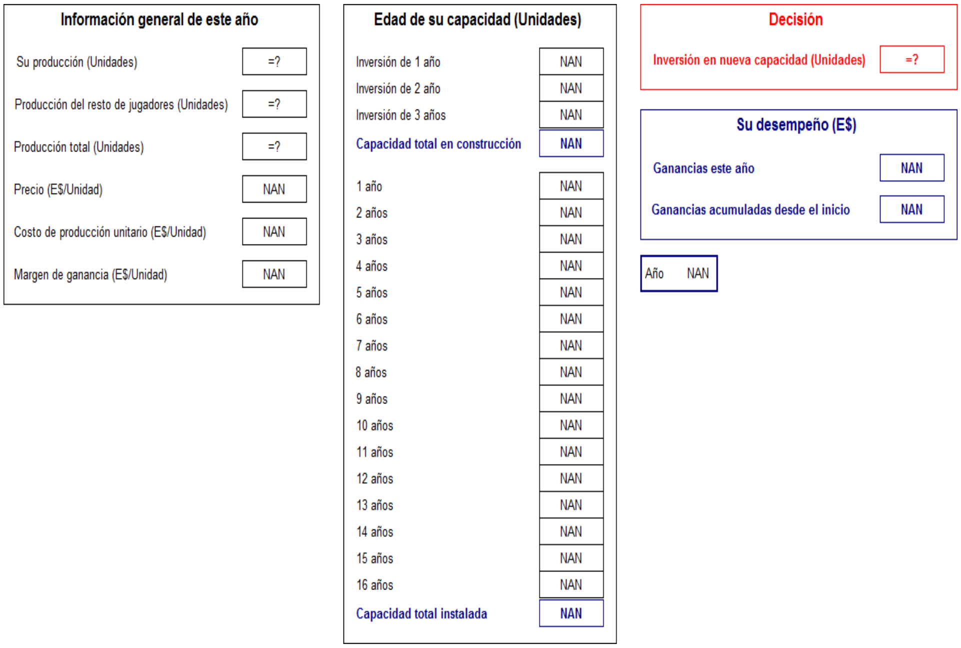
Appendix 1. Software interfaces (in Spanish).



Información general de este año

Su producción (Unidades)	=?
Producción del resto de jugadores (Unidades)	=?
Producción total (Unidades)	=?
Precio (E$/Unidad)	NAN
Costo de producción unitario (E$/Unidad)	NAN
Margen de ganancia (E$/Unidad)	NAN

Edad de su capacidad (Unidades)

Inversión de 1 año	NAN
Inversión de 2 año	NAN
Inversión de 3 años	NAN
Capacidad total en construcción	NAN
1 año	NAN
2 años	NAN
3 años	NAN
4 años	NAN
5 años	NAN
6 años	NAN
7 años	NAN
8 años	NAN
9 años	NAN
10 años	NAN
11 años	NAN
12 años	NAN
13 años	NAN
14 años	NAN
15 años	NAN
16 años	NAN
Capacidad total instalada	NAN

Decisión

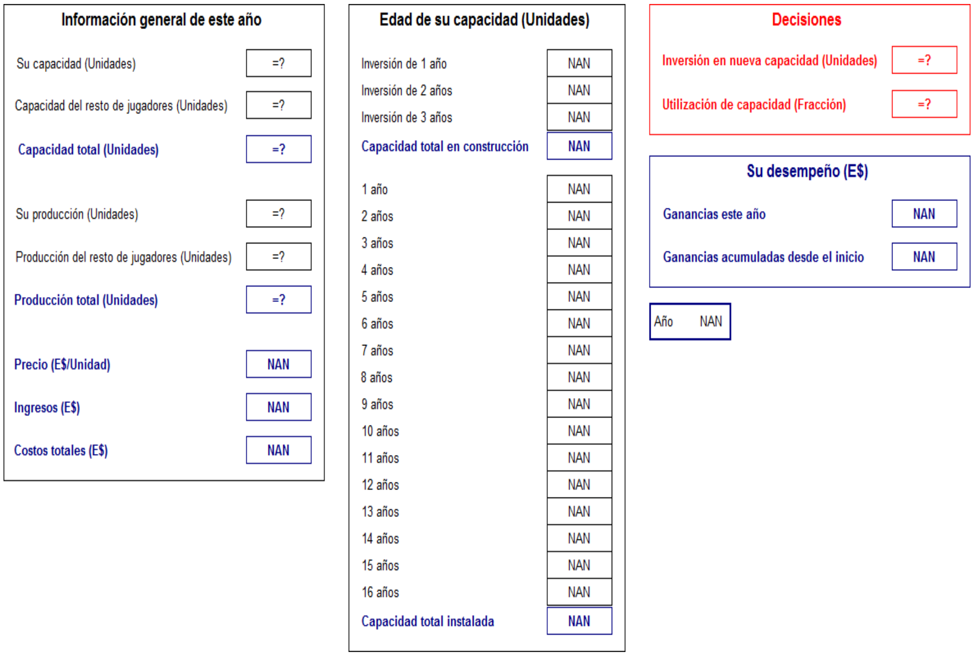
Inversión en nueva capacidad (Unidades)	=?

Su desempeño (E$)

Ganancias este año	NAN
Ganancias acumuladas desde el inicio	NAN

Año	NAN

T1 software interface.



Información general de este año

Su capacidad (Unidades)	=?
Capacidad del resto de jugadores (Unidades)	=?
Capacidad total (Unidades)	=?
Su producción (Unidades)	=?
Producción del resto de jugadores (Unidades)	=?
Producción total (Unidades)	=?
Precio (E$/Unidad)	NAN
Ingresos (E$)	NAN
Costos totales (E$)	NAN

Edad de su capacidad (Unidades)

Inversión de 1 año	NAN
Inversión de 2 años	NAN
Inversión de 3 años	NAN
Capacidad total en construcción	NAN
1 año	NAN
2 años	NAN
3 años	NAN
4 años	NAN
5 años	NAN
6 años	NAN
7 años	NAN
8 años	NAN
9 años	NAN
10 años	NAN
11 años	NAN
12 años	NAN
13 años	NAN
14 años	NAN
15 años	NAN
16 años	NAN
Capacidad total instalada	NAN

Decisiones

Inversión en nueva capacidad (Unidades)	=?
Utilización de capacidad (Fracción)	=?

Su desempeño (E$)

Ganancias este año	NAN
Ganancias acumuladas desde el inicio	NAN

Año	NAN

T2 software interface.

Appendix 2. Cournot Nash equilibrium derivation.

According to the Cournot Nash model, an oligopolistic market is in equilibrium if each company produces the same expected production of the other companies in the market, under conditions of profit maximization. The profit function for each company is:

$$\pi_i = (P - C) \cdot q_i \tag{15}$$

where P is the market price, C corresponds to the marginal costs, which include both capital and operational costs, and q_i is the production for subject i.

The electricity price is given to equilibrate supply and demand. Supply is the sum of the production of the five subjects. Demand is price sensitive and is given by the following expression:

$$P = A - B \cdot S \tag{16}$$

with $A = 6$ and $B = 0.1$. S corresponds to the sum of the production of the five subjects, *i.e.*, total electricity supply.

In summary, with high production rates, the price will be low. Respectively, with low production rates, the price will be high. There is no economic growth, which means that demand only changes because of changes in the price.

According to the Cournot Nash model:

$$S = 5q_i \tag{17}$$

Replacing (17) in (16):

$$P = A - 5 \cdot B \cdot q_i \tag{18}$$

Each subject assumes that the rest of the subjects will produce the same quantities than him. The quantity is the result of a profit maximization exercise assuming that others' production is constant, and in equilibrium the quantity is not time dependent. The following expression gives us the first-order condition for the production q_i (Martin, 2002):

$$\frac{\partial \pi_i}{\partial q_i} = P + q_i \cdot \frac{dP}{dS} - \frac{dc(q_i)}{dq_i} \equiv 0 \tag{19}$$

Taking the cost function from T1 the first-order condition becomes:

$$\frac{\partial \pi_i}{\partial q_i} = P - B \cdot q_i - C \equiv 0 \tag{20}$$

Replacing (18) in (20):

$$\frac{\partial \pi_i}{\partial q_i} = A - 5 \cdot B \cdot q_i - B \cdot q_i - C \equiv 0 \tag{21}$$

We know $A = 6$, $B = 0.1$ and $C = 1$. Replacing these values in (21) we obtain that the equilibrium production for the Cournot Nash model is:

$q_i = 8.33$ *Units*

Replacing this value in (18) we obtain the equilibrium price for the Cournot Nash model:

$P = 1.83$ *E\$/Unit*

To link T2 with T1 the Cournot Nash equilibrium must be the same. Given that in T2 we have variable capacity utilization, the production for each subject is given by:

$$q_i = IC_i \cdot CU_i \tag{22}$$

where IC_i and CU_i are the installed capacity and the capacity utilization of subject i respectively. Isolating the installed capacity and replacing in the cost function showed in equation (7) in section 2.1.2, we obtain the following total cost function for each subject:

$$c_i = \beta \cdot q_i + \alpha \cdot \frac{q_i}{CU_i} \tag{23}$$

Taking this cost function, the first-order condition becomes:

$$\frac{\partial \pi_i}{\partial q_i} = P - B \cdot q_i - \left(\beta + \frac{\alpha}{CU_i} \right) \equiv 0 \tag{24}$$

Replacing (18) in (24):

$$\frac{\partial \pi_i}{\partial q_i} = A - 5 \cdot B \cdot q_i - B \cdot q_i - \left(\beta + \frac{\alpha}{CU_i} \right) \equiv 0 \tag{25}$$

In T1 we work under a full utilization assumption, *i.e.*, $CU_i = 1$ *(100%)*. With this value, the expression in parentheses becomes $\beta + \alpha$. Isolating this expression, replacing A and B by the known values and replacing q_i by the Cournot Nash equilibrium in order to link T2 with T1 and therefore with Arango (2006a and 2006b), we obtain the following expression:

$$\beta + \alpha = 1 \tag{26}$$

Thus, parameters β and α must be chosen in such a way that they hold the expression shown in (26).

Appendix 3. Experimental instructions (in Spanish).

T1 instructions

INSTRUCCIONES

ADVERTENCIA: NO TOQUE EL COMPUTADOR HASTA QUE SE LE AVISE

INTRODUCCIÓN

Bienvenidos. Éste es un experimento de toma de decisiones y el caso es un mercado eléctrico desregulado, apoyado por la Vicerrectoría Nacional de Investigación de la Universidad Nacional de Colombia. Las instrucciones son simples y si las sigue cuidadosamente y toma buenas decisiones usted podría ganar una suma de dinero considerable, el cual será entregado en efectivo al final del experimento Usted va a jugar el rol de un productor de electricidad que vende en un mercado. Cada período usted tomará decisiones de inversión que afectarán su producción futura. Su objetivo es maximizar las ganancias a lo largo de todos los períodos del experimento. **Entre mayores sean sus ganancias acumuladas, mayor será su pago.**

ESTRUCTURA DEL MERCADO

Usted es uno entre cinco productores de electricidad. Usted no sabe quiénes son los otros jugadores en el mercado y cómo se desempeñan individualmente. Sus ganancias son estimadas como:

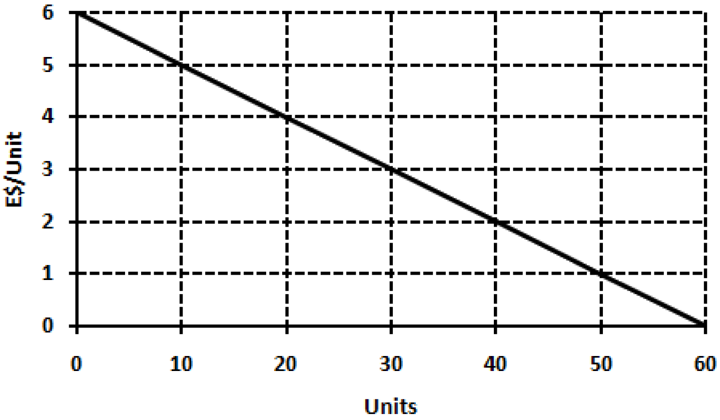
$$\text{Ganancias} = \text{Producción} \cdot (\text{Precio} - \text{Costos})$$

$$\pi_t = q_t \cdot \left(P_t - C\right)$$

Donde q_t corresponde a su producción en el tiempo t, P_t al precio de la electricidad en el tiempo t y C a los costos tanto de operación como de capital, que son constantes y equivalen a **1 E$/Unidad**. Su producción **no puede ser negativa** y siempre debe estar por debajo de **20 unidades**, que es un límite superior que garantiza un mínimo de competencia. El precio de la electricidad es fijado para equilibrar el suministro total y la demanda. El suministro total es la suma de la producción de los cinco jugadores, y la demanda es sensitiva al precio así:

$P = 6 - 0.1 \cdot Q$, donde Q es el suministro total (véase la figura *Curva de demanda* abajo).

Para resumir, **entre mayor sea la producción total de electricidad, menor es el precio**. Respectivamente, entre menor sea la producción total de electricidad, mayor es el precio. No hay crecimiento económico, lo que significa que la demanda sólo cambia debido a cambios del precio.



Curva de demanda.

PRODUCCIÓN

Su producción será siempre igual a su capacidad de producción, lo que significa que usted no puede reducir su utilización de capacidad. Cada año usted toma decisiones de inversión en capacidad nueva (**usted puede decidir 0 Unidades**). Características importantes de los generadores de electricidad son:

Retraso en la construcción = 4 años.
Tiempo de vida de la capacidad instalada = 16 años.

Esto significa que si usted decide invertir en una capacidad adicional de **0.8 Unidades** en el **año 6**, esta capacidad estará bajo construcción por **4 años** y añadirá **0.8 Unidades** a su capacidad en el **año 10**. Esta capacidad adicional durará hasta el **año 26 inclusive.**

CONDICIÓN INICIAL

Cuando el experimento comience los administradores anteriores de la firma han invertido una cantidad constante de **11 Unidades/vida útil = 0.69 Unidades/año** por un largo tiempo. Consecuentemente, usted comienza con una capacidad de producción de **11 Unidades** y una tasa de depreciación de **0.69 Unidades/año**. Todas las firmas son idénticas, tienen los mismos costos y la misma capacidad inicial. El mercado comienza con una capacidad total inicial de **11 Unidades·5 firmas = 55 Unidades**; para un producción total de **55 Unidades**, el precio es **0.5 E$/Unidad**. Esto significa que **inicialmente todos están operando con precios más bajos que sus costos.**

PAGO

Usted recibirá un pago de acuerdo a su desempeño. Su desempeño es medido por sus ganancias acumuladas. **Entre mayores sean las ganancias acumuladas, mayor será el pago**. El pago estará entre **Col$ 10.000 y Col$ 50.000.**

CORRIENDO EL EXPERIMENTO

Sea cuidadoso, no presione **"Accept Decisions"** A MENOS QUE ESTÉ SEGURO. Luego de presionar **"Accept Decisions"** su decisión no puede ser cambiada.

1. Mire la información disponible de la firma y el mercado y tome decisiones de inversión.
2. Escriba sus decisiones en la hoja que le fue entregada (sus decisiones deben estar anotadas en la hoja pues ésta es su recibo para el pago) y presione "Accept Decisions".
3. Espere hasta que todos los participantes en el mercado hayan tomado sus decisiones.

La ventana con el botón "Accept Decisions" aparece de nuevo, el juego ha avanzado al siguiente año. La información es actualizada y es tiempo de tomar decisiones nuevamente. La simulación correrá por un número indefinido de años. Cuando el experimentador pare el juego usted debe escribir sus ganancias acumuladas en la hoja y preguntar por su pago. Los pagos se harán en privado.

NOTA

De acuerdo al propósito del experimento se requiere no compartir ningún tipo de información (verbal, escrita, gestos, etc.). Por favor, respete estas reglas pues éstas son importantes para el valor científico del experimento. Romper las reglas implica que el grupo involucrado es anulado y sus participantes no reciben pago.

Gracias por unirse a este experimento y haga su mejor esfuerzo!!!

T2 instructions

INSTRUCCIONES

ADVERTENCIA: NO TOQUE EL COMPUTADOR HASTA QUE SE LE AVISE

INTRODUCCIÓN

Bienvenidos. Éste es un experimento de toma de decisiones y el caso es un mercado eléctrico desregulado, apoyado por la Vicerrectoría Nacional de Investigación de la Universidad Nacional de Colombia. Las instrucciones son simples y si las sigue cuidadosamente y toma buenas decisiones usted podría ganar una suma de dinero considerable, el cual será entregado en efectivo al final del experimento. Usted va a jugar el rol de un productor de electricidad que vende en un mercado. Cada período usted tomará decisiones de inversión que afectarán su capacidad instalada futura, además de decisiones de utilización de capacidad que afectarán su producción. Su objetivo es maximizar las ganancias a lo largo de todos los períodos del experimento. **Entre mayores sean sus ganancias acumuladas, mayor será su pago.**

ESTRUCTURA DEL MERCADO

Usted es uno entre cinco productores de electricidad. Usted no sabe quiénes son los otros jugadores en el mercado y cómo se desempeñan individualmente. Sus ganancias son estimadas como:

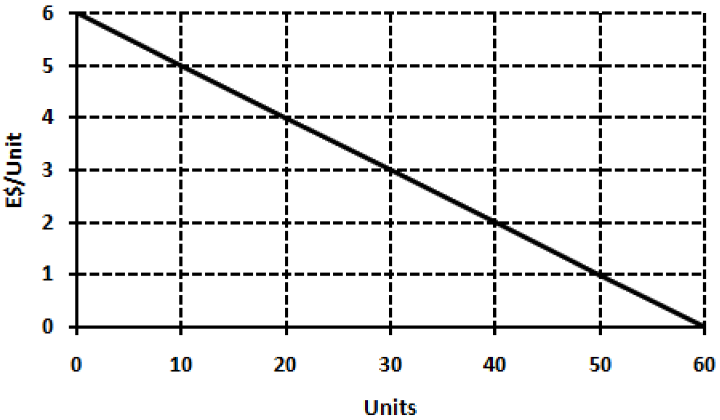
Ganancias = Ingresos – Costo de Producción – Costo de Capital

$$\pi_t = P_t \cdot q_t - \beta \cdot q_t - \alpha \cdot CI_t$$

Donde q_t corresponde a su producción en el tiempo t, P_t al precio de la electricidad en el tiempo t, CI_t a su capacidad instalada en el tiempo t, β a los costos de producción y α a los costos de capital (piense en los costos de capital como costos de arrendamiento). Los costos de producción equivalen a **0.4 E$/Unidad** y los costos de capital a **0.6 E$/Unidad**. Su capacidad instalada **no puede ser negativa** y siempre debe estar por debajo de **20 unidades**, que es un límite superior que garantiza un mínimo de competencia. El precio de la electricidad es fijado para equilibrar el suministro total y la demanda. El suministro total es la suma de la producción de los cinco jugadores, y la demanda es sensitiva al precio así:

$P = 6 - 0.1 \cdot Q$, donde Q es el suministro total (véase la figura *Curva de demanda* abajo).

Para resumir, **entre mayor sea la producción total de electricidad, menor es el precio**. Respectivamente, entre menor sea la producción total de electricidad, mayor es el precio. No hay crecimiento económico, lo que significa que la demanda sólo cambia debido a cambios del precio.



Curva de demanda.

PRODUCCIÓN

Su producción es función de la capacidad instalada y la utilización de capacidad. Cada año usted toma decisiones de inversión en nueva capacidad (**usted puede decidir 0 Unidades**) así como decisiones de utilización de capacidad (**usted puede decidir utilizar entre el 70% (0.7) y el 100% (1) de su capacidad**). Su producción es la capacidad instalada por la utilización de capacidad. Características importantes de los generadores de electricidad son:

Retraso en la construcción = 4 años.
Tiempo de vida de la capacidad instalada = 16 años.
Retraso en la utilización = 1 año.

Esto significa que si usted decide invertir en una capacidad adicional de **0.8 Unidades** en el **año 6**, esta capacidad estará bajo construcción por **4 años** y añadirá **0.8 Unidades** a su capacidad en el **año 10**. Esta capacidad adicional durará hasta el **año 26 inclusive**. Además, si usted decide utilizar el **80% (0.8)** de su capacidad en la producción en el **año 6**, esta decisión se hará efectiva en el **año 7**. Debe tener en cuenta que esta decisión de utilización de capacidad **no** se hará efectiva con la capacidad instalada del **año 6 sino** con la capacidad instalada del **año 7.**

CONDICIÓN INICIAL

Cuando el experimento comience los administradores anteriores de la firma han invertido una cantidad constante de **11 Unidades/vida útil = 0.69 Unidades/año** por un largo tiempo. Consecuentemente, usted comienza con una capacidad instalada de **11 Unidades**. Adicionalmente, durante el mismo período de tiempo han tomado decisiones de utilización de capacidad de **100% (1)**. De esta manera, usted comienza con una producción de **11 Unidades** y una tasa de depreciación de **0.69 Unidades/año**. Todas las firmas son idénticas, tienen los mismos costos y la misma capacidad inicial. El mercado comienza con una producción total inicial de **11 Unidades·5 firmas = 55 Unidades**; para un producción total de **55 Unidades**, el precio es **0.5 E$/Unidad**. Esto significa que **inicialmente todos están operando con precios más bajos que sus costos.**

PAGO

Usted recibirá un pago de acuerdo a su desempeño. Su desempeño es medido por sus ganancias acumuladas. **Entre mayores sean las ganancias acumuladas, mayor será el pago**. El pago estará entre **Col$ 10.000 y Col$ 50.000.**

CORRIENDO EL EXPERIMENTO

Sea cuidadoso, no presione **“Accept Decisions”** A MENOS QUE ESTÉ SEGURO. Luego de presionar **“Accept Decisions”** su decisión no puede ser cambiada.

1. Mire la información disponible de la firma y el mercado y tome decisiones de inversión y de utilización de capacidad.

2. Escriba sus decisiones en la hoja que le fue entregada (sus decisiones deben estar anotadas en la hoja pues ésta es su recibo para el pago) y presione “Accept Decisions”.
3. Espere hasta que todos los participantes en el mercado hayan tomado sus decisiones.

La ventana con el botón “Accept Decisions” aparece de nuevo, el juego ha avanzado al siguiente año. La información es actualizada y es tiempo de tomar decisiones nuevamente. La simulación correrá por un número indefinido de años. Cuando el experimentador pare el juego usted debe escribir sus ganancias acumuladas en la hoja y preguntar por su pago. Los pagos se harán en privado.

NOTA
De acuerdo al propósito del experimento se requiere no compartir ningún tipo de información (verbal, escrita, gestos, etc.). Por favor, respete estas reglas pues éstas son importantes para el valor científico del experimento. Romper las reglas implica que el grupo involucrado es anulado y sus participantes no reciben pago.

Gracias por unirse a este experimento y haga su mejor esfuerzo!!!

Appendix 4. Derivation of the linear form of the proposed aggregated heuristics.

Investment behavior

We derivate the linear decision rule with the following equations:

$$x_t = Max\left(\frac{C_t}{LT} + \alpha_{sl}\left(\frac{C_t^*}{ID} - SL_t\right) + \alpha_c\left(C_t^* - C_t\right), 0\right)$$

$$C_t = 60 - 10P_t$$

$$C_t^* = Max\left(a + \left(\frac{q^e - a}{P^e}\right)P_t, 0\right) \cong a + YP_t \text{, where } Y = \frac{q^e - a}{P^e}$$

To shorten the presentation, we neglect the index *t* and take the linear parts. The equations become:

$$x = \frac{C}{LT} + \alpha_c\left(C^* - C\right) + \alpha_{sl}\left(\frac{C^*}{ID} - SL\right)$$

$$C = 60 - 10P$$

$$C^* = a + YP$$

Replacing, grouping and simplifying:

$$x = \frac{C}{LT} + \alpha_c C^* - \alpha_c C + \alpha_{sl}\frac{C^*}{ID} - \alpha_{sl} SL$$
$$x = \frac{60 - 10P}{LT} + \alpha_c (a + YP) - \alpha_c (60 - 10P) + \alpha_{sl}\frac{a + YP}{ID} - \alpha_{sl} SL$$
$$x = \frac{60}{LT} - \frac{10P}{LT} + \alpha_c a + \alpha_c YP - 60\alpha_c + 10\alpha_c P + \frac{\alpha_{sl} a}{ID} + \frac{\alpha_{sl} YP}{ID} - \alpha_{sl} SL$$

We get the following expression:

$$x = SL(-\alpha_{sl}) + P\left(-\frac{10}{LT} + \alpha_c Y + 10\alpha_c + \frac{\alpha_{sl} Y}{ID}\right) + \left(\frac{60}{LT} + \alpha_c a - 60\alpha_c + \frac{\alpha_{sl} a}{ID}\right),$$ which is analogous to the expression needed:

$$x_t = m_2 SL_t + m_1 P_t + b$$

The parameter values are:

$a = 38$
$q^e = 41{,}7$
$P^e = 1{,}83$
$LT = 16$
$ID = 4$
$\alpha_c = 0{,}26$ *(set 1) and* $0{,}5$ *(set 2)*
$\alpha_{sl} = 0{,}1$ *(set 1) and* $0{,}5$ *(set 2)*

Finally, the coefficient values are presented in the following table:

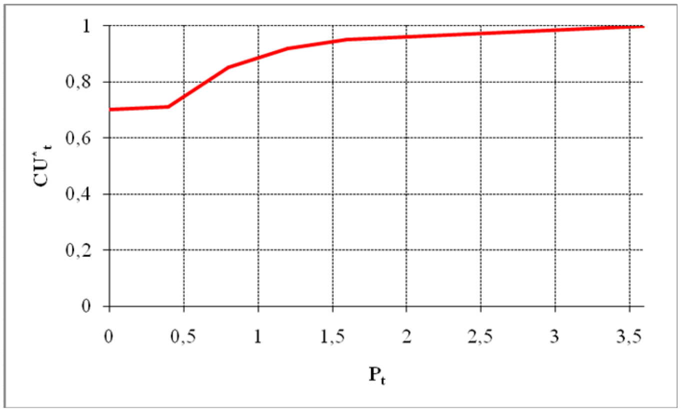
Coefficient values of the linear form of the investment heuristic.

Coefficient	**Set 1**	**Set 2**
m_2	-0,10	-0,50
m_1	2,55	5,63
b	-1,02	-2,5

Capacity utilization adjustment behavior

We derivate the linear decision rule with the following functions:

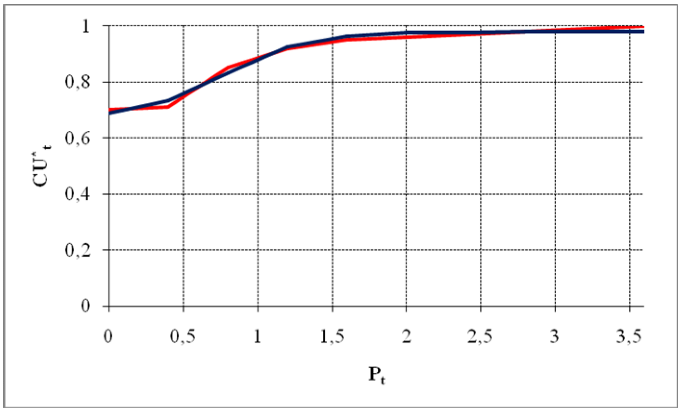
$$CU_t^{adjust} = \alpha_{cu}\left(CU_t^* - CU_t\right)$$



As the desired capacity utilization function is a tabular function, we fit a function to the curve of the desired capacity utilization. The fitting was done using the Artificial Neural Network method. The function is:

$$CU_t^* = 0{,}67 + \frac{0{,}31}{1 + e^{-2{,}82 - 3{,}63P_t}}$$

The following figure shows the results of the fitting process. It can be observed that the obtained function is a good approximation for the actual desired capacity utilization function.



Curve fitting for the desired capacity utilization function.

To shorten the presentation, we neglect the index *t*. Replacing CU^* in CU^{adjust} we obtain the following expression:

$$CU^{adjust} = \alpha_{cu}\left(0{,}67 + \frac{0{,}31}{1 + e^{-2{,}82 - 3{,}63P}} - CU\right)$$

Replacing, grouping and simplifying:

$$CU^{adjust} = 0{,}67\alpha_{cu} + 0{,}31\alpha_{cu}\frac{1}{1+e^{-2{,}82-3{,}63P}} - \alpha_{cu}CU$$

We get the following expression:

$CU^{adjust} = CU\left(-\alpha_{cu}\right) + Z\left(0{,}31\alpha_{cu}\right) + \left(0{,}67\alpha_{cu}\right)$, where $Z = \frac{1}{1+e^{-2{,}82-3{,}63P}}$. This expression is analogous to the expression needed:

$$CU_t^{adjust} = m_2 CU_t + m_1 Z + b$$

We have one parameter value: $\alpha_{cu} = 0{,}5$.

Finally, the coefficient values are presented in the following table:

Coefficient values of the linear form of the capacity utilization adjustment heuristic.

Coefficient	**Value**
m_2	-0,5
m_1	0,16
b	0,34