CAPACITY MECHANISMS FOR THE LONG-TERM SECURITY OF SUPPLY IN ELECTRICITY MARKETS: AN EXPERIMENTAL STUDY

DAVID LARA ARANGO

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS
DEPARTAMENTO DE CIENCIAS DE LA COMPUTACIÓN Y DE LA DECISIÓN
MEDELLÍN
2013

CAPACITY MECHANISMS FOR THE LONG-TERM SECURITY OF SUPPLY IN ELECTRICITY MARKETS: AN EXPERIMENTAL STUDY

DAVID LARA ARANGO

Thesis for the degree
Magíster en Ingeniería – Ingeniería de Sistemas

Supervised by
Prof. Santiago Arango Aramburo, Ph.D.

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS
DEPARTAMENTO DE CIENCIAS DE LA COMPUTACIÓN Y DE LA DECISIÓN
2013

NOTES ON SOFTWARE AND DOCUMENTATION

The experimental markets in this thesis were created on a local area network of Windows-based computers using markets developed by the author in Powersim Constructor version 2.51. The data coming from the experimental markets were compiled in Microsoft Office Excel version 2013.

The autospectra and autocorrelograms were done using MATLAB version R2012b. The simulations of the decision rules with the parameter estimates were done in Microsoft Office Excel version 2013.

All data files and software are available upon request for documentation purposes.

ACKNOWLEDGMENTS

This thesis is part of the research project "Desarrollo y evaluación de políticas y mecanismos para la estabilización de mercados eléctricos; Estudio del mecanismo de obtención de contratos de reservas estratégicas de largo plazo". The work was financed by the Colciencias Jóvenes Investigadores – Convocatoria 566 scholarship program and the School of Mines, Universidad Nacional de Colombia, via Resolution 0865 of 2013. I express my sincere gratitude to these institutions.

I express my deep gratitude to Prof. Santiago Arango, my advisor in this work. His support, encouragement and example have made him a role model to me. I want to thank him for helping me whenever I requested his valuable help.

I am grateful to John Jairo Tabares for allowing us to conduct all the experimental sessions in the room M7-501 of LABSIS (Laboratorio de Sistemas), located at the School of Mines, Universidad Nacional de Colombia. I also want to thank Felipe Mejia for his help with the calling of the students who took part in the experiments. In addition, thanks to Alejandra Montoya who helped me with the several administrative procedures requested by the University to conduct the experiments and to Karla Alvarez who helped me to conduct the experimental sessions. I also want to thank Jaime Andres Castañeda for his valuable commentaries about this work.

Finally, and foremost, thanks to my mother, my uncle and my friends for their support, advice and the motivation they have given me throughout this and many others endeavors in my life.

Thanks to all of you!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

At the first years of deregulation, the academic discussion was first oriented to discuss the short-term efficiency and competitiveness of the electricity markets. Now, after more than twenty years of deregulation, the issue of the long-term security of supply has become increasingly relevant. A number of authors have used simulations and laboratory experiments to study capacity mechanisms in order to address this issue.

This thesis explores the rationality of individuals' decisions in a set of pilot experimental markets to test capacity mechanisms in electricity markets. We start from a previous experiment as base case, which is presented by Arango and Moxnes (2012).Thereafter; we take the second treatment with the capacity mechanism Procurement for long strategic reserve planning, by introducing a regulatory firm to the base case market. The third treatment test the capacity mechanism Centralized auctioning for capacity contracts, by introducing an auction for licenses system. We compare three treatments with six pilot experimental markets, two per treatment. We evaluate the performance in terms of the market's long-term security of supply and the society's welfare.

Results from the pilot experiments provides only initial indications about the experiment. In Treatments 1 and 2, the experimental results show evidence of cyclical behavior in both prices and capacities. On the other hand, in Treatment 3, the experimental results show a more stable behavior due to the introduced auction for licenses system. Although the simulation tests indicate that both Treatments 2 and 3 should exhibit more stable behaviors in prices and capacities than Treatment 1, Treatment 2's experimental results do not represent an improvement with respect to Treatment 1's ones. In fact, results suggest that the regulatory firm introduced by Treatment 2 -Procurement for long strategic reserve planning- represents the less desirable scenario for market actors. On the contrary, Treatment 3's experimental results are consistent with the simulation tests. In addition, the auction for licenses system introduced by Treatment 3 Centralised auctioning for capacity contracts- leads to more stable behaviors than both Treatments 1 and 2 results. These results suggest, first, that the Centralised auctioning for capacity contracts could help to stabilize the market without significant costs for the society's welfare, and second, that the Procurement for long strategic reserve planning may not lead to any price stabilization or society's welfare improvement.

Keywords: Electricity markets, Capacity mechanisms, Decision-making, Experiments, System Dynamics.

RESUMEN

En los primeros años de la desregulación, la discusión académica fue primeramente orientada a discutir la eficiencia y competitividad de los mercados de electricidad en el corto plazo. Ahora, después de más de veinte años de la desregulación, la cuestión de la seguridad de suministro en el largo plazo es cada vez más relevante. Un número de autores han utilizado simulaciones y experimentos de laboratorio para estudiar los mecanismos de capacidad con el fin de abordar esta cuestión.

En esta tesis se analiza la racionalidad de las decisiones de los individuos en un conjunto de mercados experimentales piloto para poner a prueba los mecanismos de capacidad en los mercados eléctricos. Partimos de un experimento anterior como caso base, que es presentado por Arango y Moxnes (2012). A partir de entonces, Tomamos el segundo tratamiento con el mecanismo de Contratación de capacidad para la planificación estratégica de reservas, mediante la introducción de una firma reguladora para el mercado de caso base. El tercer tratamiento prueba el mecanismo Subastas centralizadas para contratos de capacidad, mediante la introducción de una subasta para el sistema de licencias. Comparamos tres tratamientos con seis mercados experimentales piloto, dos por tratamiento. Evaluamos el desempeño de los mecanismos en términos de seguridad de suministro en el largo plazo y el bienestar de la sociedad de mercado.

Los resultados de los experimentos piloto proporcionan sólo indicaciones iniciales sobre el experimento. En los tratamientos 1 y 2, los resultados experimentales muestran evidencia de comportamiento cíclico en los precios y las capacidades. Por otra parte, en el tratamiento 3, los resultados experimentales muestran un comportamiento estable debido a la introducción de las subastas por licencias. A pesar que las pruebas de simulación indican que tanto el Tratamiento 2 y 3 deberían exhibir comportamientos más estables en precios y capacidades que el tratamiento 1, los resultados experimentales del tratamiento 2 no representan una mejora con respecto a los resultados del tratamiento 1. De hecho, los resultados sugieren que la firma reguladora introducida en por Tratamiento 2 – Contratación para la planificación de reservas estratégicas a largo plazo- representa el escenario menos deseable para los actores de mercado. Por otra parte, los resultados experimentales del tratamiento 3 son consistentes con las pruebas de simulación. Adicionalmente, el sistema de licencias introducido en el tratamiento 3 - Subastas centralizadas por licencias de capacidad- lleva a comportamientos más estables que los presentados por los tratamientos 1 y 2. Estos resultados sugieren, primero, que las Subastas centralizadas para los contratos de capacidad podrían ayudar a estabilizar el mercado sin costos significativos para el bienestar de la sociedad y segundo, que la Contratación para la planificación de reservas estratégicas a largo plazo podría no conducir ninguna estabilización de precios o mejora para el bienestar de la sociedad.

Palabras clave: mercados de electricidad, mecanismos de capacidad, toma de decisiones, Experimentos de laboratorio, Dinámica de Sistemas.

1. INTRODUCTION

Since deregulation, electricity markets have had substantial changes in their structure and dynamics. After the Second World War, society's need for efficient services brought with it a series of questioning remarks about the state-owned monopoly paradigm that had ruled the management of the electricity industry for decades (Jaccard, 1995). To address this issue, many countries considered to restructure their electricity industries by introducing competition within them (Barker et al., 1994). By attracting private capitals and setting rules for competition, the electricity industry would go from a state-owned monopoly to a market that benefits society or i.e. competition would improve society's welfare.

The new management paradigm in the electricity industry carries a series of changes For instance, major changes such as the increase in the number of stakeholders along with a change in the management focus and planning methods, makes the electricity industry a more complex system than it was before deregulation (Dyner and Larsen, 2001; Larsen and Arango, 2013).

One could expect the market actors to have a good understanding of such markets after more than two decades of deregulation experience. However, there is evidence that deregulation still presents important difficulties for the market actors, as it presented in previous years (e.g. Slow transition in the business rationale, planning methods and a new consumer focus) (Sioshansi and Pfaffenberger, 2006; Larsen and Arango, 2013). Thus, while in the initial stages of deregulation, the academic discussion was oriented to short-term concerns such as market efficiency and competitiveness (Joskow, 2008), the discussion is now focused on the long-term security of supply (IEA, 2003, 2007).

One particular concern about the long-term security of supply is the possibility of the occurrence of cycles in prices, driven by periods of under-capacity followed by periods of overcapacity and vice versa (Green, 2006; Roques, 2008). Different scholars have found indications that cycles may occur in electricity markets using different methodologies such as simulation (Bunn and Larsen, 1994; Kadoya et al., 2005; Olsina et al., 2006), laboratory experiments (Arango and Moxnes, 2012), and by making analogies with other industries such as real estate and aluminum (Ford, 1999; Krapels and Stagliano, 1996; IEA, 2002). Nowadays, after more than 2 decades of deregulation, there is evidence of occurrecy of such cycles in Chile and UK (Arango and Larsen, 2011). The importance of this concern is justified by the adverse effects caused by capacity cycles. On the one hand, a period of under-capacity leads to high prices for consumers, and possibly shortages and blackouts. On the other hand, a period with overcapacity leads to low profit margins for electricity companies, with the possibility of bankruptcy for the weakest of them (Arango and Larsen, 2011).

Given that a market structure implies competition among agents, any effort to intervene in the natural investment dynamics will be contrary to competition as a market principle (Fignon and Pignon, 2008). Therefore, the market behavior is caused by the individual behavior of investors (Larsen and Arango, 2013). If we assume perfect rationality on the part of the investors, we can expect little or no cyclical tendency in the market, but if we assume non-perfect rationality, we can have investment concentration in periods where the prices are high. Such concentration leads to periods of excess capacity and low prices, which discourages investment due to the reduced profit margins and subsequently leads to periods of low capacity and high prices. Thereafter, there is investment concentration in such periods due to the high prices and so, the cycle is generated (Bunn and Larsen, 1994; Ford, 1999; Roques, 2008).

To address the issue of long-term security of supply and, particularly, to eliminate or at least mitigate the occurrence of cycles, several capacity mechanisms [1]have been studied. In fact, there are some real power market implementation experiences (Barroso et al., 2006; Cámac et al., 2006; CEER, 2006; Cramton and Stoft, 2006; Fignon and Pignon, 2008), studies with different research methodologies (Liu et al., 2010; van der Veen et al., 2012; Arango et al., 2013) and theoretical proposals (Zou, 2009; Fu and Ren, 2011) of capacity mechanisms. All capacity mechanisms seek to induce rather than force an investment behavior that could lead to stable prices, minimizing the intervention in the market.

To analyze market mechanisms' effectiveness, some authors have employed simulation (Zou, 2009; van der Veen et al., 2012) and laboratory experiments (Arango et al., 2013), while others have acknowledged the benefits of using both in conjunction (Liu et al., 2010). We use both simulation and laboratory experiments to evaluate both mechanisms' potential for price stabilization and their impact on society's welfare.

This thesis is an extension of Arango and Moxnes (2012) where we study two capacity mechanisms, namely Procurement for long-term strategic reserve planning and Centralized auctioning for capacity contracts. We use Arango and Moxnes' extension of the Cobweb theorem[2] to test both mechanisms. The thesis is organized as follows: chapter 2 presents the problem formulation. Chapter 3 presents the objectives of the thesis. Chapter 4 presents the theoretical framework with the literature survey. Chapter 5 presents the experimental design and the experimental procedure. Chapter 6 presents the hypothesis of this work. Chapter 7 presents the experimental results and, finally, chapter 8 presents the final conclusions.

[1] Capacity mechanisms are a set of market rules, implemented in a market to secure that such market's needs for capacity are met.

[2] The Cobweb Theorem is part of the classic economic classic theory and postulates that demand responds to price immediately, but supply responds with a one period lag. The model oscillates with a period equal to twice the production lag. Besides, depending on the assumptions about price elasticity, the oscillations may be damped (convergence to equilibrium), sustained, or explosive.

2. PROBLEM FORMULATION

The long-term security of supply is matter of great importance for society, and an obligation for the electricity industry (IEA, 1999, 2003). While in the regulated scheme the planning of the system relies heavily in traditional optimization and centralized planning (Arango and Larsen, 2013), in deregulated electricity markets the supply depends directly on the investments made by the agents, which means that security of supply relies on investment behavior and activity.

In a regulated market, a government agency makes the plans for expansion with their associated costs. To prevent shortages, this centralized expansion planning often leads to overcapacity scenarios (IEA, 2002). In opposition, there is no such generalized planning in deregulated electricity markets, where investors are profits maximizers in principle. In fact, the investors' focus on these investments determines the security of supply of the system (IEA, 2002). If the investors are primarily driven by price signals (periods with high prices) the market could present pronounced price cycles caused by sequences of periods with over and under-capacity (Bunn and Larsen, 1994; Gary and Larsen, 2000). Nevertheless, if the investors take a strategic, long-term approach to make their investments, the market could present a stable price behavior, which gives the investors a return close to the normal profit[3], where market signals are expected to provide long-term security of supply (secure investment). In other words, the long-term security of supply in deregulated electricity markets depends on the investors' rationality (Arango and Larsen, 2011).

The occurrence of cycles can cause a great deal of harm to both producers and consumers (Bunn and Larsen, 1992; Ford, 1999; Bidwell and Henney, 2004; White, 2005; Green, 2006). If there are periods of capacity deficit, with high prices, there could be eventual shortages and blackouts, thus the consumers are seriously affected. Thereafter, herd behavior on the part of the investors could occur in periods of high prices, which causes subsequent periods of excess capacity with low prices, thus the generation companies face economic loses, with the risk of bankruptcy for the weakest of them (Arango and Larsen, 2011).

There is a generalized concern about the occurrence of cycles in electricity markets (Bunn and Larsen, 1992, 1994; IEA, 1999, 2002, 2007; de Vries and Hakvoort, 2004; Kadoya et al., 2005; White, 2005; Green, 2006; Roques, 2008). However, to determine the existence of such behavior, it is imperative to have historical data of the development of some deregulated electricity markets with a corresponding evaluation (Sioshansi and Pfaffenberger, 2006). Consider, for instance, the analysis done by Arango and Larsen (2011) about the three oldest deregulated electricity markets: Chile (in operation since 1986), England and Wales (in operation since 1990) and the Nordpool (in operation since 1991). Arango and Larsen (2011) shows the development of the reserve margin in each of the three markets. The reserve margin has been used as an indicator of the long–term reliability of electricity markets, as it relates the difference between installed capacity and peak demand with the current amount of installed capacity (IEA, 2002; Joskow, 2008). The inter-annual reserve margin is defined as:

[3] The normal profit is the profit that the producers of a good make when the market reaches perfect equilibrium, that is, when the benefit for society is maximized. The normal profit is commonly presented as zero profit, which means, the producers are not taking anything from society's welfare to get richer.

$$Reserve\ margin = \frac{Installed\ capacity - Peak\ demand}{Installed\ capacity}\ \mathrm{x}\ 100\%$$

Even when the reserve margin does not take into account some elements, such as geographical distributions, potential imports, the availability of fuel/water for generation and the age of the capacity (IEA, 2002), the reserve margin does show the long-term relationship between installed capacity and demand. Figure 1 shows the development of the reserve margin for the Chilean market, the Nordpool market, and the England and Wales market. Table 1 shows the summary statistics of the reserve margin for the three markets.

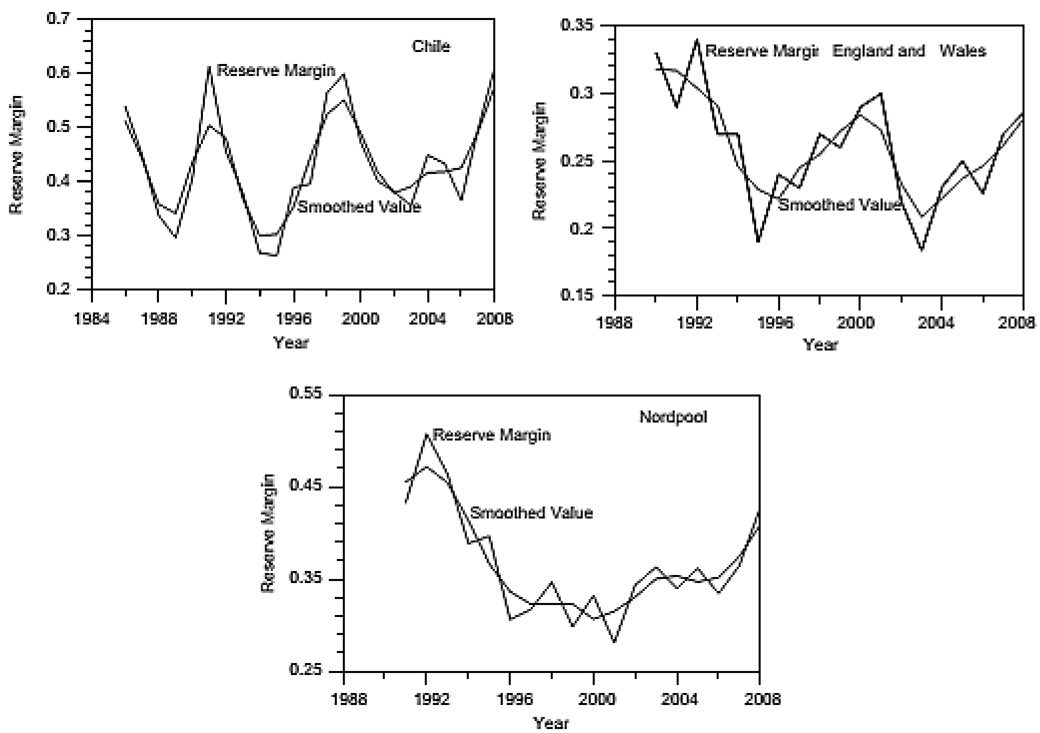


Figure 1: Development of the reserve margin in the Chilean market, the Nordpool market, and the England and Wales market. Source: Arango and Larsen (2011).

Market	Average	Std dev	α_1	α_2	Period length
Chile	0.43	0.10	0.45	-0.26	7.7
Nordpool	0.26	0.04	0.41	0.20	9.5
England and Wales	0.37	0.06	0.65	0.47	19.0

Table 1: Summary statistics for the Chilean market, the Nordpool market and the England and Wales market (average of the reserve margin, standard deviation, first and second lag autocorrelations and period length. Source: Arango and Larsen (2011).

The autocorrelation for the first lag is significantly greater than zero for all three markets (Table 1, Arango and Larsen, 2001), which indicates a likely cyclical behavior. Moreover, it is interesting to note the resemblance between the actual data and the simulations presented by Ford (1999) on cyclical behavior. Moreover, Arango and Larsen (2011) point out the apparent lack of cycles occurrence in the Nordpool market; they suggest that one explanation could be that the period length of the cycles for that market is more than 15 years and thus the cycle would not be captured by the available data. By performing laboratory experiments, Arango and Moxnes (2012) conclude that there is no decisive evidence to either reject or support the cycle's occurrence hypothesis.

At this point, we need to point out the role of delays in the occurrence of cycles. There is a time when an investment decision is made. At that time, the investors make price forecasts; determine their power plants' utilization and form expectations about future profitability. Such time constitutes a first delay. The second delay is the time between the decision-making and the materialization of that decision, i.e., construction time, the time to get the permissions to build a new power plant, the time needed to get money loans, etc. Such delays add complexity to the market and therefore they are an important source of market instabilities (Bunn and Larsen, 1992; Ford, 1999)

Other indications of cycle's occurrence in electricity markets come from comparisons or analogies with similar industries. The structural elements in the electricity industry are investors that face large capital investments, long construction times, high fixed costs and seek a high utilization rate to recover such costs. Some of these analogous industries are aluminium (Newbery, 1995), copper (Brennan and Schwartz, 1985) and oil tankers (Randers and Göluke, 2007). Nevertheless, there are still some differences between electricity and these other goods, for instance, electricity cannot be stored as inventory, which may imply different correlation in prices for electricity as well as higher prices in cycles compared to other commodities (Ford, 1999). This difference has stimulated other analogies with industries that share this non-storage characteristic, such as real estate (Ford, 2001), where capacity cannot be stored as well. This analogy has shown price swings with tight vacancy rates that are similar to the price swings in electricity with tight reserve margins. This particular analogy with the real estate industry has generate concerns about the electricity prices showing boom and bust behaviors, like the ones seen in real estate (Ford, 2001; IEA, 2002).

While it is worthy to note that industry analogies offer valuable insights, simulations models provide an opportunity to test different scenarios, with different parameters and different decisions rules that can be adapted to replicate real markets (Ford, 1999). Some simulation models have shown a consistent cycle's occurrence, with periods of over and under-capacity (Bunn and Larsen, 1992, 1994; Ford, 1999, 2001; Larsen and Bunn, 1999; Kadoya et al., 2005; Olsina et al., 2006). Besides, these models serve to test the sensitivity of the decision rules' realized performance to different parameters, i.e., they help to understand the influence of investment decision inputs in the occurrence of cycles. Nevertheless, these parameters and decisions rules are modelled by the authors under an assumed rationality and, hence, they may not completely represent the actual decision made by real investors.

To study the decision-making of real decision makers in electricity markets and evaluate their performance, Arango and Moxnes (2012) carried out a series of experiments. Starting from the original Cobweb model, they gradually added complexity in each treatment, showing that if complexity increases, the rationality and performance of the decision makers decreases. In a later work, Arango et al. (2013) relaxed the restriction of full capacity utilization used in Arango and Moxnes (2012), i.e., they allow capacity mothballing (variable capacity utilization), and concluded that variable capacity utilization leads to more damped cycles than full capacity utilization does. In a further extension of Arango and Moxnes (2012), Alvarez (2013) included future markets in order to test their potential to stabilize market prices, finding that the inclusion of future markets seems to reduce the cyclical tendency in commodity markets (electricity among them).

This thesis is a further extension of Arango and Moxnes (2012), where we test two different capacity mechanisms that aim to stabilize market prices taken from the literature (Fignon and Pignon, 2008). First, we test Procurement for long strategic reserve planning (direct intervention in market's capacity), where we introduce a regulatory firm that invest in the electricity market with predefined rules to invest; and second, we test Centralised auctioning for capacity contracts where we use a centralized auction market for licenses system (Alcaraz, 2010). We expect to answer some questions: can these two mechanisms aid to prevent cycle's occurrence in electricity market? If not, what are the effects of their introduction? Further, what would the expected society´s welfare be if these mechanisms were implemented?

3. OBJECTIVES

3.1. General objective:

Evaluate the stabilization potential of two capacity mechanisms, namely Procurement for long strategic reserve planning and Centralised auctioning for capacity contracts, through simulation and laboratory experiments.

3.2. Specific objectives:

- Study the two mechanisms and how they can be implemented to prevent cycle's occurrence situations.
- Develop a simulation model to evaluate different scenarios of the problem
- Propose some criteria to evaluate the performance of such mechanisms in the electricity markets.
- Design laboratory experiments that allow us to study the mechanisms' effectiveness in face of real decision makers.
- Run simulations of the proposed model and evaluate the performance of it in comparison with the experimental results.

4. METHODOLOGY

In this chapter, we present a revision of Experimental Economics and a brief review of its development in System Dynamics.

4.1. Experimental Economics:

In Experimental Economics, the experimenter isolates an economic environment to test some hypotheses through an experimental design, i.e., she runs a laboratory experiment. Three elements are needed to do this. There has to be, first, a goal for the participants to pursue; second, an experimental environment (which emulates a real system) with clear decision rules and restrictions; and third, the actual decisions of the participants, which determine the behavior captured by the experiment (Friedman and Cassar, 2004).

For instance, a goal could be to maximize profits in a market (Arango and Moxnes, 2012; Arango et al., 2013), to stabilize CO_2 concentrations in the atmosphere (Moxnes and Saysel, 2009), or even to achieve a desired level of drunkenness (Moxnes and Jensen, 2009). With a clear goal, the decision rules and restrictions of the experimental design are portrayed. Following the examples, the players could be generators in an electricity market (Arango et al., 2013), world leaders determining the CO_2 emissions policy (Moxnes and Saysel, 2009) or some people who wants to reach a desired level of drunkenness (Moxnes and Jensen, 2009). In such settings, the experimenter fixes the goal, controls the environment and observes the behavior (Smith, 1994).

Three of the main concepts in Experimental Economics are the Induced Value, the Parallelism (External Validity) and the Internal Validity. The Induced Value states that with an adequate incentive, the experimenter can induce a behavior in the participants that serves the experiment's purpose, regardless of the participants' particular interests (Smith, 1982). The Parallelism, also known as External Validity, refers to the level of resemblance between an experimental design and the real system, i.e., how much the results of an experiment can tell about reality (Smith, 1982). The third concept is the Internal Validity, that is, how adequate is a set of rules and incentives in relation with the task required from the participants (Cook and Campbell, 1979). Traditionally, there has been a confrontation between the Internal and External Validity (Guala, 2002), in fact, their relationship is often described as a trade-off between them (Guala, 2005). If an experiment lacks internal validity, then cause and effect relationships cannot be properly determined; if it lacks external validity, then the experimental results are of little worth in the understanding of the real world (Cook and Campbell, 1979). However, some authors like Jimenez and Miller (2010) have shown that such trade-off relationship is not as definitive as the academic discussion may suggest, i.e., the experimenter can effectively enhance the two aspects simultaneously.

Some feature emerge from the Induce Value Theory, which are monotonicity, salience and dominance (Smith, 1982). Monotonicity means that participants will always want to have more (or less depending on the case) of something specific. For instance, it can be assumed that every person would like to have more money income instead of less, and less money liabilities instead of more. Salience means that participants understand that they receive a payoff determined by their own actions and the other participants' actions. For instance, if participants know they will be paid 1 dollar for every unit of experimental money earned in an experimental market, there is salience in the experiment, because the experimental earnings are determined by participants' actions and they are aware of that. Dominance means that individual utility[4] is only affected by the individual payoff. For instance, it is common that participants take interest in knowing the other participants' results to see how they fare in comparison. To ensure dominance, the experimental procedures must make sure that each participant does not know and does not have the means to know the other participants' results. Finally, an effective way to ensure that the payoff is really an incentive for participants to perform the best they can is to offer cash payments that exceed the participants' opportunity cost (Friedman and Cassar, 2004).

The limitations of Experimental Economics are mainly related with Smith's (1982) concept of Parallelism previously introduced. Smith explains that even when an experimental design cannot capture all the complexities of a real system, the underlying behavior will present itself in reality if the experiment conditions are satisfied. This statement implies that if a single laboratory experiment does not answer all the questions of a given phenomenon, or does not include some relevant features of the real system, another laboratory experiment should be run to address this issue. The method of Experimental Economics is well presented by Friedman and Cassar (2004) and its main findings are well presented in The Handbook of Experimental Economics Results (Plott and Smith, 2008).

4.2. Experimental Economics and System Dynamics:

System Dynamics is a simulation methodology, which allows the construction of models that represents some complexities of real world systems (Hasani and Hosseini, 2011). Among the advantages of this methodology are the possibility to capture feedback cycles, delays and nonlinear relationships between variables. Moreover, System Dynamics allows the modeler to replicate the system structure and to know how such structure induces the system behavior (Ponzo et al., 2010). On this line, System Dynamics is a powerful way to make laboratory experiments that replicates complex environments such as electricity markets (Arango et al., 2013), supply chains (Cantor and Katok, 2012) and natural resources markets (Moxnes, 2012), among others.

Experiments with System Dynamics models have been used to test decision-making processes (Sterman, 1989a, 1989b; Moxnes, 1998a, 1998b), finding interesting results that highlight people's weak mental models when it comes to decide about complex problems. These results suggest that people use some simple decision rules or heuristics (Tversky and Kahnemann, 1974). Such decision rules serve as a rough guide to make decisions when the complexity of the task overwhelms individuals' rational capacity as Bounded Rationality theory explains (Simon, 1955, 1979; Tversky and Kahneman, 1974; Kleinmuntz, 1993). The method of Experimental Economics in System Dynamics and its main findings are presented by Arango et al. (2012). In the next chapter, we present our theoretical framework and literature review for capacity mechanisms

[4] Utility is an economic construct that aims to represent the well-being of a person when she faces a certain situation. It can also be understood as a measure for preferences over some set of offerings.

5. THEORETICAL FRAMEWORK AND LITERATURE SURVEY

In this chapter, we discuss some principals for the evaluation of a capacity mechanism found in the literature. Thereafter, we present some of the most discussed mechanisms in the literature.

5.1. Capacity mechanisms evaluation:

Capacity mechanisms are sets of market rules that aim to ensure that a market's needs for production capacity are met. One of the main concern in the design and implementation of capacity mechanisms is to have unified criteria to assess their stabilization potential in electricity markets. The main goal for a capacity mechanism is to secure long-term security of supply, but that raises concerns about what is needed in capacity mechanism to do so. Fignon and Pignon (2008) present a comprehensive survey of the academic discussion regarding such concern and present seven commonly agreed evaluation parameters:

The efficiency of capacity adequacy targeting:

One of the main aspects to evaluate in a capacity mechanism is the time in which it can help to achieve a desired level of reliability in the market (Weitzman, 1974; Roberts and Spence, 1976; Joskow, 2006). Therefore, it is of great importance to determine how long it would take a mechanism to achieve a capacity goal for a market.

Securing the profitability of new peaking units:

A mechanism with a long-term adequacy must secure the profitability of new investment, i.e., it must support that extra capacity that gives reliability to the system. By securing this profitability, the mechanism ensures that investors maintain a long-term capacity goal for the market (Turvey, 2003).

The consistency of the mechanism with the energy market:

Although the primary interest of a mechanism should be the long-term stability of supply, i.e., society's welfare, it has to be designed with market considerations (e.g., the benefits for investors). Otherwise, the market might end up with an excess in capacity with the related low prices and low profits, which makes the market less sustainable as it is a less attractive investment opportunity (Perez-Arriaga, 2001).

Incentives to generation availability:

The reliability of an electricity market is strongly related to how the response of the generators is in the face of lack-of-supply scenarios. A good capacity mechanism must ensure that generators have proper incentives to attend this kind of scenarios when it is needed (Oren, 2005).

Robustness to the exercise of strategic behavior:

A capacity mechanism can be understood as a set of new rules that are added to a set of pre-existing market rules. Hence, a mechanism must present opportunities for benefit maximization to the players in the game if they follow the new set of rules (Meunier and Finon, 2006).

Institutional feasibility:

This aspect not only refers to the compatibility of a mechanism with the existing legal framework of a market, but it also refers to what extent the mechanism can be implemented in any given country, regardless of its political and economic situation (Vasquez et al., 2003).

Effectiveness of the mechanism in an open market:

A capacity mechanism must consider the relationships among different electricity markets. In other words, how does the implementation of a given mechanism affect the market's interactions with other markets? (Creti and Fabra, 2004).

Having presented the criteria to evaluate capacity mechanisms, in the next section we proceed to show a survey of the most discussed ones in the literature. We leave the selected two for the last.

5.2. Mechanisms survey:

Before we present the two capacity mechanism studied in this thesis, namely Procurement for long strategic reserve planning and Centralized auctioning for capacity contracts, we present a brief description and evaluation of some of the most discussed capacity mechanisms in the literature.

1*. Capacity payment:*

With this mechanism, a capacity goal for the system is fixed in such a way that the decentralized decisions of the investors lead to that goal. In mathematical terms, the payment can be explained as the equality between capacity's shadow price in a scenario of full capacity utilization and the cost to install a new capacity unit (Weitzman, 1974).

This mechanism has been implemented in Spain, Chile, Argentina, Colombia and Perú and it has shown both theoretical and practical problems. The main problem is the lack of control over the capacity statements of generators at any given time, which makes this mechanism one of the least recommended in the literature (Batlle et al., 2007).

2*. Reliability charge:*

This mechanisms aims to give economic incentives to generators that are able to support eventual energy deficits in the market, i.e. those generators with reserve capacity that give reliability to the system. Colombia implemented the reliability charge in 2006 (Dyner et al., 2008) as a way to solve the needs for supply the country had by stabilizing the generators' income based on a payment related with their generation availability. Now, the effects of this implementation over the MMEC (Mercado Mayorista de Electricidad Colombiana) remain unclear.

3*. Capacity obligations with exchangeable rights:*

This mechanism is based on the decentralization of quantities, in which the main generators represent the consumers' needs for reliability. In other words, the main generators acquire commitments with the consumers that can be traded in the market (Wolak, 2004). In this sense, a generator may propose itself to be in the group of main generators, thus acquiring the obligation to have reserve capacity and use it when needed. In addition, this right of being part of the main generators can be traded with others interested generators.

Some states of the USA have implemented this mechanism, presenting some practical implementation issues like the duration of the commitments and difficulties with the selling of them (Cramton and Stoft, 2006).

4*. Margin Clearing Price (Uniform Price):*

This mechanism is a way to determine the prices for specific auctions with generators. These auctions are decided based on the production' price offered by different generators. Therefore, it has been the conventional auction system for generators, given that it aims to attend specific market's production needs at the lowest price (aims to minimize system's cost). It also attempts to enforce competition by giving the generators a significant freedom to bid (Liu et al., 2010)

Regarding its evaluation, the MCP is considered to have a great potential to promote competition in a market. It also offers less risk to generators due to a less rigid price regulation, i.e., less risk to have low prices because of the mechanism. However, it does present larger prices' fluctuations than the more rigid mechanisms (Bouttes, 2005)

5*. Pay as Bid:*

It appears as a response to the Margin Clearing Price (Uniform Price). In this mechanism, the bidding margin is reduced for the generators; thus, the market creates an acceptable range of price instead of deciding a price based on marginal offerings. Therefore, a generator receives the same price of its bid as long as the price is accepted for the price range. This mechanism has been strongly promoted by China and the UK as a way to secure less variability in electricity prices by giving the generators a smaller range to bid. Under this setting, coalition among generators is discouraged and a higher society's welfare is expected (Zhang et al., 2003).

The evaluation of this mechanism is not yet clear since the countries that have implemented it have also incurred in several market reforms that does not allow the evaluation of the mechanism in isolation. Furthermore, the discussion of this mechanism has been closely related to the discussion of the Margin Clearing Price (Uniform Price), particularly, the change of strategy that comes from the generators if one is implemented replacing the other (Zou and Ren, 2007).

6*. Double-sided Auction:*

Zou (2009) proposes this mechanism, in which both sides of the market (supply and demand) participate in an auction. The auction winners of each side are selected by their marginal contribution to the social welfare, i.e., how much they can increase the social welfare with their auction positions.

According to Zou (2009), simulation models for this mechanism report better results than the ones presented with the Margin Clearing Price (Uniform Price) and Pay as Bid mechanisms because a double auction limits the strategic options of generators and brings their offers close to their marginal cost (Zou, 2009)

7. *Imbalancing pricing:*

This mechanism is based on finding the "imbalanced prices", which are calculated using the difference between the desired electricity exchange and two foreseen scenarios for the actual electricity exchange (van der Veen et al., 2012). Therefore, two prices are determined: one for cases of excess of supply and another one for cases of deficit.

The idea of determining the two prices based on the supply rather than total costs is own to the fact that if the prices were determined by total costs, the system would be bound to higher uncertainties and shortages (Weidlich and Veit, 2008).

8. CO_2 *Emissions related mechanisms:*

Some authors have proposed that a $\mathrm{CO_2}$ emissions certificates market could be implemented to operate alongside the electricity market. This mechanisms aim to incentive generators towards production efficiency and cleaner technologies. The authors state that by ensuring an attractive joint profitability for both markets, the prices of each would stabilize and society's welfare would be improved, since the generators may regulate their own capacities by getting emissions certificates and trading them with other generators (Bompard et al., 2010; Fu and Ren, 2011).

9. *Procurement for long strategic reserve planning:*

In this mechanism, a government institution has the power to demand capacity installment, either from the generators or by a state-owned firm (Fignon and Pignon, 2008). Some countries like France, Sweden and New Zealand have implemented this mechanism.

Regarding the evaluation of this mechanism, the literature shows good stabilization results in prices (de Vries, 2004). However, some authors present concerns about its counter-market nature since through a direct intervention the regulator could have the power to manipulate the market at will if there are no constrains for its behavior (Meunier and Finon, 2006).

On the one hand this mechanism advantages are:

Good efficiency of adequacy targeting, good institutional feasibility, and a good robustness for strategic behavior (Meunier and Finon, 2006).

On the other hand, this mechanism disadvantages are:

A reduced compatibility with the market (due to its likely counter-market nature) and a non-existing operational frame that secures the mechanism effectiveness in an open market (Fignon and Pignon, 2008)

10. Centralised auctioning for capacity contracts:

This mechanism seeks to control the total capacity in a market to later auction it as contracts. By auctioning contracts, the government promotes competition in the market, ensures profitability incentives and entry of new participants. New England is one of the implementation cases of this mechanism (Vasquez et al., 2003).

Regarding its evaluation, this mechanism presents significant advantages in ensuring investments stability, market consistency and efficiency, reaching thus the market goal for capacity. Therefore, it has shown a remarkable effectiveness for market prices stabilization (Bidwell, 2005; Cramton and Stoft, 2006).

This mechanism advantages are:

Good efficiency of adequacy targeting, good effectiveness in an open market, good compatibility with the market (Bidwell, 2005)

This mechanism disadvantages are:

Limited robustness for strategic behavior (since the total market total capacity is beyond agents control) and restricted institutional feasibility, given that this mechanism has shown better results in mandatory markets that in non-mandatory markets, since in the latter, the bilateral forward sales contracts for energy complicates the definition of physical responsibilities (Vasquez et al., 2003)

We chose these two mechanisms for two main reasons. First, both are frequently discussed in the literature and second, they are opposites in nature i.e. the first one is interventionist while the second one is market-oriented. In order to test these two last mechanisms we use the work of Arango and Moxnes (2012) as our starting point. Arango and Moxnes (2012), replicate markets for different types of commodities in a series of System Dynamics based experiments, and, by gradually increasing the market complexity, show how individuals' rationality decreases when the system complexity increases, which results in significant cyclical tendencies in both prices and production capacities. However, these authors assumed full capacity utilization in all of their treatments. In Arango et al. (2013), the full capacity utilization restriction is relaxed for the last treatment of Arango and Moxnes (2012) to replicate an electricity market where agents can decide what percentage of their capacity they want to use in generation (between 70% and 100%). The authors show that this new element seems to reduce price fluctuations but leads to higher prices in average. In a later extension of the last treatment of Arango and Moxnes (2012), Alvarez (2013) introduces futures negotiations to the market, finding that the inclusion of futures negotiations also seems to reduce the cyclical tendencies of market prices. In this thesis, we use the last treatment of Arango and Moxnes (2012) as a base case like other previous works (Arango et al., 2013; Alvarez, 2013) to make a further extension of it to evaluate Procurement for long strategic reserve planning and Centralized auctioning for capacity contracts. In the next chapter, we present the experimental design we use to test these two mechanisms.

6. EXPERIMENTAL DESIGN AND EXPERIMENTAL PROCEDURE

In this chapter, we present the experimental design. First, we present the economic model of the three treatments considered. Second, we present a brief description of the underlying System Dynamics models. Finally, we explain the experimental procedure.

6.1. Economic model:

Our starting point is a symmetrical experimental market with five players to induce non-collusive behavior, and we expect the results to be somewhere between the Cournot-Nash equilibrium[5] and the Perfect Competition equilibrium[6] (Huck et al., 2004). The players can invest freely, but considering two restrictions: first, their individual installed capacity cannot be over 20 capacity units to ensure a minimum of competition among players; and second, they cannot make investment decisions that are less than zero (no negative amounts allowed). We use the investment scheme of the fourth treatment of Arango and Moxnes (2012), where the capacity has a 4-year construction time and a 16-year lifetime. The players receive feedback about market's and their own performance, and make decisions each year, following a standard Cournot experiment procedure[7] (Huck et al., 2004). A linear, non-negative, inverse demand function of the capacity determines the market price. The market price in period t is:

$$P_t = max\left\{A - B\sum_{i=1}^{5} q_{i,t}\,, 0\right\} \tag{1}$$

Where $q_{i,t}$ is the production of player i in period t, and A and B are parameters (A=6, B=0.1, as defined by Arango and Moxnes). Following, we present the three experimental treatments.

Treatment 1: Base case

We study the same setting as Arango and Moxnes (2012) in their fourth treatment, where players invest in a yearly basis and production equals capacity. The production of player i in period t is:

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

[5] Resulting state from a set of actions in a game in which no player can benefit from an individual change of strategy if the other players leave theirs unchanged.

[6] Resulting state in a market, where the producers produce as long as there is profit margin and they end up earning the normal profit.

[7] The standard conditions are (Huck, 2004, p. 106): (1) interaction takes place in fixed groups. (2) Interaction is repeated over a fixed number of periods, (3) products are perfect substitutes, (4) costs are symmetric, (5) there is not communication between subjects, (6) subjects have complete information about their own payoff functions, (7) subjects receive feedback about the aggregated behavior of the other subjects, and (8) the experimental instructions use an economic framework.

Where $x_{i,j}$ is the investment decision of player i in period j. The profit function for each player in period t is given by:

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

Where P_t is the market price in period t, c is the cost (includes both capital and operational costs) and $q_{i,t}$ is the production of player i in period t.

To guarantee model transparency for the players, we designed an interface where the players receive feedback information, year by year, about (1) their total investments, aggregated over three years, (2) their capacities, aggregated over sixteen years, (3) their productions, (4) aggregated production of the other players, and (5) total production of the market (see Appendix 3 in Spanish). In the System Dynamics mode, we use the same model structure of Arango and Moxnes (2012) for all the three treatments. The yearly investments take four years to be part of a player's production; once that production is available, it lasts for 16 years. The sum of the five players' productions is the total market production. As the base case, Treatment 1 uses this structure without modifications. Figure 2 shows an aggregated stock and flow diagram of this process.

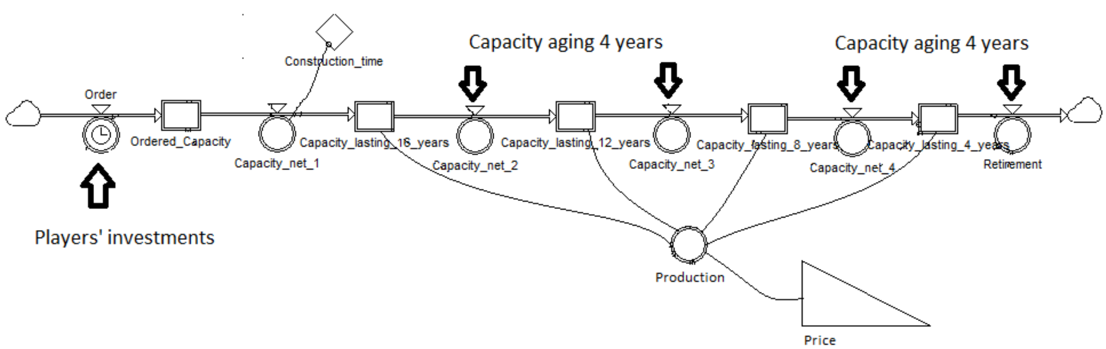


Figure 2: Representation of the stock and flow diagram for the base case.

Treatment 2: Regulatory firm included

In this treatment, we use the same scheme we used in the base case. However, now we introduce a sixth player in the market, which is a regulatory firm, operated by the model (or the government in real life). This firm also invests in capacity, but it only invests if the market production will be less than 50 units (perfect competition equilibrium) in four years. The regulator has a capacity limit of 10 units, which is 20% of the capacity goal, to ensure that it does not have the power to manipulate the market (Meunier and Pignon, 2006). Hence, the regulatory firm investment (Z) in period t is represented by:

$$Z_t = if \sum_{i=1}^{5} q_{i,t+4} < 50 \begin{cases} 10 & if\ 50 - \sum_{i=1}^{5} q_{i,t+4} \geq 10 \\ 50 - \sum_{i=1}^{5} q_{i,t+4} & if\ 50 - \sum_{i=1}^{5} q_{i,t+4} < 10 \end{cases} \quad (4)$$

We also considered model transparency in this treatment. The players receive all the information they received in Treatment 1, plus the information about the regulator's capacity (See Appendix 3 in Spanish). In the System Dynamics model, we include a second production structure, which corresponds to the regulatory firm. The regulator has the ability to foresee the future market production in a four-year horizon. The regulator production is added to the players' production and both determine the total market production. Figure 3 shows a stock and flow diagram of the regulator introduction.

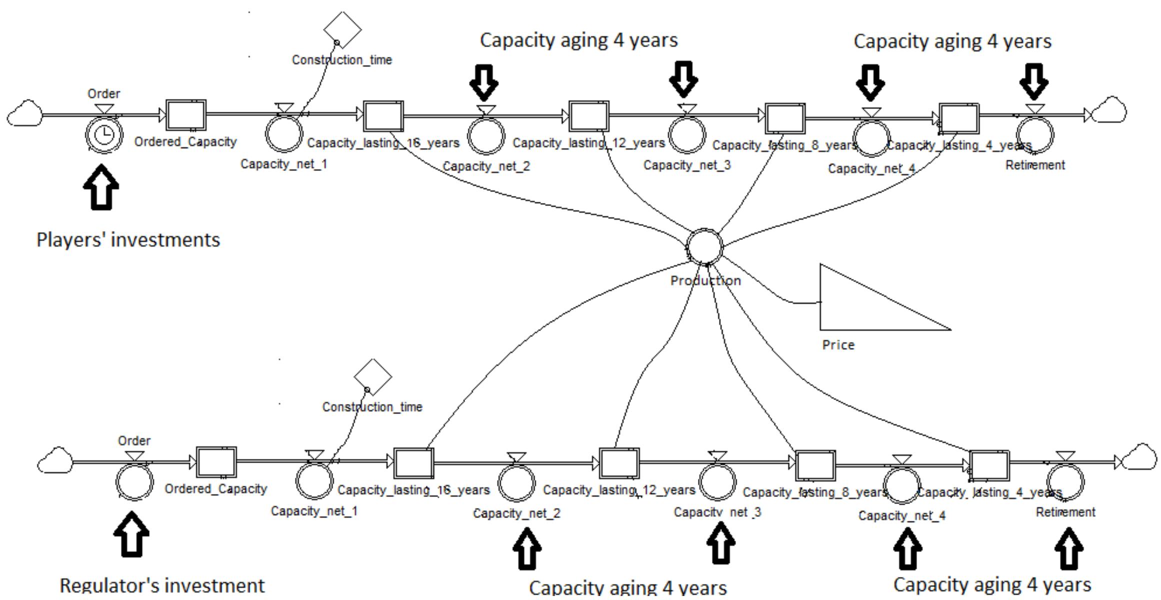


Figure 3: Representation of the stock and flow diagram for the regulator introduction – Treatment 2.

Treatment 3: Centralized auctions system included

In this treatment, we use the same production scheme we used in the previous treatments. However, now we introduce a clearing house that auctions each year capacity. We use the auction system proposed by Alcaraz (2010). Now, the players have to make bids for licenses to build capacity. Accordingly, their new profit function is:

$$\pi_{i,t} = (P_t - c)q_{i,t} - Y_{i,t} * LP_t \quad (5)$$

Where $Y_{i,t}$ is the number of licences given to player i in period j and LP_t is the licence's price in period t.

Since the clearing house controls each year investment, the total production of the market is under its control. The market production is fixed to 50 units (perfect competition equilibrium) for all the years. This situation implies that the players' profits are only determined by the trading of licences.

The licence prices ranges between -2.1 and 2.4. Negative prices means that the government subsides the licences and positive prices means that the producers are actually paying for them, thus the players benefit from negative prices and lose money with positive prices. In the System Dynamics model, this treatment incorporates an auction system. Therefore, players' investments are assigned by a centralized auction. The players make their bids by taking positions in desired productions for given licences prices. We used the design presented by Alcaraz (2010). Figure 4 and 5 show a stock and flow diagram for this treatment.

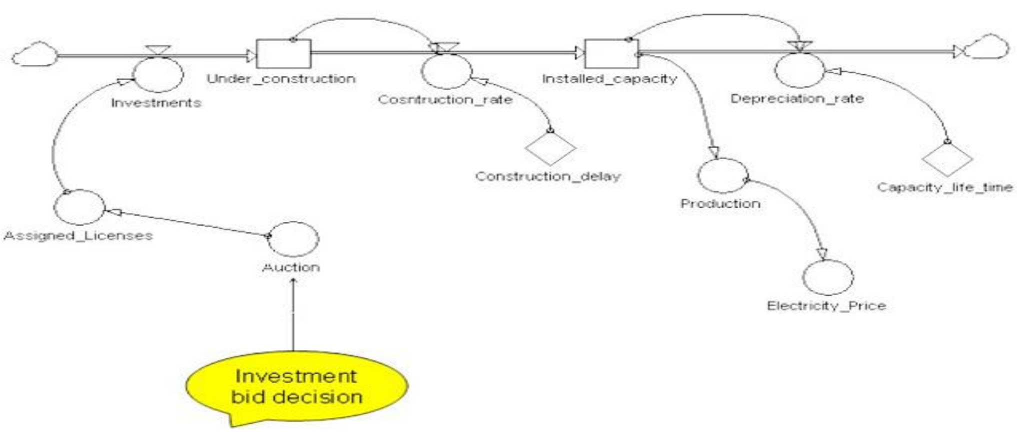


Figure 4: Stock and flow diagram representation for the auction system introduction – Treatment 3. Source: Alcaraz (2010, p. 10).

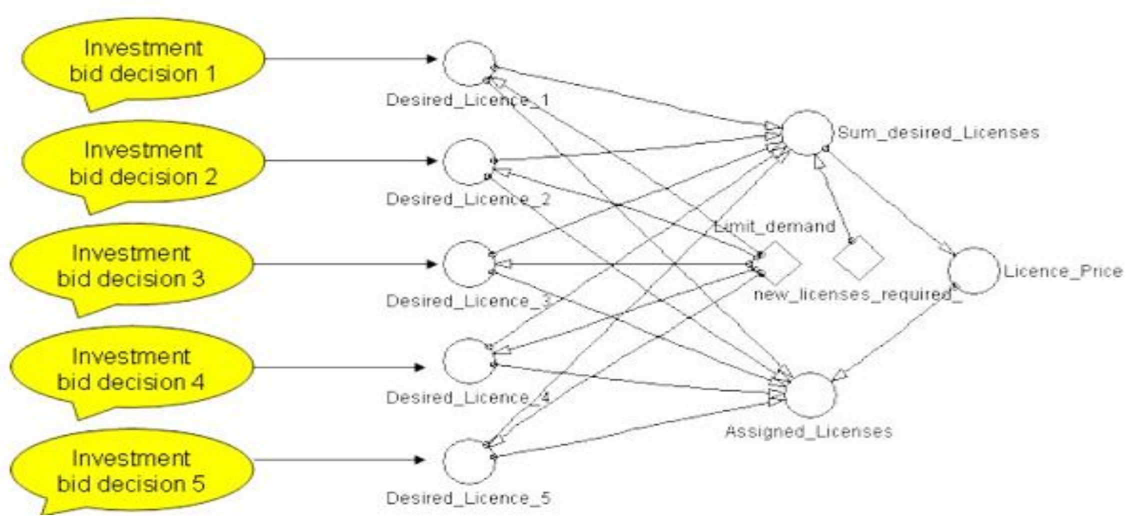


Figure 5: Stock and flow diagram for the auction between the five players in Treatment 3. Source: Alcaraz (2010, p. 10).

To ensure model transparency, the players received all the information they received in treatment 1, plus the information about the licences. Another variation is that in this treatment the players decide by drawing graph functions, in which they show how many production units they want, given a licence price. They face two restrictions in drawing such function: first, as the price increases, the desired production must decrease (to prevent logical errors); and second, the desired production at the maximum price (2.4) must be zero for the model to calculate the licenses' price that results from all the biding functions.

In order to be able to compare results between treatments, Treatments 2 and 3 are linked by the fact that both aim to achieve a perfect competition equilibrium, which means they both aim to maximize the society's benefits measured as the sum of the consumers' surplus[8] and the producers' surplus[9], i.e., the economic surplus[10].

6.2. Experimental procedure:

We conducted two pilot experimental markets for Treatment 2 and two more for Treatment 3, following the Experimental Economics standard procedure (Friedman and Sunder, 1994; Friedman and Cassar, 2004). Regarding Treatment 1, we used the results of two randomly selected markets conducted by Arango and Moxnes (2012) in their original work. All participants were selected randomly from the population of fourth to five year students of management and industrial engineering at the Universidad Nacional de Colombia in Medellín, Colombia in the first semester of the year 2013. We told participants they could earn a payoff between Col$10.000 and Col$40.000 (US$5.28 and US$21.23 at the time) in one and a half hours, depending on their performance, which was measured in accumulated profits. The payoff exceeded the opportunity cost estimated for the students for the duration time of the experiment.

Participants were organized randomly in the workstations of the experiment, so they were not able to identify their competitors in the market. The instructions (see Appendix 2 in Spanish) were distributed among participants. After 15 minutes, we gave participants an additional explanation of the market dynamics and posted some general questions to make sure they understood their task. We asked participants to make their decisions and write them down on a record sheet we gave them as a backup for the experiment. We ran the experiments using a computer network with Powersim Constructor 2.51. The software runs year by year automatically once all participants have made their decision and keeps record of all variables, including participants' decisions. The experiment interfaces are presented in Appendix 3 (in Spanish). The experiment is available upon request.

[8] The consumer's surplus is the area defined by the quantity and the difference between the maximum and the actual price of the market.

[9] The producer's surplus is the area defined by the quantity and the difference between the actual price in the market and the production cost.

[10] The economic surplus is the sum of the consumer's surplus and the producer's surplus. It serves as a measure for society's benefits.

7. HYPOTHESES

In this chapter, we present three formal hypotheses with their corresponding theoretical backgrounds. The first hypothesis is based on the Perfect Rationality theory, the second one is based on the Bounded Rationality theory, and the third one is based on our simulations' results and the evaluations given in the literature of the two mechanisms we consider in this work.

Hypothesis 1: Average prices in all treatments are equal to their respective Cournot-Nash equilibrium values.

The Perfect Rationality theory predicts that there will be a stable price behavior and prices will converge to the Cournot-Nash equilibrium, as every firm makes profit-maximizing decisions given the others' outputs (Muth, 1961; Huck, 2004). Table 2 shows the values of Joint Maximization, Cournot-Nash and Perfect Competition equilibria for each treatment (see Appendix 1 for the equilibria derivation).

	T1			T2			T3		
	ID	Cap	Price	ID	Cap	Price	ID	Cap	Price
JM	0.31	25.0	3.50	0.25*	30.0*	3.00	NA	NA	NA
CN	0.52	41.7	1.83	0.42*	43.3*	1.67	NA	NA	NA
PC	0.63	50.0	1.00	0.50-0.63*	50.0*	1.00	0.63	50.0	1.00

Table 2: Players individual investments (ID), Market capacity (Cap) and Price for Joint Maximization (JM), Cournot-Nash (CN) and Perfect Competition (PC) equilibria. *In this treatment, a regulator firm intervenes, so the individual investments of the players do not match with the market production (see Appendix 1)

Since Treatment 3 has a fixed market production by design, the price will always be constant, conversely to the other two treatments. Hence, we will need to analyse the licences prices behavior separately for this treatment in order to make further comparisons.

Hypothesis 2: Treatments 1 and 2 show cyclical behavior.

The Bounded Rationality theory poses that human decision makers do not have the capabilities assumed by the Perfect Rationality theory. Furthermore, it is expected that individuals make satisfying decisions rather than optimal ones (Simon, 1955, 1979). Typically, human decision makers use simple decision rules called heuristics (Tversky and Kahneman, 1974), which serves as tools to make decisions without too much mental cost (time and effort spent on making a decision). The quality of the decisions driven by heuristics seems to be near optimal when people face simple tasks, but the quality reduces as the complexity of the task increases (Diehl and Sterman, 1995; Moxnes, 2004; Arango y Moxnes, 2012). Therefore, we use an investment heuristic for the decisions in Treatments 1 and 2.

We use the heuristic proposed by Arango and Moxnes (2012) to simulate investment behavior for both Treatments 1 and 2. Equation 6 shows the formulation of the heuristic to determine the value to invest.

$$x_{i,t} = Max(\partial_i * Dep_{i,t+4} + \gamma_i * Cap_{i,t+4} + \varepsilon_i * ExP_{i,t} + \mu_i * P_t + \omega_i, 0) \quad (6)$$

Where ∂_i, γ_i, ε_i, μ_i and ω_i are decisions parameters of player I for depreciation, capacity, expected price, actual market price (this four parameters constitute the basic heuristic outcome) and decision adjustment with respect to the basic heuristic outcome, respectively. $Dep_{i,t+4}$ and $Cap_{i,t+4}$, are depreciation and capacity for player i four years ahead of period t, $ExP_{i,t}$ is the price expected by player i for period t, and P_t is the market price in period t.

To run the simulations, we assume identical behavior for all the five players, i.e., they have the same parameters and values. Therefore, they have the same behavior and results. The parameters we use were the same used by Arango and Moxnes (2012), ∂_i = -0.02, γ_i = -0.04, ε_i = 0.42, μ_i = 0.16 and ω_i = 0.54. For this set of parameters, we run simulations for Treatments 1 and 2. Figure 6 shows the results for each treatment.

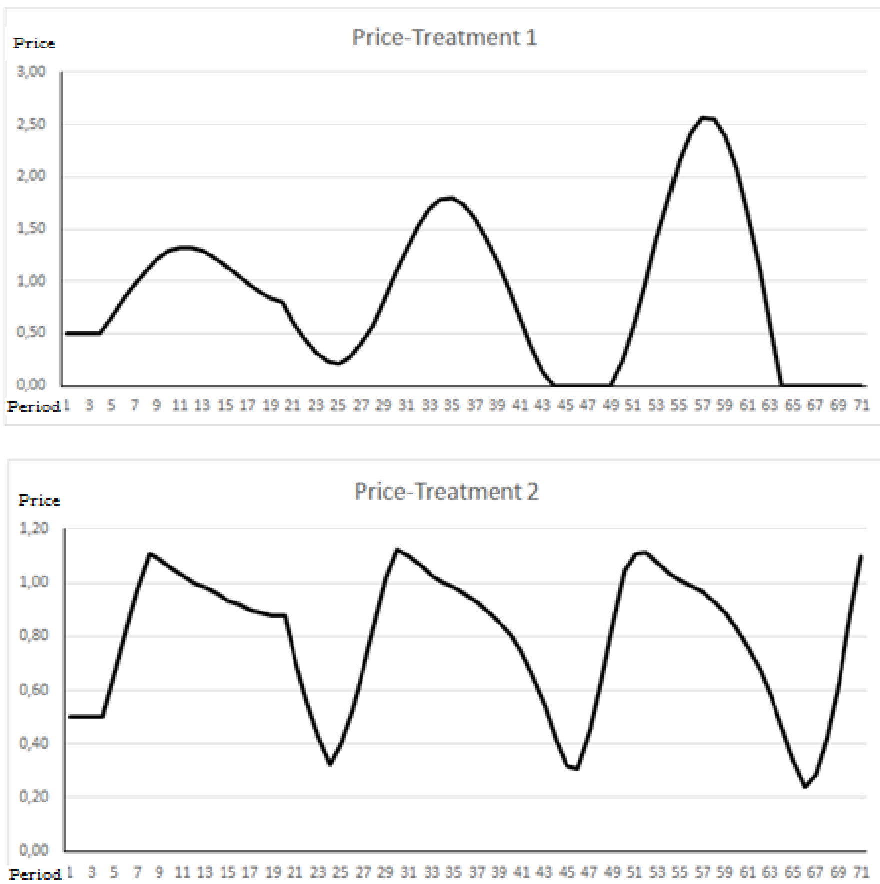


Figure 6: Simulations results for Treatments 1 and 2 using the first set of parameters.

Our first simulations suggest the presence of cycles in Treatments 1 and 2. The inclusion of a regulator in Treatment 2 seems to reduce the average amplitude of the cycles but it does not eliminate them. We explore how variations in investment parameters could affect the basic cycle's behavior.

We performed several sensitivity analyses to identify the parameters that have the highest influence on behavior. Table 3 shows how a 1% increment in each of the parameters can affect price volatility (measured as the standard deviation).

Treatment 1			
Variable (1% variation)	Original Standard deviation	New Standard deviation	Variation (%)
∂_i	0.7163	0.7159	-0.05
γ_i	0.7163	0.7101	-0.87
ε_i	0.7163	0.7164	0.01
μ_i	0.7163	0.7154	-0.13
ω_i	0.7163	0.7069	-1.31
Treatment 2			
Variable (1% variation)	Original Standard deviation	New Standard deviation	Variation (%)
∂_i	0.2575	0.2575	0.01
γ_i	0.2575	0.2605	1.15
ε_i	0.2575	0.2615	1.55
μ_i	0.2575	0.2585	0.41
ω_i	0.2575	0.2614	1.51

Table 3: Sensitivity analysis of the investment parameters for treatment 1 and 2.

Table 3 shows that ω_i is the most influencing parameter for Treatment 1 and the second most influencing parameter for Treatment 2. Table 3 also shows that γ_i is the second most influencing parameter for Treatment 1 and ε_i is the most influencing parameter for Treatment 2. The differences are explained by the inclusion of a regulator that invests in the market along with the players, which brings different price behaviors and, thus, different influencing parameters. We proceed to show how these influencing parameters could enhance/mitigate cyclical behavior in the market price.

For Treatment 1, we first consider joint changes in ω_i and γ_i that could lead to price stabilization. We found that a 30% percent increase in both of these parameters would be enough to reduce price volatility by almost 90% (89.33%). This means that cycles could be mitigated if players give significantly more value to their future capacity and their decision adjustment with respect to the basic heuristic outcome i.e. the players change their decision making parameters by giving more importance (weight) to their future capacity and decision adjustment. Figure 7 shows the price behavior for these new values of ω_i and γ_i. It is important to note the low prices and their impact on the electricity generators i.e. there is tradeoff between stabilization and agents benefits in this case.

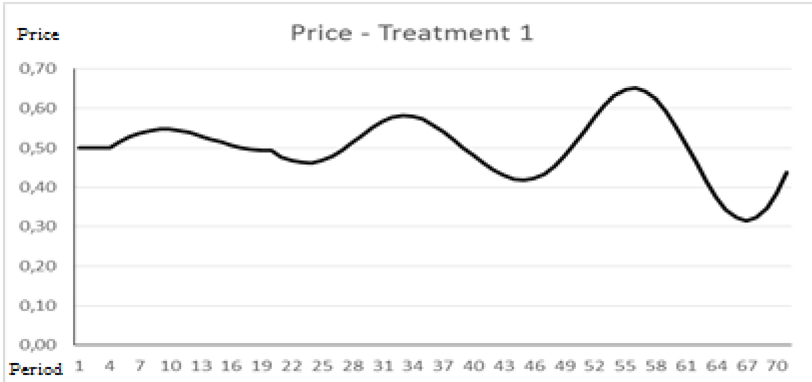


Figure 7: Price in Treatment 1 after a 30% percent increase in both ω_i and γ_i (ω_i = 0.7 and γ_i= -0.03).

For Treatment 2, we consider joint changes in ε_i and ω_i. We found that players could reduce market price variability by 45% (-45.25%) by reducing both parameters by 22%. However, any further reduction in these parameters will increase the volatility. This means that cycles could be mitigated if players give less value (with a maximum reduction of 22%) to their price expectations and their decision adjustment with respect to the heuristic basic outcome. Figure 8 shows the market price for Treatment 2 when ε_i and ω_i are reduced by 22%, while Figure 9 shows the market price for Treatment 2 when such parameters are reduced by 30% with the resulting increases in price volatility by more than 100% (+103.57%).

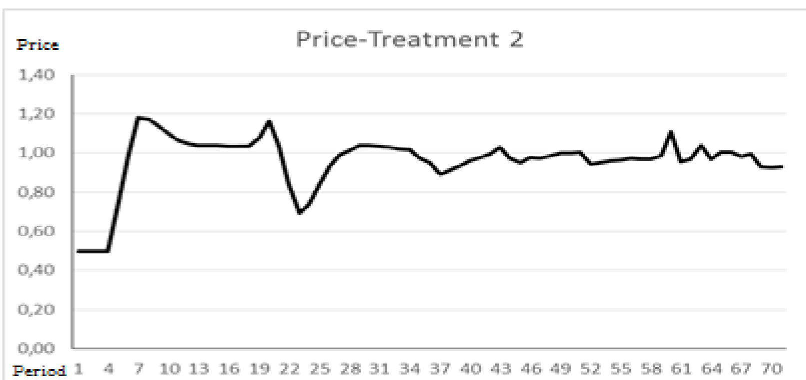


Figure 8: Price in treatment 2 after a 22% decrease in both ε_i and ω_i values. ω_i = 0.42 and ε_i= 0.33.

Figure 9: Price in treatment 2 after a 22% decrease in both ε_{i} and ω_{i} values. ω_{i} = 0.38 and ε_{i}=0.30.

Once again, the changes in price behavior are explained by the interaction between the players and the regulator firm. If we assume this heuristic to be a good approximation of the actual decision rules the players have, the unlikelihood that five different players make cycle-mitigating adjustments to their heuristics lead us to consider the possibility of cycles occurrence as this hypothesis states.

The frequency or periodicity, amplitude and attenuation are the features that characterize cycles in a time series. However, such features are not always easy to detect by visual inspections, especially when irregular cycles are in place. The variance gives an idea of how much the data is dispersed around an average value while the attenuation indicates the variance for different time intervals, but neither of these two estimations gives an idea about frequencies or autocorrelations. To study these aspects and to test random and cyclical behavior we turn to spectral analysis and autocorrelation.

Spectral analysis: The frequency decomposition of variance is called the autospectrum or the autospectral density function. Peaks in the autospectrum indicate that variance is concentrated at certain frequencies. This allows detection of both cyclical tendencies and period lengths. For instance, white noise has a uniform autospectrum while a sine wave has an autospectrum totally concentrated at a single frequency (the period).

Correlation analysis (autocorrelogram): The autocorrelogram measures the correlation of the variable with itself, at different time lags. The autocorrelogram is most directly interpreted as a measure of how well future values can be predicted based on past observations. While random processes have autocorrelation functions rapidly reduced to zero, cyclicality is observed when there are values significantly different from zero at different lags.

Hypothesis 3: Treatments 2 and 3 present better scenarios for society's welfare than Treatment 1.

The literature show that both mechanism may represent significant benefits in terms of economic welfare (Fignon and Pingon, 2008). To test this, we first performed a series of simulations for Treatment 3, in order to assess the possible behavior of licenses in this treatment. Equation 7 shows the proposed heuristic for Treatment 3.

$$DCap_{-2.1} = Min(Max(z + x * MProf + y * Cap, 0), 20) \qquad (7)$$

Where MProf is the market's profit and Cap is the market's capacity. z, x, y are parameters estimated based on the results reported by Alcaraz (2010). These parameters' values are z=-10.09, x=1.87 and y=1.46. With this initial value, we can determine the heuristic for the subsequent point in the curve, and then repeat the process for all the other points. The heuristics for the subsequent points of the bidding curve are given by

$$DCap_{Lp} = Max\left(i + l * DL_{Lp-m}, 0\right) \qquad (8)$$

Where $DCap_{Lp}$ is desired capacity at a license priceLp, DL_{Lp-m} is the desired capacity at the previous curve point (m is the separation between the curve points), and i, l are coefficients estimated for the particular curve point in case (Lp, $DCap_{Lp}$) using Alcaraz (2010) results. Assuming identical behavior on the part of the five players, we simulate the licenses' price behavior. Figure 10 shows the results.

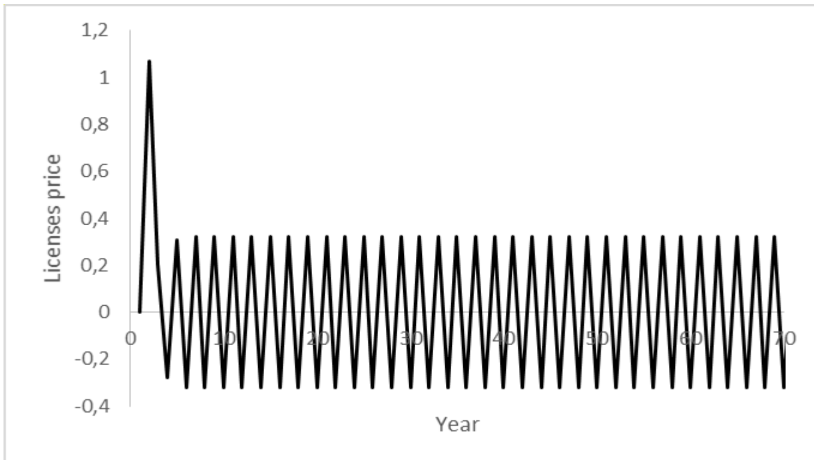


Figure 10: Licenses prices for Treatment 3 using the first set of parameters

With the auctioning system, the market's capacity is fixed; therefore, the electricity price is stabilized. However, it may present some instability in the licenses price. In this treatment, the producers' profits are only determined by the licenses' price. This solely dependence in licenses, leads the market towards a similar decision making to the ones we observed in the previous cases i.e. the market makes high orders for capacity when the price is attractive and makes low orders for capacity when the price is not attractive. In turn, this decision making approach may lead to oscillations in the licenses prices (Cramton and Stoff, 2006).

As we presented in the Literature Survey, both the Procurement for Long Strategic Reserve Planning and the Centralised auctioning for capacity contracts can improve the market efficiency (price stabilization) and society's welfare (de Vries, 2004; Bidwell ,2005; Meunier y Finon, 2006; Cramton and Stoft, 2006). Therefore, based on the simulations we have performed, we estimate the Average value and the Standard deviation of the Economic Surplus for each of the treatments. The Economic Surplus is the sum of the Consumer Surplus and the Producer Surplus. The Consumer Surplus is the area under the demand curve (Eq 1), defined by the market's capacity and the difference between the maximum price and the market price (triangle shape). The Producer Surplus is the area under the demand curve (Eq 1) defined by the market's capacity and the difference between the market's price and the producers cost. Equations 9, 10 and 11 illustrate this.

$$Consumer\ surplus = \frac{(Maximum\ Price - Market\ Price) * Q_t}{2} \qquad (9)$$

$$Producer\ Surplus = (Market\ Price - Producer\ Cost) * Q_t \qquad (10)$$

$$Economic\ Surplus = Consumer\ Surplus + Producer\ Surplus \qquad (11)$$

With these equations, we calculate the Economic Surplus for Treatment 1 and 2. For treatment 3, we include the cost for the government. Therefore, the Economic Surplus for Treatment 3 is the sum of the Consumer and Producer's Surplus minus the cost to government. The cost to the government is calculated as follows

$$Cost\ to\ gov = \begin{cases} 2 * L_p * Y_{i,t} & If\ prices\ are\ subsidized \\ 0 & If\ prices\ are\ not\ subsidized \end{cases} \qquad (12)$$

When there are subsidized prices, the government incurs in a double cost. There is the tangible cost of the subsidies and there is the opportunity cost of those public resources going to subsidies when they could be used to meet other public needs. We test Economic Surplus using the Average value and the Standard deviation to test for both expected value and stability. Table 4 shows these results of the Economic Surplus calculations for all the three Treatments.

	Treatment 1	Treatment 2	Treatment 3
Average Economic Surplus	121.13	124.44	123,98
Standard deviation of the Economic Surplus	5.11	0.78	0,31

Table 4: Average value and Standard deviation of the Economic Surplus for each of the treatments simulations.

As Table 4 shows, both Treatments 2 and 3 present more desirable scenarios for society's welfare than Treatment 1. Treatment 2 shows the highest Average value and a minor Standard deviation for Economic Surplus than Treatment 1, which means that the Procurement for Long Strategic Reserve Planning could offer a higher and more stable society's welfare. Treatment 3 shows a similar case, where the average value is increased and the standard deviation is reduced when compared with Treatment 1. Treatment 3 shows the lowest Standard deviation and the second highest Average value. Hence, both treatments 2 and 3 show better market scenarios than Treatment 1 as the literature suggests.

The two mechanisms seem to improve the society's welfare state. However, our simulations suggest that there is no clear dominance between the mechanism i.e. they both improve the market, but each one improves one measure (average value, standard deviation) more than the other does. This appreciation seems to be contrary to what we presented in the mechanisms' evaluation in chapter 4, where we briefly showed some assessments about the mechanism considered in Treatment 2

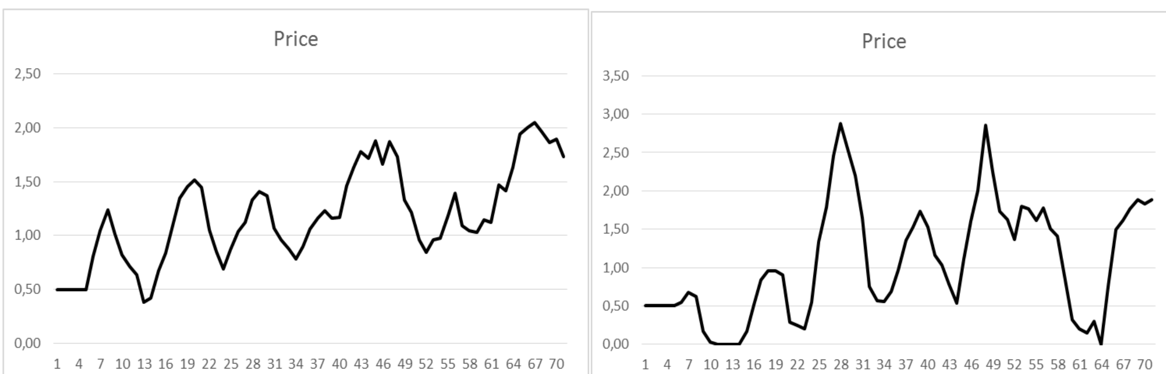
(Procurement for long strategic reserve planning) and the mechanism considered for Treatment 3 (Centralised auctioning for capacity contracts). Both mechanisms present good results for price stabilization (de Vries, 2004; Meunier y Finon, 2006; Vasquez et al., 2003). However, in comparison, there seems to be a preference for the mechanism we test in Treatment 3 (Centralised auctioning for capacity contracts) in regard of its results in investment stability, market consistency and market's capacity goal reaching (Fignon y Pignon, 2008; Bidwell, 2005; Cramton and Stoft, 2006). Therefore, we also want to see whether the benefits obtained by society with Centralised auctioning for capacity contracts are significantly greater than the ones obtained with Procurement for long strategic reserve planning or vice versa in our experiments. The next chapter presents and overview of the main results and discusses the tests for the hypotheses we have proposed.

8. EXPERIMENTAL RESULTS

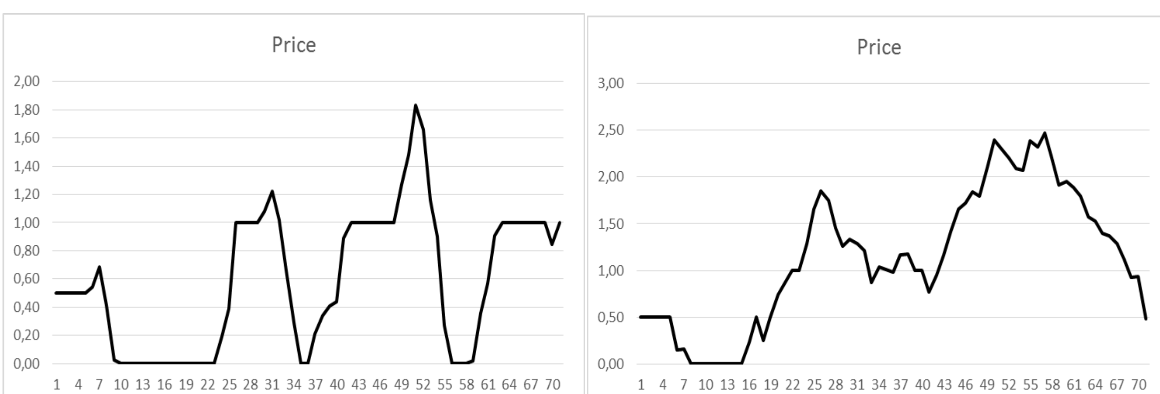
In this section, we show the experimental results. We conducted two markets for both Treatments 2 and 3, while for Treatment 1 we used two randomly selected markets from Arango and Moxnes (2012). First, we present an overview of the results and then we present the hypotheses tests.

8.1. Results' overview:

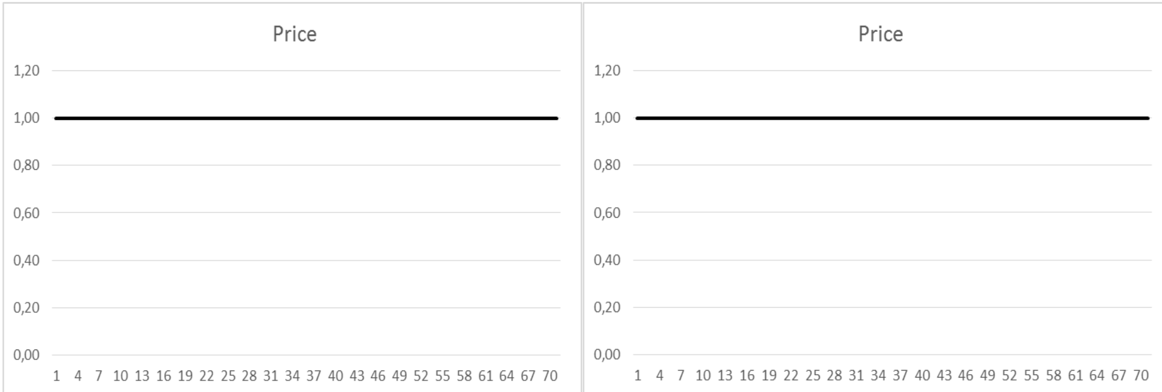
Since we are primarily studying the long-term security of supply, we focus our analysis in the development of two main variables, price and capacity. While our main interest lies in the occurrence of cycles in the electricity's price, we consider that price behavior is determined by capacity behavior in our experimental designs; thus, we decided to consider both variables for our analysis. Figure 11 shows price behavior for the two markets of each treatment we consider. Although formal tests are needed, visual inspections is a first assessment of cycles in a variable's behavior, such as price (Ricci, 2003). Both Treatments 1 and 2 seem to present cyclical tendencies in all of their respective markets. On the other hand, Treatment 3 does not show any variation in price because its design keeps the total market capacity constant. Therefore, in Treatment 3 it is necessary to study licenses prices to evaluate the markets' behavior.



Treatment 1



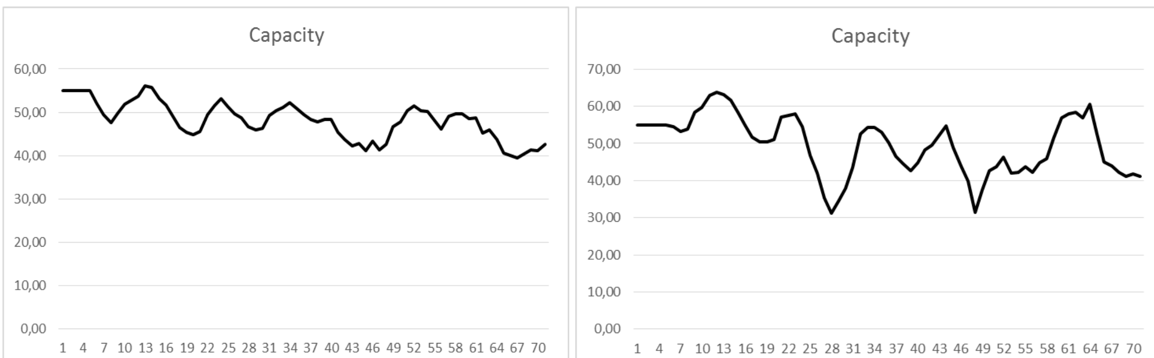
Treatment 2



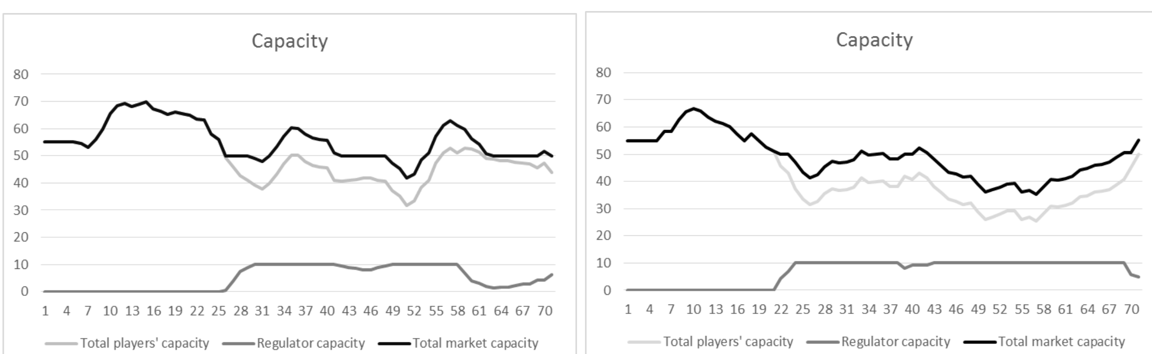
Treatment 3

Figure 11: Prices of the three treatments

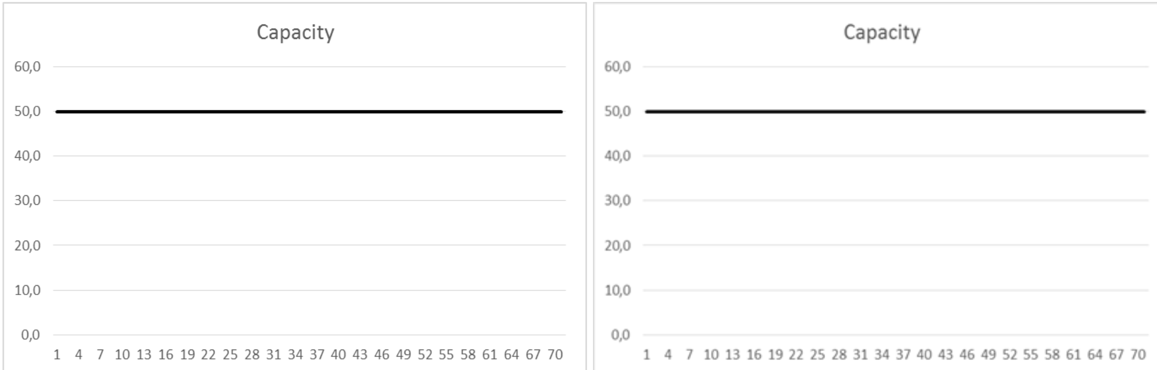
Price behavior depends on capacity, but total capacity is different for each treatment. Thus, we examine capacity behavior as well. Figure 12 shows the capacity behavior for each treatment.



Treatment 1



Treatment 2



Treatment 3

Figure 12: Capacity of the three treatments.

For both price and capacity, we find that there seems to be cyclical tendencies in Treatments 1 and 2. In the Treatment 1, for the first market, we found price cycles with an increasing price tendency (i.e. decreasing capacity tendency) and for the second market we found cycles with no evident tendency and bigger rise and fall movements in comparison with the first market. In Treatment 2, for the first market, we found cycles with no evident tendency and marked rise and fall movements, conversely, in the second market, we found cycles with increasing price tendency and less marked rise and fall movements. In addition, there does not seem to be significant difference between the cyclical tendencies of Treatments 1 and 2. Table 5 shows summary statistics for the price behavior in each of the three treatments.

	Treatment 1				**Treatment 2**				**Treatment 3**			
	AP	SD	CV	α	AP	SD	CV	α	AP	SD	CV	α
M1	1,18	0,43	0,36	0,89	0,59	0,49	0,83	0,91	1,00	0,00	0,00	-
M2	1,07	0,75	0,71	0,88	1,15	0,72	0,63	0,96	1,00	0,00	0,00	-

Table 5: Summary statistics for treatments' price. AP= Average Price, SD= Standard Deviation, CV= Coefficient of Variation and α= one-lag autocorrelation coefficient.

An overview of the results suggests cyclical tendencies in both Treatments 1 and 2, and, as expected, stable behavior in Treatment 3 by design. The Coefficient of Variation is greater than 0.5 for the two markets in Treatment 2 and for one in Treatment 1, the α shows high correlation between prices in different sets of times for all the markets in both Treatment 1 and 2. Furthermore, these statistics suggest that the inclusion of a regulatory firm causes greater variability in the price and stronger cyclical tendencies.

Moreover, we present the same analysis for capacity to seek indications of cyclical behavior. Table 6 shows the summary statistics for the capacity behavior in each of the three treatments.

	Treatment 1				**Treatment 2**				**Treatment 3**			
	AC	SD	CV	α	AC	SD	CV	α	AC	SD	CV	α
M1	48,16	4,32	0,09	0,89	55,53	6,95	0,13	0,94	50,00	0,00	0,00	-
M2	49,51	7,79	0,16	0,88	48,95	7,92	0,16	0,96	50,00	0,00	0,00	-

Table 6: Summary statistics for treatments' capacity. AC= Average Capacity, SD= Standard Deviation, CV= Coefficient of Variation and α= one-lag autocorrelation coefficient.

The summary statistics for capacity shows significant variations (CV) in capacity. Such variations in capacity lead to variations in price due to the linear relationship between the two variables. Moreover, the one-lag autocorrelation coefficient shows high values for the two markets in both Treatments 1 and 2, which suggests cyclical tendencies in capacity behavior in prices, which in turn causes cyclical behavior in prices. In addition, the capacity and price average values are closer to the Perfect Competition values (capacity= 50.00, Price=1.00) than to the Cournot-Nash values (capacity=41.66, Price=1.83). This is consistent with previous experiments for Treatment 1 (Arango and Moxnes, 2012; Arango et al, 2013).

Since Treatment 3 has a fixed market production by design, the price will always be constant. Hence, we analyze licenses prices instead. Figure 13 shows the results.

T3M1

T3M2

Figure 13: Licenses price behavior for Treatment 3

Experimental results for Treatment 3 show variations in the licenses price, forming ups and downs in a similar way that our simulations suggested. To assess differences in society's welfare, we first calculate the Economic Surplus for every market. Table 7 shows the Consumer, Producer and Economic surpluses for each market and the average treatment result.

	Treatment 1		Treatment 2		Treatment 3	
Units: Experimental money	**M1**	**M2**	**M1**	**M2**	**M1**	**M2**
AES	123.91	122,02	121,58	121,95	122,57	123,19
SES	1,41	3,60	4,55	3,40	2,38	1,75
Treatment Average	122,97		121,76		122,88	
Treatment SD	2,89		4,00		2,11	

Table 7: Results of average Economic Surplus (AES) and standard deviation for Economic Surplus (SEC) for every market with the corresponding average and standard deviation values for each treatment.

Results of the experiments show that neither Treatment 2 nor 3 present a higher Economic Surplus than Treatment 1. Moreover, these results show that Treatment 2 has the greatest standard deviation of the three treatments and the lowest average value, which means that our first mechanism (Procurement for long strategic reserve planning) presents the worse market scenario. We now proceed to sketch our formal hypotheses testing.

In a comparative analysis of the three treatments, we found that Treatment 1 presented the highest average Economic Surplus and second highest standard deviation of the three. We also found that Treatment 2 reports the lowest average Economic Surplus and highest standard deviation. In addition, while we were not expecting total cyclical tendency elimination in Treatment 2, we expected some reduction, as our simulations suggests. However, we did not find any significant reduction from Treatment 1 to Treatment 2 in the cyclical tendency. These preliminary findings suggest that, under the assumptions we run the markets, Procurement for long strategic reserve planning could make the market less profitable and less stable than it was before such mechanism was included. Conversely, Treatment 3 reports an average Economic Surplus that is almost the same as the one reported by Treatment 1 and the standard deviation of the Economic Surplus of Treatment 3 is significantly minor than Treatment 1. Under the assumptions we run the markets, these pilot experimental results suggest the Centralized auctioning for capacity contracts could improve the stability of the market prices, without reducing the total benefits for society.

8.2. Hypothesis testing:

We turn now to sketch the test of the hypotheses. We must consider that these are pilot experiments, and thus, we do not aim to present them as formal test. Instead, our experiments are expected to provide initial indication of both the result and improvement of the experimental design.

Hypothesis 1: Average prices in all treatments are equal to their respective Cournot-Nash equilibrium values.

To test this hypothesis, we use 95% confidence intervals for both prices and capacities to perform an Acceptance region hypothesis testing. We use an adjusted statistic (Z) to see if the treatments' average prices are statistically different from their respective Cournot-Nash equilibrium values. Table 8 summarizes the results for prices and Table 9 for capacities.

	Treatment 1		Treatment 2		Treatment 3	
	M1	M2	M1	M2	M1	M2
Z	1,96	1,96	1,96	1,96	1,96	1,96
CN	1,83	1,83	1,67	1,67	NA	NA
AP	1,18	1,07	0,59	1,15	1,00	1,00
SD	0,43	0,75	0,49	0,72	0,00	0,00
N	70	70	70	70	70	70
Ad SD	0,05	0,09	0,06	0,09	0,00	0,00
Ad Z	-12,69	-8,60	-18,66	-6,11	NA	NA

Table 8: Summary of price results for Hypothesis 1. Z is the statistical value for the given confidence interval, CN is the Cournot-Nash equilibrium value, AP is the average price, SD is the standard deviation of the price, N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AP-CN}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

	Treatment 1		Treatment 2		Treatment 3	
	M1	M2	M1	M2	M1	M2
Z	1,96	1,96	1,96	1,96	1,96	1,96
CN Value	41,66	41,66	43,33	43,33	NA	NA
AC	48,16	49,51	50,66	42,22	50,00	50,00
SD	4,32	7,79	9,92	11,92	0,00	0,00
N	70	70	70	70	70	70
Ad SD	0,51	0,93	1,18	1,42	0,00	0,00
Ad Z	12,69	8,49	6,23	-0,79	N/A	N/A

Table 9: Summary of capacity results for Hypothesis 1. Z is the statistical value for the given confidence interval, CN is the Cournot-Nash equilibrium value, AC is the average capacity, SD is the standard deviation of the capacity, N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of sample $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AC-CN}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

If the Ad Z value falls within the acceptance region (-Z, Z), we fail to reject the hypothesis. Nevertheless, in this case, only the Ad Z value for capacity in M2 of Treatment 2 fulfills such condition. Therefore, we reject the Cournot-Nash hypothesis, that is, average prices in all treatments are not equal to their respective Cournot-Nash equilibrium values as the Perfect Rationality theory suggests. Instead, prices reached levels closer to competitive prices, which is consistent with previous experiments (Arango and Moxnes, 2012; Arango et al. 2013).

Hypothesis 2: Treatments 1 and 2 show cyclical behavior.

For this hypothesis, we perform an analysis of the autospectra[11]and autocorrelograms (with a 95% confidence interval) of the price series for both Treatments 1 and 2. Figure 14 shows the results for the prices in both treatments.

[11] When calculating the auto spectra, we use the last 64 out of 70 data points because the Fourier transform works better with length series to the power of two (Bendat and Piersol, 1980).

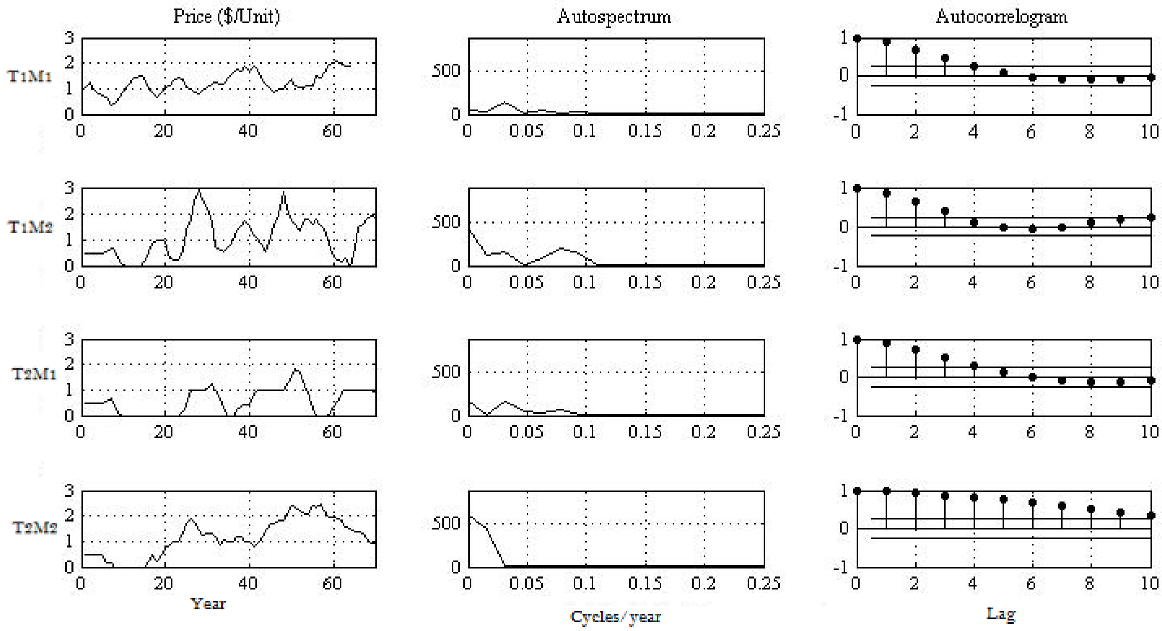


Figure 14: Time series, autospectra and autocorrelograms for the market prices of Treatments 1 and 2

The autocorrelograms show significant numbers for three or more lags for every market, which is consistent with cyclical behavior. The autospectra show frequencies concentrations in all the markets, which suggest the prices' time series do not come from random process[12]. M2 of Treatment 1 shows significant concentrations in different frequencies, which suggest that there could be more than one cycle in operation in that single market. The cycles' periods showed by the auto spectra range from 13 to 50 years in length (from 0.075 in T1M2 to 0.02 in T1M1 frequency concentrations).

In order to consider the implications derived from delays in the economic model, and the linear relationship between variables, we use the same analysis for capacities. The results for capacities are consistent with the results for prices, i.e., we find significant numbers in the autocorrelograms for at least the first three lags and we also find significant frequency concentrations in the auto spectra. Figure 15 shows the results of the capacity analysis.

[12] For a perfectly random process, the autospectra does not show any significant frecuency concentration and the autocorrelogram does not show significant correlation in the lags (the correlation are within the significance limits). For a perfectly cyclical process, the autospectra shows one significant frequency concentration (the period) and the autocorrelogram shows significant positive correlation for the first half of lags and significant negative correlation for the last half of lags

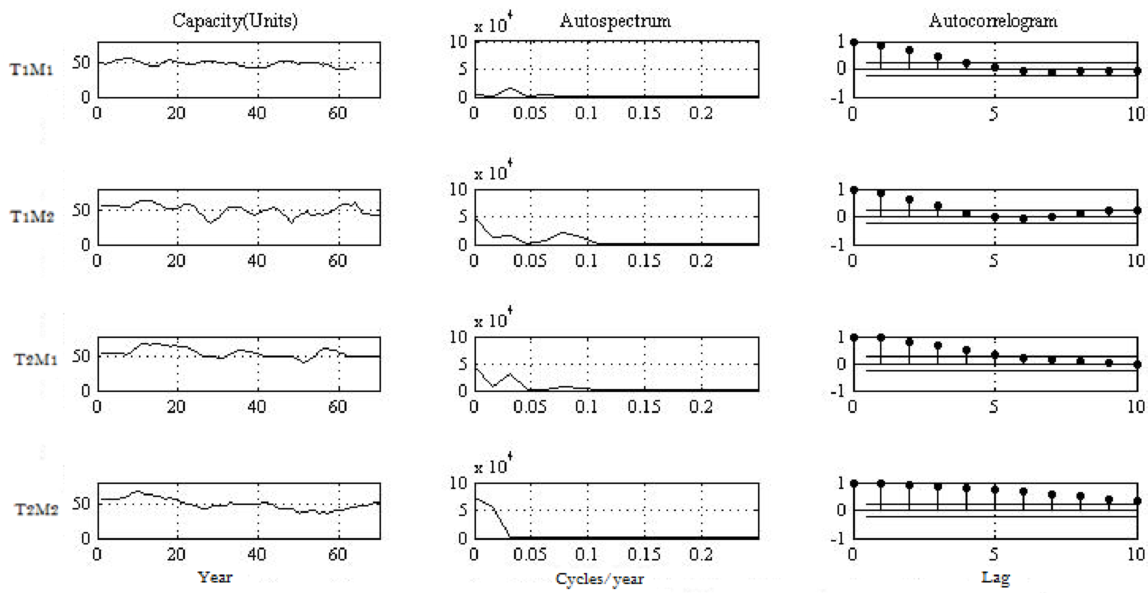


Figure 15: Time series, autospectra and autocorrelograms for market capacities of Treatments 1 and 2.

In general, both prices and capacities show behaviors consistent with the presence of cycles in Treatments 1 and 2. Both treatments present autospectra with frequencies concentration and significant numbers in the autocorrelograms, indicating that neither prices nor capacities behave as a random process over time.

With respect to the double cycle presence (Sterman, 2000; Randers and Göluke, 2007), we do not find strong indications of it. While there are multiple concentrations in the prices´ autospectra in T1M2, this could be caused by adjustments in the players' strategies overtime (the market switches from one cycle to another as the time advances). If time were increased, these strategic adjustments may appear, showing different cycles in different times. Nevertheless, formal experiments are needed to explore this issue.

Based on the results we obtained, we fail to reject the cycles' hypothesis. This suggests that the inclusion of a regulatory firm does not seem to contribute to price stabilization. However, due to the limitation of pilots experimental markets considered in this thesis; it is worth to carry on more experimental markets to have better insights regarding the effects of including a regulatory firm in a deregulated electricity market.

Hypothesis 3: Treatments 2 and 3 present better scenarios for society's welfare than Treatment 1.

In order to compare Treatment 2 and Treatment 3 to Treatment 1, we performed two Acceptance region hypothesis tests. Table 10 shows the results of the hypothesis test we performed to check whether Treatment 1's Economic Surplus is statistically greater than the one reported by Treatment 2.

	General
Z	1,96
BD	0,00
AD	1,20
SD	3,90
N	70
Ad SD	0,47
Ad Z	2,58

Table 10: Summary of results for Hypothesis 3. Difference in Economic Surplus between Treatments 1 and 2. Z is the statistical value for the given confidence interval, BD is the benchmark for the difference between economic surplus values, AD is the average difference, SD is the standard deviation of the difference, N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AD-BD}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

Since Ad Z does not fall within the acceptance region (-Z, Z), the difference between the Economic Surplus of Treatments 1 and 2 is significantly greater than zero. Therefore, we find no evidence in the experimental results to state that Treatment 2 leads to a greater Economic Surplus than Treatment 1 i.e. Treatment 1 Economic surplus is, in fact, significantly greater than Treatment 2m Economic surplus. We now show in Table 11 the summary of the hypothesis test we performed to check whether the difference between Treatment 1's Economic Surplus is statistically greater than the one reported by Treatment 3.

	General
Z	1,96
BD	0,00
AD	0,09
SD	2,64
N	70
Ad SD	0,32
Ad Z	0,27

Table 11: Summary of results for Hypothesis 3. Difference in Economic Surplus between Treatments 1 and 3.Z is the statistical value for the given confidence interval, BD is the benchmark for the difference between economic surplus values, AD is the average difference, SD is the standard deviation of the difference, N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{\mathrm{SD}}{\sqrt{\mathrm{N}}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{\mathrm{AD-BD}}{\mathrm{Ad\ SD}}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

Since the Ad Z falls within the acceptance region (-Z, Z), the difference between the Economic Surplus of Treatments 1 and 3 is not significantly greater than zero. Therefore, we find no evidence in the experimental results to state that the auction market considered in Treatment 3 leads to a greater Economic Surplus than the base case or Treatment 1.

Based on these pilot results, we cannot state that neither Treatment 2 nor 3 lead to a greater Economic Surplus due to the inclusion of the corresponding capacity mechanisms. Hence, we reject the better society's welfare hypothesis (Hypothesis 3). Compared to Treatment 1, Treatment 3 shows a reduction in the standard deviation of the Economic Surplus, while it keeps a statistically equal average value. On the other hand, Treatment 2 shows an increase in the standard deviation of the Economic Surplus and a statistical reduction of the average value compared to Treatment 1.

Now, to compare both capacity mechanisms, we performed a hypothesis test to check whether the difference between the average Economic Surplus in Treatments 2 and 3 is significantly different from zero. Table 12 summarizes the results.

	General
Z	1,96
BD	0,00
AD	1,12
SD	3,11
N	70
Ad SD	0,37
Ad Z	3,01

Table 12: Summary of results for the difference in Economic Surplus between Treatments 2 and 3.Z is the statistical value for the given confidence interval, BD is the benchmark for the difference between economic surplus values, AD is the average difference, SD is the standard deviation of the difference , N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AD-BD}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected

Since the Ad Z does not fall within the acceptance region of (-Z, Z), the average difference is statistically significant, i.e., Treatment 3 reports a significantly higher Economic Surplus than Treatment 2. That is, the Centralized auctioning for contracts presents better results than Procurement for long strategic reserve planning as the literature suggest. In addition, Treatment 2 shows results we were not expecting, we performed a comparison between the actual Economic Surplus of treatment 2 and the resulting Economic surplus if the regulator firm results were not taken into account, the resulting Economic Surplus were 120,56. Table 13 shows the Acceptance region hyphotesis test we performed to compare this hypothetical value for treatment 2 (120, 56) with the actual one (121, 76).

	General
Z	1,96
BD	0,00
AD	1,25
SD	2,94
N	70
Ad SD	0,35
Ad Z	3,54

Table 13: Summary of results for the difference in Economic Surplus between Treatments 2 with the regulator firm results included and excluded. Z is the statistical value for the given confidence interval, BD is the benchmark for the difference between economic surplus values, AD is the average difference, SD is the standard deviation of the difference , N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AD-BD}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

Since the Ad Z does not fall within the acceptance region of (-Z, Z), the average difference is statistically significant, i.e., if the regulator were not present in the market, the Economic surplus would have been lower.

Another concern in our analysis of the third hypothesis is the Producer Surplus in treatment 3. This concerns is based on the seen in the licenses price behavior with its variations. Therefore we performed an Acceptance region hypothesis test to see if the average profit of Treatment 3 (-0.39) is statistically different from the average profit of Treatment 1 (2.26). Table 14 presents the results.

	General
Z	1,96
BD	0,00
AD	2,65
SD	24,00
N	70
Ad SD	2,87
Ad Z	0,92

Table 14: Summary of results summary for the difference in Producer Surplus between Treatments 1 and 3. Z is the statistical value for the given confidence interval, BD is the benchmark for the difference between economic surplus values, AD is the average difference, SD is the standard deviation of the difference , N is the number of periods taken, Ad SD is the standard deviation adjusted for the number of samples $\left(\frac{SD}{\sqrt{N}}\right)$ and Ad Z is the statistical value to be proved $\left(\frac{AD-BD}{Ad\ SD}\right)$. If Ad Z does not fall within the interval (-Z, Z), the hypothesis is rejected.

Since the Ad Z fall within the acceptance region of (-Z, Z), the average difference is not statistically significant, i.e., this test confirms that the statistical equality between the Economic Surplus of Treatment 1 and 3 is not caused by losses in agents profits. Therefore, not only Treatment 3 preserves the society's welfare, it also preserves the agents profits (Producer Surplus).

In both Treatment 1 and 2, we found indications of cycles in capacities and prices in the pilot experimental markets considered. We found significant numbers in the autocorrelograms (for three or more lags), frequency concentrations in the autospectra, significant values for the coefficient of variation and high values for the one-lag autocorrelation coefficient. This type of behavior is consistent with previous works with simulation models and experiments (Olsina et al., 2006; de Vries and Heijnen, 2008; Arango and Moxnes, 2012; Arango et al., 2013). With respect to the general price and capacity behavior, we found, on average, a tendency closer to the Perfect Competition than to the Cournot-Nash equilibrium in the two markets.

In Treatment 3, we found stable electricity price behavior in the two experimental markets, since this treatment design fixes the total market capacity. Regarding the licenses price behavior, we found a tendency towards variations similarly to the variations presented by our simulations. However, even with these variations in licenses' price, the Economic Surplus is significantly more stable in this treatment than it is in the others. These results are also consistent with other works that suggest that centralized auctions could help to stabilize market prices by reducing the risk of non-desired capacity investment behavior derived from price signals (Cramton and Stoft, 2006; Moreno et al., 2007, 2008).

In the next chapter, we present our conclusions, discuss some implications that the results might have for different market actors, and pose further works according to some limitations of the present experiment.

9. CONCLUDING REMARKS

In this chapter, we present the main findings of this work. First, we present a review of the main findings derived from the hypotheses tests we performed. Then, we discuss some implications of our findings related to market dynamics. Finally, we discuss some of the limitations of the work and propose further research based on such limitations.

9.1. Findings:

This thesis presented a series of simulations and experimental treatments to study the effects of two capacity mechanisms, namely Procurement for long strategic reserve planning and Centralised auctioning for capacity contracts in a deregulated electricity market. The pilot experiment conducted for Treatment 1 and 2 only gives first indicatives of how the formal experimental results might be. We explored the occurrence of cycles and the social welfare in three treatments: First, we considered as a base case a deregulated electricity market with full capacity utilization (Treatment 1), which is the most complex case of Arango and Moxnes (2012). Second, we introduced a computer-operated firm that acted as a regulator of the market (Treatment 2); and third, we introduced an auction for licenses system to the base case (Treatment 3).

Previous works in simulation and experimental economics have shown cyclical behaviors (Olsina et al., 2006; Randers and Göluke, 2007; Arango and Moxnes, 2012; Arango et al., 2013). Other works have addressed the cycles issue by including variations like futures markets (Alvarez, 2013) and mothballing (Arango et al., 2013) in experimental settings like the one proposed by Arango and Moxnes (2012). Hence, we study the rationality of individuals' decisions in three different treatments, evaluating the long-term security of supply and the society's welfare.

We use simulation to study the expected market behavior. For Treatment 1, we replicate the analysis made by Arango and Moxnes (2012), which shows cyclical price behavior with increasing amplitude. For Treatment 2, we found cyclical price behavior without increasing amplitude. Finally, for Treatment 3, we found stable electricity price behavior with stable licenses price. In addition, it is noteworthy to point out that in Treatment 3, we found strong tendency to negative licenses prices (subsidies)

The simulations we performed show consistency with the experimental results of Treatment 1, as they show cyclical behavior. For Treatment 2, however, the simulations suggested a reduction in price volatility compared to Treatment 1, which did not correspond to the results of the experiments. The experiments showed no significant reduction in price volatility from Treatment 1 to Treatment 2, along with a reduction of the average Economic Surplus and an increase of the standard deviation of the Economic surplus, making this treatment the less profitable and the less stable of the three from the society's welfare point of view. For Treatment 3, our simulations suggested variations in licenses' price. The experimental results confirmed the electricity price stability and some variations in the licenses' price. This treatment reports a statistically equal average Economic Surplus to Treatment 1 and the lowest standard deviation of the Economic Surplus, which makes this treatment the most profitable (along with Treatment 1) and the most stable.

We conclude that these pilot experiments shows initial indications about the study of Procurement for long strategic reserve planning and Centralized auctioning for capacity contracts. These pilot experiments provides a starting point to run formal experiments to test out our hypotheses.

9.2. Implications:

We compared three scenarios: a deregulated electricity market with no capacity mechanism (Treatment 1), a second market with a regulatory firm to test the Procurement for long strategic reserve planning mechanism (Treatment 2), and a third market with an auctions system to test the Centralised auctioning for capacity contracts mechanism.

Our analysis is based only on two pilot experiments, which means that the results are not conclusive but provides some indications. Results show tendency in the sense that the introduction of a regulatory firm (Procurement for long strategic reserve planning mechanism) does not seem to have beneficial effects on the market's long-term security of supply. First, we found no evidence of cycle-mitigation potential in this mechanism. Furthermore, we found that, regarding the Economic Surplus of the market, the inclusion of a regulator could reduce its expected value and increase its volatility. These results appear to be counterintuitive since one may be tempted to think that having a firm that secures part of a capacity (price) goal should have a stabilizing effect (de Vries, 2004; Fignon and Pignon, 2008). In fact, this train of thought is supported by the simulations we did. Further variations in the settings to test this mechanism may present different results.

We also found that the introduction of an auctions system seems to offer beneficial effects in the long-term security of supply to the electricity markets. First, the market structure we considered sets a fixed capacity (and thus, fixes the price) for the market, which automatically eliminates any possibility of cycles. Second, we found that this treatment does not seem to present any significant effect on the average Economic Surplus, but it does seem to stabilize its value, that is, the market keeps its profitability but with greater stability. These results suggest that the cost to the government is outweighed by the market's improvements in stability in the long term.

The internal validity of the experiment is ensured, since cause (players' decisions), settings (regulatory firm, auction system) and effect (price behavior) can be isolated and examined. Therefore, cause and effect relationships can be established. The external validity of the experiment is greatly influenced by the fact that we do not have conclusive results, since our results are only indicatives obtained from pilot experiments. However, we make some remarks about this point:

First, the results obtained in Treatment 3 are consistent with the literature evaluation of the mechanism Centralised auctioning for capacity contracts, since our results show stable electricity price behavior, and preservation of society's welfare (Bidwell, 2005; Cramton and Stoft, 2006). Second, in Treatment 2 we found no consistency between the literature evaluation of the mechanism Procurement for long strategic reserve planning, since we did not find price stabilization potential nor beneficial effects for society's welfare (de Vries, 2004; Meunier and Finon, 2006). In addition, we found that the most market compatible mechanism (Centralized auctioning for capacity contracts) presents better results than the interventionist mechanism (Procurement for long strategic reserve planning) as the literature suggests (de Vries, 2004; Meunier and Finon, 2006; Fignon and Pignon, 2008).

Considering that this is a pilot experiment, our results suggest, that the Centralised auctioning for capacity contracts is a better option than Procurement for long strategic reserve planning for the long-term security of supply, regarding price stabilization and society's welfare. While the first preserves and stabilizes the Economic Surplus, and eliminates cycles, the second does not seem to solve the cycle's occurrence and it seems to reduce and even destabilize the Economic Surplus. However, we must acknowledge the possibility of different results if the Procurement for long strategic reserve planning is tested in a different experimental design (e.g. considering variations in the regulator capacity). Furthermore, in the terms we tested it, Centralised auctioning for capacity contract presents a market-oriented structure because it just sets new of rules for competition. Conversely, in the terms we tested it, Procurement for long strategic reserve planning is an interventionist mechanism, which by definition is not consistent with free competition as a market principle (Fignon and Pignon, 2008).

9.3. Limitations and further research

This thesis presents indicative results obtained from pilot experiments, which means our results are not conclusive. This is both our first limitation and our first work for future research, which means that we should perform the formal experiments.

This work represents an extension of previous experiments (Alcaraz, 2010; Arango and Moxnes, 2012); however, our experimental treatments still have simplifying assumptions. Further research could consider other extensions to increase external validity. For instance, none of our treatments takes into account any dynamic behavior in demand, which could influence the long-term security of supply in a market (Ford, 1999). Further experimental designs may deal with this issue.

Our experimental design also assumes no bankruptcy, that is, individuals can invest regardless of their firms' financial state. This issue poses both theoretical and practical challenges to further experimental designs. On one hand, the possibility of a variable number of individuals (their initial number is reduced as they go bankrupt), implies that the economic model could have a dynamic behavior as the market equilibrium change. On the other hand, one has to define a benchmark for bankruptcy (i.e., individuals with less than a certain amount of experimental money in their firms' bank accounts are bankrupt and, thus, out of the game). Furthermore, this bankruptcy possibility may include also a possibility for individuals to get loans or government incentives. Therefore, further works should consider these financial aspects in order to have more realistic experimental markets.

We did not also consider any issue regarding uncertainty in the experimental markets. Some of the variables in a market have a stochastic behavior (Moxnes, 2012). In our case, for instance, the availability of the resource needed for electricity generation or the price determination itself. The first relates to the possibility of having a generation capacity that is affected by some non-fully predictable event (e.g., the hydrological cycle), while the second refers to lack of correspondence between the production capacity and the price for some reason (e.g., political and economic changes in a country). The presence of uncertainties can influence individuals' behavior, as they make strategic adjustments to their decisions to protect themselves from non-desirable scenarios (Just and Weninger, 1997); hence, further experiments could consider uncertainties to improve the understating of the decisions made by individuals in a more realistic environment.

The consideration of different generation technologies is another feature of realism that is lacking in our experimental design. Generation technologies differ in aspects like construction time, lifetime and economics. The construction time we consider in this experiment (4 years), is fairly close to the construction time of a medium-sized hydro plant, while other technologies have a minor construction time (e.g., fossil power plants) and others have greater construction times (e.g., large-sized hydro plants). This difference in construction times (difference in delays) may have a significant effect in the performance of the system, as previous work has shown that the greater the delays, the greater the instabilities in the market price (Diehl and Sterman, 1995; Arango and Moxnes, 2012). The lifetime also differs from one technology to another (e.g., about 40 years for fossil fuels plants and 100 years for large-sized hydro plants), which can also contribute to different investment behaviors (Arango and Moxnes, 2012). Furthermore, the economics of every generation technology marks a distinctive difference from the others. For instance, events related to the hydrological cycle and the volatile cost of natural gas influence the economics of hydro power plants and gas turbine combined-cycle plants, respectively. Therefore, further experimental designs should consider different generation technologies in order to have more realistic market designs. Finally, our experimental can be adapted to embrace new elements that address these limitations to explore more capacity mechanisms and market scenarios.

Finally, there are some practical concerns about the external validity of our experiment. The real implementation of the two capacity mechanisms studied in this thesis can present differences with our results. For instance, in Treatment 3, what would happen if players could avoid their obligation to build capacity? In Treatment 2, what would happen if the regulator's capacity were expanded? What would happen if the regulator were not controlled by the model but for a human decision-maker? These questions could be address by future research.

10. BIBLIOGRAPHY

Alcaraz, s. 2010. Free competition vs. auctioning of licenses for electricity production. m.phil thesis. System dynamics group, Department of geography, University of Bergen.

Álvarez, k. 2013. Efecto de la introducción de mercados de futuros en la estabilización de ciclos en los precios de commodities mediante experimentos y simulación. Msc thesis. Escuela de sistemas, Universidad nacional de colombia.

Arango, s., Larsen, E.R. 2011. Cycles in deregulated electricity markets: empirical evidence from two decades. Energy policy 39 (5), 2457-2466.

Arango, S., moxnes, E. 2012. Commodity cycles, a function of market complexity?. Extending the cobweb experiment. Journal of economic behavior & organization 84 (1), 321-334.

Arango, S., Castañeda, J.A., Larsen, E.R. 2013. Mothballing in power markets: an experimental study. From regulation to competition. Energy economics 36, 125-134.

Arango, S., Castañeda, J.A., Olaya, Y. 2012. Laboratory experiments in the system dynamics field. System dynamics review 28(1), 94-106

Barker jr., J., Dunn jr., W., Shean, M.K. 1994. Practical considerations in restructuring of the electricity supply industries. at: m. einhorn (ed.). From regulation to competition: new frontiers in electricity markets. Editorial kluwer, 7.

Barroso, L.A., Bezerra, B., Rosenblatt, J., Guimarães, A., Pereira, M.V. 2006. Auctions of contracts and energy call options to ensure supply adequacy in the second stage of the brazilian power sector reform. IEEE PES general meeting 2006, Montreal, Canada.

Battle, C., River, C., Vasquez, C., Perez-Arriaga, I. 2007. A regulatory mechanism to enhance security of supply in the spanish wholesale electricity market. Energy policy 35 (9), 4545-4554.

Bidwell, M., Henney, A. 2004. Will the new electricity trading arrangements ensure generation adequacy? The electricity journal 17 (7), 15–38.

Bompard, E., Wene, l., Napoli, R., Jiang, X. 2010. A supply function model for representing the strategic bidding of the producers in constrained electricity markets. Int j electr power energy syst; 6(32), 678–87

Bouttes, j.p. 2005. sécurité d'approvisionnements et investissements dans l'électricité. Revue de l'energie.

Brennan, M.J., Schwartz, E.S. 1985. Evaluating natural resource investments. Journal of business 58 (2), 135–157.

Bunn, D.W., Larsen, E.R. 1992. Sensitivity of reserve margin to factors influencing investment behavior in the electricity market of England and wales. Energy policy 20(5), 420-429.

Bunn, D.W., Larsen, E.R. 1994. Assessment of the uncertainty in future UK electricity investment using an industry simulation model. Utilities policy 4 (3), 229–236.

Bidwell, M. 2005. Reliability options. A market-oriented approach to long-term adequacy. The electricity journal 18 (5), 11e25.

Cantor, D.E., Katok, E. 2012. Production smoothing in a serial supply chain: a laboratory investigation. Transportation research part e: logistics and transportation review 48 (4), 781–794.

Cámac, D., Ormeño, V., Espinoza, l. 18-22 June 2006. Assuring the efficient development of electricity generation in Peru. Power engineering society general meeting, 2006. IEEE, p. 5.

CDEC-SIC. 2009. Operation statistics (several years). Central interconnected electric system/load economic dispatch center. Santiago, Chile. Available at /https://www.cdec-sic.cl/datos/anuario2009_ing.pdfs. Last visit in November 2009

ceer (council of european energy regulators), 2006. Survey of capacity support mechanisms in the energy community. Ref: c06-see-15-06, 6.

Cook, T.D., Campbell, D.T. 1979. Quasi-experimentation: design & analysis issues for field settings. Boston: Houghton Mifflin company.

Cramton, P., Stoft, S. 2006. The convergence of market designs for adequate generating capacity, with special attention to the caiso's resource adequacy problem, white paper for the electricity oversight board, March.

Creti, a., Fabra, n. 2004. Capacity markets for electricity communication to the colloquium efficiency on electricity markets, toulouse, december 2003. Journal of regulatory economics.

de vries, l.J., Hakvoort, R.A. 2004. The question of generation adequacy in liberalized electricity markets. Working papers no. 120.2004, fondazione eni enrico mattei.

de vries, l., Heijnen, P. 2008. The impact of electricity market design upon investment under uncertainty: the effectiveness of capacity mechanisms. Utilities policy 16 (3), 215–227.

Diehl, E., Sterman, J.D. 1995. Effects of feedback complexity on dynamic decision-making. Organizational behavior and human decision processes 62(2), 198-215.

Dyner, I., Larsen, E.R. 2001. From planning to strategy in the electricity industry, energy policy 29(13), 1145–54.

Dyner, I., Franco, C.J., Arango, S. 2008. El mercado mayorista de electricidad colombiano. Colección facultad de minas 120 años.

Entsoe. 2009. Nordic annual report (several years). European network of transmission system operators for electricity. Available at /http://www.entsoe.eu//index.php?id=66s. Last visit November 2009.

Finon, D., Pignon, V. 2008. Electricity and long-term capacity adequacy: the quest for regulatory mechanism compatible with electricity market. Utilities policy, 16, 143 – 158.

Ford, A. 1999. Cycles in competitive electricity markets. Energy policy 27, 637–658.

Ford, A. 2001. Waiting for the boom: a simulation study of power plant construction in California. Energy policy 29(11), 847-869.

Friedman, D., Cassar, A. 2004. Economics lab: an intensive course in experimental economics. London: Routledge.

Friedman, D., Sunder, S. 1994. Experimental methods: a primer for economists. Cambridge: Cambridge university press.

Fu, S., Ren, Y. 2011. A motivating mitigation mechanism for generators on condition of coordinated regulation of emission and electricity market. International journal of electrical power & energy systems 33 (5), 1151–1160.

Gary, S., Larsen, E.R. 2000. Improving firm performance in out-of-equilibrium deregulated markets using feedback simulation models. Energy policy 28(12): 845-855.

Green, R. 2006. Investments in generation capacity. In: lévêque, f. (ed.), competitive electricity markets and sustainability. Edward Elgar, Cheltenham, pp. 21–53

Guala, F. 2002. On the scope of experiments in economics: comments on siakantaris. Cambridge Journal of economics, 26, pp.261-267.

Guala, F. 2005. The methodology of experimental economics. Cambridge: Cambridge University press.

Jacquard, M. 1995. Oscillating currents, the changing rationale for government interventions in the electricity industry. Energy policy, 23(7), 579-592.

Hasani, M., and Hosseini, S.H. 2011. Dynamic assessment of capacity investment in electricity market considering complementary capacity mechanisms. Energy 277 – 293.

Huck, S. 2004. Oligopoly. D Friedman and a Cassar (eds.), economics lab: an intensive course in experimental economics. London: Routledge.

Jiménez, M., miller l.m. 2010. Why a trade-off? The relationship between the external and internal validity of experiments. theoria, 25 (69), 301-321.

Joskow, P. 2006, competitive electricity markets and investment in new generating capacity, ceepr-mit, working paper 06 e009 wp, april.

Joskow, P. 2008. Lessons learned from electricity market liberalization. The energy journal, special issue on the future of electricity, papers in honor of David Newbery, 9–42.

Just R.E., Weninger, Q. 1997. An analysis of transition from limited entry to transferablequota: non-marshaling principles for fisheries management. Natural resource modeling 10, 53–83.

Kadoka, T., Sasaki, T., Ihara, S., Larose, E., Sanford, M., Graham, A.K., Stephens, C.A., Eubanks, C.K. 2005. Utilizing system dynamics modelling to examine impact of deregulation on generation capacity growth. Proceedings of the IEEE 93(11), 2060-2069.

Kleinmuntz, D.N. 1993. Information processing and misperceptions of the implications of feedback in dynamic decision-making. System dynamics review 9(3), 223-237.

Krapels, E., Stagliano, V., 1996. A milestone year: power in the commodity markets. Fortnightly 134(10), 32-36.

IEA. 1999. Electricity market reform: an IEA handbook. Paris: organization for economic cooperation and development.

IEA. 2002. Security of supply in electricity markets: evidence and policy issues. Paris: organization for economic co-operation and development.

IEA. 2003. Power generation investment in electricity markets competition in electricity markets. OECD/IEA, Paris, France, 104

IEA. 2007. Tackling investment challenges in power generation in IEA countries. OECD/IEA, Paris, France, 210.

Larsen, E.R., Bunn, D.W., 1999. Deregulation in electricity: understanding strategic and regulatory risk. The journal of the operational research society 50(4), system dynamics for policy, strategy and management education, 337-344.

Larsen, E.R., Arango, S. 2013. Thinking about the future: System Dynamics and the process of deregulation. Energy policy modelling in the 21 century.

Liu, Z., Zhang, X., Lieu, J. 2010. Design of the incentive mechanism in electricity auction market based on the signaling game theory. Energy economics 35 (35), 1813–1819.

Meunier, G., Finon, D., 2006. Market power in electricity markets, suboptimal investment and iso procurement, presentation a` la 26 usaee/iaee conference.

Moreno, R., Barroso, I.A., Rudnick, H., Mocarquer, S., Bezerra, M. 2007. Auction approaches to ensure resource adequacy in electricity markets, submitted to IEEE transactions on power systems.

Moreno, R., Rudnick, H., Barroso, l.A. 2008. First price and second price auction modelling for energy contracts in latin american electricity markets", 16th power systems computation conference, July, 2008, Glasgow, Scotland

Moxnes, E. 1998a. Not only the tragedy of the commons: misperceptions of bioeconomics. Management science 44(9), 1234-1248.

Moxnes, E. 1998b. Overexploitation of renewable resources: the role of misperceptions. Journal of economic behavior and organization 37(1), 107-127.

Moxnes, E. 2004. Misperceptions of basic dynamics: the case of renewable resource management. System Dynamics review 20(2), 139-162.

Moxnes, E. 2012. Individual transferable quotas versus auctioned seasonal quotas: an experimental investigation. Marine policy 36, 339–349.

Moxnes, E., Jensen, l. 2009. Drunker than intended: misperceptions and information treatments. Drug and alcohol dependence 105, 63–70.

Moxnes, E., Saysel, A.K. 2009. Misperceptions of global climate change: information policies. Climatic change 93, 15–37.

Muth, J.F. 1961. Rational expectations and the theory of price movements. Econometrica 29(3), 315-335.

Newbery, D. 1995. Power markets and market power. The energy journal 16 (3), 41–66.

Olsina, F., Garcés, F., Haubrich, H.J. 2006. Modeling long-term dynamics of electricity markets. Energy policy 34(12), 1411-1433

Oren, S. 2005. Generation adequacy via call options: safe passage to the Promised Land, university of California energy institute, working paper UCEI, EPE-016.

Perez-Arriaga, I. 2001. Long-term reliability of generation: a critical review of issues and alternative options. Working paper iit-00-0981t, instituto de investigation tecnologica, Commillas University, Madrid.

Ponzo, R., Dyner,I., Arango, S., Larsen, E.R. 2010. Regulation and development of the argentinean gas market. Energy policy 39, 1070–1079.

Plott, C.R., Smith, V.L. 2008. The handbook of experimental economics results. Amsterdam: north Holland.

Postnote. 2003. Security of electricity supplies. Parliamentary office of science and technology, September 2003, number 203, 4 pp. available at http://www.parliament.uk/post/pn203.pdfs, last visit October 2009

Randers, J., Göluke, U. 2007. Forecasting turning points in shipping freight rates: lessons from 30 years of practical effort. System dynamics review 23 (2), 253–284.

Ricci, H. 2003. Análisis de los ciclos en commodities agrícolas. Bolsa de comercio de rosario (argentina) pp. 117-131.

Roberts, M.J., Spence, M. 1976. Effluent charges and licenses under uncertainty. Journal of public economics 5, 193e208

Roques, F.A. 2008. Market design for generation adequacy: healing causes rather than symptoms. Utilities policy 16 (3), 171–183.

Simon, H.A. 1955. A behavioral model of rational choice. The quarterly journal of economics 69 (1), 99-118.

Simon, H.A. 1979. Rational decision making in business organizations. The American economic review 69(4), 493-513.

Sioshansi, F.P., Pfaffenberger, W. 2006. Electricity market reform, Amsterdam, Elsevier.

Smith, V.L. 1982. Microeconomic systems as an experimental science. The American economic review 72(5), 923-955.

Smith, V.L. 1994. Economics in the laboratory. The journal of economic perspectives 8(1), 113-131.

Sterman, J.D. 1989a. Misperceptions of feedback in dynamic decision-making. Organizational behavior and human decision processes 43(3), 301-335.

Sterman, J.D. 1989b. Modeling managerial behavior: misperceptions of feedback in a dynamic decision making experiment. Management science 35(3), 321-339.

Sterman, J.D. 2000. Business dynamics: systems thinking and modeling for a complex world. Boston, ma: Irwin/McGraw-Hill

Turvey, R. 2003. Ensuring adequate generation capacity. Utilities policy 11, 95e102.

Tversky, A., Kahneman, D., 1974. Judgment under uncertainty: heuristics and biases. Science 185 (4157), 1124-1131.

Van der veen, Reinier, A.C., Abbasy, A., Hakvoort, R.A. 2012. Agent-based analysis of the impact of the imbalance pricing mechanism on market behavior in electricity balancing markets. Energy economics 34 (4) 874–881.

Vásquez, C., Battle, C., Rivier, M., Perez-Arriaga, I. 2003. Security of supply in the Dutch electricity market: the role of reliability options. Report iit-03-0841c, (prepared for the office for energy regulation of the netherlands-dte), Comillas University, iit.

Weitzman, M.L. 1974. Prices vs. Quantities. The review of economic studies 41 (4), 477 e491.

Weidlich, A., Veit, D. 2008. A critical survey of agent-based wholesale electricity market models. Energy economics. 30, 1728 – 1759.

White, A. 2005. Concentrated power. Public utilities fortnightly. Arlington 143 (2), 43–47.

Wolak, F. 2004, what is wrong with capacity markets? Mimeo, Ucei

Zhang, S.H., Fang, Y., Li, Y.Z. 2003. An incentive compatible bid-ding mechanism in power generation markets. Automation of power systems, 27(7), 27–31.

Zou, X. 2009. Double-sided auction mechanism design in electricity based on maximizing social welfare. Energy policy 37 (11), 4231–4239.

Zou, X., Ren, Y. 2007. Auction mechanism design in wholesale electricity market considering impacts of long-term contract. Systems engineering - theory and practice, 27 (8) 118–126.

APPENDIX 1: Equilibria derivation

Treatment 1:

Joint Maximization:

Consider the main equations in this economic model, namely the price equation and the player's profits equation.

$$P_t = A - B * Q_t \qquad (1)$$

$$\pi_{i,j} = \left(P_t - C_{i,j}\right) * q_{i,j} \qquad (2)$$

Since the sum of the players' individual capacities is the total market production Q and we assume that all n players are identical, then we have

$$Q_t = n * q_{i,j} \qquad (3)$$

By replacing (3) in (1) we have

$$P_t = A - B * n * q_{i,j} \qquad (4)$$

Then we replace (4) in (2) and we have

$$\pi_{i,j} = A * q_{i,j} - B * n * q_{i,j}^2 - C_{i,j} * q_{i,j} \quad (5)$$

We now derive (5) with respect to $q_{i,j}$ and equal it to zero, in order to find the maximum value

$$\frac{\partial \pi_{i,j}}{\partial q_{i,j}} = A - 2 * B * n * q_{i,j} - C_{i,j} = 0 \quad (6)$$

We now find the value of $q_{i,j}$ given that A=6, B=0.1, n=5 and $C_{i,j}$=1

$$q_{i,j} = \frac{A - C_{i,j}}{2 * B * n} \quad (7)$$

$$q_{i,j} = \frac{6 - 1}{2 * 0.1 * 5} = 5$$

Since we now have the value of $q_{i,j}$, we can find the values for Q_t and P, by replacing the value of $q_{i,j}$ in (3) to obtain the value of Q_t and then replace this value in (1) to find P

$$Q_t = 5 * 5 = 25$$

$$P_t = 6 - 0.1 * 25 = 3.5$$

Cournot-Nash:

In this equilibrium, we follow the same process we followed in Joint Maximization. However, we now assume that each player maximize its own benefits while the other players' benefits remain constant. This implies that the marginal change in the total market capacity is equal to the change of the player that is making profit maximization. In mathematical terms, the previous statements can be described as:

$$\frac{\partial Q_t}{\partial q_{i,t}} = 1 \quad (1)$$

The starting point is the same as the Joint Maximization equilibrium with the price and profits equations. Like the previous case, we have the following equation:

$$\pi_{i,j} = A * q_{i,j} - B * n * q_{i,j}^2 - C_{i,j} * q_{i,j} \quad (2)$$

We also know that:

$$Q_t = n * q_{i,j} \quad (3)$$

We can rewrite (2) as:

$$\pi_{i,j} = A * q_{i,j} - B * q_{i,j} * Q_t - C_{i,j} * q_{i,j} \quad (4)$$

Since we have the assumption stated in (1), the derivation is:

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = A - \left(B * q_{i,j} * \frac{\partial Q_t}{\partial q_{i,j}} + Q_t * B\right) - C_{i,j} = 0 \ (5)$$

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = A - \left(B * q_{i,j} + Q_t * B\right) - C_{i,j} = 0 (6)$$

By replacing (3) in (6), we have:

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = A - \left(B * q_{i,j} + n * q_{i,j} * B\right) - C_{i,j} = 0 \ (6)$$

We then find the value for $q_{i,j}$, and then we find the value for Q_t and

$$q_{i,j} = \frac{A - C_{i,j}}{B * (n+1)} \quad (7)$$

$$q_{i,j} = \frac{6-1}{0.1 * (5+1)} = 8.33$$

$$Q_t = 8.33 * 5 = 41.66$$

$$P_t = 6 - 0.1 * 41.66 = 1.83$$

Perfect Competition:

This equilibrium is achieved when the price is equal to the marginal cost, that is, when the profits are theoretically zero. This theoretical zero does not mean that the firms actually receive zero profits; rather it means that the firms receive the normal economic profit (no extra gains).

Margin cost = 1

Price = Margin cost

$$P_t = A - B * Q_t = Margin\ cost$$

$$Q_t = \frac{A - Margin\ cost}{B}$$

$$Q_t = \frac{6-1}{0.1} = 50$$

Now that we know the value for Q_t that makes $P_t = 1$ we proceed to find the values for P_t and $q_{i,j}$

$$q_{i,j} = \frac{50}{5} = 10$$

Treatment 2:

Joint Maximization:

In this treatment, we based our derivations in the basic scheme of Treatment 1, but we now have to consider the regulatory firm. Therefore, we start with the same two equations of the previous treatment and the regulator contribution (RC = Regulator Contribution) to the total production capacity of the market:

$$P_t = A - B * Q_t \qquad (1)$$

$$\pi_{i,j} = \left(P_t - C_{i,j}\right) * q_{i,j} \qquad (2)$$

$$Q_t = n * q_{i,j} + RC \qquad (3)$$

Since we know that the RC value depends on $n * q_{i,j}$, we can form 3 intervals for this value:

$$If\ n * q_{i,j} \leq 40, \qquad RC = 10$$

$$If\ 40 > n * q_{i,j} < 50, \qquad RC = 50 - n * q_{i,j}$$

$$If\ n * q_{i,j} \geq 50, \qquad RC = 0$$

By examining these 3 intervals, we can conclude that the third interval does not have the Joint Maximization equilibrium since the players' profits are 0 or negative in it. We can also conclude that since the price ranges from 2 to 0 in the second interval, this one does not have the equilibrium value since the maximum unitary profit in it is 1. Therefore, we know that the equilibrium lies in the first interval, where RC=10. Hence, we take RC as a constant equal to 10.

We replace (3) in (1):

$$P_t = A - B * n * q_{i,j} - B * RC \quad (4)$$

We replace (4) in (2):

$$\pi_{i,j} = A * q_{i,j} - B * n * {q_{i,j}}^2 - RC * q_{i,j} * B - C_{i,j} * q_{i,j} \ (5)$$

Now we derive with respect to $q_{i,j}$ an equal to zero to find the maximum:

$$\frac{\partial \pi_{i,j}}{\partial q_{i,j}} = A - 2 * B * n * q_{i,j} - RC * B - C_{i,j} = 0 \ (6)$$

$$q_{i,j} = \frac{A - RC * B - C_{i,j}}{2 * B * n} \ (7)$$

Now we find the values of$q_{i,j}$, Q_t and P_t

$$q_{i,j} = \frac{6 - 10 * 0.1 - 1}{2 * 0.1 * 5} = 4$$

$$Q_t = 5 * 4 + 10 = 30$$

$$P_t = 6 - 0.1 * 30 = 3$$

Cournot-Nash:

For this equilibrium, we assume that Q_t changes as a result of a maximization process made by one player while the rest of the variables remain constant.

$$\frac{\partial Q_t}{\partial q_{i,t}} = 1 \ (1)$$

Which is the same as saying that, for this equilibrium, the derivation with respect to $q_{i,t}$ is the same as the one obtained with the derivation with respect to Q_t. Therefore, we have:

$$\frac{\partial P_t}{\partial q_{i,t}} = \frac{\partial P_t}{\partial Q_t} = -B \ (2)$$

With the consideration exposed in (2), we proceed to derive the profits equation:

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = P_t * \frac{\partial q_{i,t}}{\partial q_{i,t}} + \frac{\partial P_t}{\partial q_{i,t}} * q_{i,t} - C_{i,j} \ (3)$$

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = P_t - B * q_{i,t} - C_{i,j} = 0 \quad (4)$$

We consider the price equation (5) and the production capacity equation (6):

$$P_t = A - B * Q_t \qquad (5)$$

$$Q_t = n * q_{i,j} + RC \qquad (6)$$

We replace (6) in (5) to replace them in (4)

$$\frac{\partial \pi_{i,j}}{\partial q_{i,t}} = A - B * n * q_{i,j} - RC * B - B * q_{i,j} - C_{i,j} = 0 \ (7)$$

$$q_{i,j} = \frac{A - RC * B - C_{i,j}}{B(n+1)} \quad (8)$$

We now find the value for $q_{i,j}$, Q_t and P_t (we also assume RC=10 for this equilibrium for the margin intervals we explained in Joint Maximization)

$$q_{i,j} = \frac{6 - 10 * 0.1 - 1}{0.1 * (5 + 1)} = 6.66$$

$$Q_t = 5 * 6.66 + 10 = 43.33$$

$$P_t = 6 - 0.1 * 43.33 = 1.67$$

Perfect Competition:

This equilibrium is achieved when the price is equal to the marginal cost, that is, when the profits are theoretically zero. This theoretical zero does not mean that the firms actually receive zero profits; rather it means that the firms receive the normal economic profit (no extra gains).

Margin cost = 1

Price = Margin cost

$$P_t = A - B * Q_t = Margin\ cost$$

$$Q_t = \frac{A - Margin\ cost}{B}$$

$$Q_t = \frac{6 - 1}{0.1} = 50$$

Since Q_t = 50 , $q_{i,j}$ and RC can make infinite combinations that sum 50 we have the following ranges $q_{i,j}$ and RC that could add up to 50 units in combination:

$$q_{i,j} = [8, 10]$$

$$RC = [10, 0]$$

Treatment 3:

Since the market production capacity is fixed in this treatment, there is only one capacity and price scenario which is equivalent to the Perfect Competition equilibrium, that is

$$Q_t = 50$$

$$P_t = 1$$

In this treatment, the players bid in auctions or, in other words, the players compete for a share of the total market production capacity (which is fixed). Therefore, $q_{i,j}$ behaves different for every individual according with the auctions results but always keeping the Perfect Competition equilibrium in the market ($Q_t = 50$ and $P_t = 1$).

To summarize the equilibriums:

	T1		T2		T3	
	Cap	Price	Cap	Price	Cap	Price
JM	25.0	3.50	30.0*	3.00	NA	NA
CN	41.7	1.83	43.3*	1.67	NA	NA
PC	50.0	1.00	50.0*	1.00	50.0	1.00

Market capacity (Cap) and Price for Joint Maximization (JM), Cournot-Nash (CN) and Perfect Competition (PC) equilibria. *In this treatment, a regulator firm intervenes, so the individual investments of the players do not match with the market production (see Appendix 1)

APPENDIX 2: Experimental instructions (in Spanish)

Treatment 1:

INSTRUCCIONES

ADVERTENCIA: NO TOQUE EL COMPUTADOR HASTA QUE SE LE INDIQUE LO CONTRARIO

INTRODUCCIÓN

Bienvenidos. Éste es un experimento de toma de decisiones apoyado por la Vicerrectoría Nacional de Investigación de la Universidad Nacional de Colombia. El caso es un mercado eléctrico desregulado. Las instrucciones son simples y si las sigue cuidadosamente y toma buenas decisiones usted podría ganar una suma de dinero considerable, la cual será entregada en efectivo al final del experimento. Usted va a jugar el rol de un productor de electricidad que vende dicha electricidad 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:

Ganancias = Producción • (Precio – Costos)

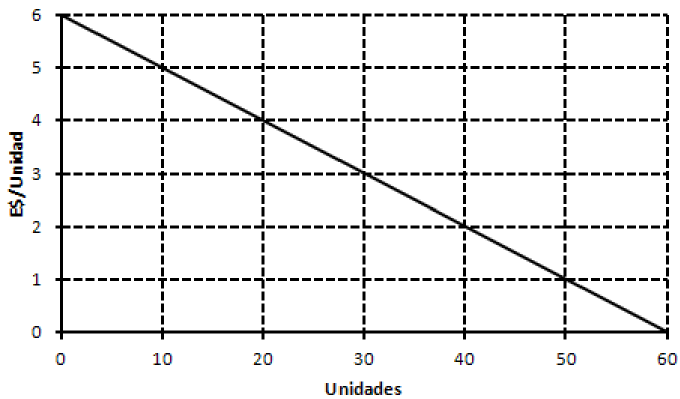
$$\pi_t = q_t \cdot (P_t - C)$$

Donde qt corresponde a su producción en el tiempo t, Pt 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:

$$P_t = 6 - 0.1 * Q_t$$

Donde Q es el suministro total (véase la figura).

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 $45.000.

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!!!

Treatment 2:

INSTRUCCIONES

ADVERTENCIA: ¡No toque el equipo hasta que se le indique!

Bienvenidos. En este juego, usted va a jugar el papel de un productor de electricidad. Año a año, usted decide la cantidad a pedir de nueva capacidad de producción (centrales eléctricas). Su objetivo es maximizar los beneficios para todos los periodos del experimento.

Usted es uno de los cinco productores de electricidad en un mercado y no sabe quiénes son sus competidores ni cómo operan individualmente.

Las centrales eléctricas tienen una vida útil de 16 años y un período de construcción de 4 años, comprendido entre el momento que usted pide una nueva capacidad hasta que las nuevas estaciones comienzan a producir electricidad.

Las ganancias anuales se dan por la producción multiplicada por la diferencia entre el precio y costos Unitarios. Los costos unitarios son constantes e iguales a 1 unidad de dinero experimental.

$$Beneficios = Producción \bullet (Precio - Costos\ unitarios)$$

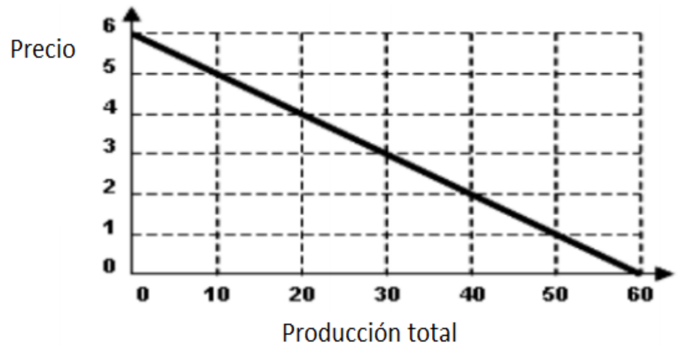
La capacidad de producción de cada jugador no puede ser negativa y debe estar por debajo de 20 unidades. Piense en este límite superior como una regulación gubernamental de mantener un mínimo de competencia en el mercado.

Cada año, la capacidad y la producción de electricidad están dadas por inversiones en años anteriores. La utilización de la capacidad es siempre el 100% para todos los jugadores, es decir que se asume que todas las centrales trabajan siempre a un 100% de su capacidad.

Toda la electricidad producida por el mercado, se consume cada año. Entre más grande sea la producción total, menor será el precio al que se vende la electricidad. La relación exacta viene dada por una curva de demanda y se expresa como:

$$Precio = 6 - 0{,}1 \bullet producción\ total \geq 0$$

El precio no puede ser negativo y no hay crecimiento económico que influya en la demanda y los precios de la electricidad. La relación entre la producción total (eje x) y precios de la electricidad (eje Y) se muestra en la siguiente figura.



Gráfica 1. Relación entre la producción total y el precio.

Cada año se deben tomar decisiones de inversión en nueva capacidad (se puede elegir 0 Unidades). Después de 4 años las nuevas inversiones se suman a la capacidad existente. La capacidad dura durante 16 años y se reduce automáticamente a medida que se van desechando las centrales antiguas. Por otra parte, se requiere que usted escriba el precio que espera para el año siguiente.

Además de los otros participantes, usted interactuará con un regulador del mercado, operado el computador. Este regulador cuenta con una capacidad máxima de 10 unidades e invertirá si detecta que la capacidad total del mercado va a ser menor a 50 unidades.

Al comenzar el experimento, los anteriores encargados de las empresas, han invertido una cantidad constante de 0.6875 unidades / año. Las 5 empresas de los jugadores son iguales, con los mismos costos unitarios y la misma capacidad inicial. El mercado comienza con capacidad inicial de 11 unidades para una capacidad total de mercado de 55 unidades. En consecuencia, el precio es igual 0.5 (dinero experimental) y los beneficios iniciales son iguales a -0.5.

TAREAS DEL EXPERIMENTO

TENGA CUIDADO DE NO PRESIONAR "aceptar las decisiones" a menos que realmente así lo quiera.

Después de haber pulsado "aceptar las decisiones", su decisión para un año en particular ya no puede ser cambiada.

1. Mire la información disponible para la empresa y el mercado.

2. Haga su decisión de inversión y escriba en el cuadro de decisión. Tenga en cuenta, que tiene que tomar una decisión activa cada año. Si no escribe nada en el cuadro de decisión, la decisión será la misma que el año anterior debido a que su decisión de inversión anterior no se borra automáticamente. El programa no le permite elegir inversiones negativas o inversiones que excedan la capacidad máxima.

3. Escriba su inversión en la hoja de papel asignada.

4. Pulse "aceptar las decisiones".

5. Espere hasta que todos los participantes del mercado han tomado sus decisiones para el año en curso y comenzar en el punto 1 de nuevo, cuando la información para la toma de decisiones para el próximo año se convierte en disponible.

El juego continuará hasta que se detenga por sí mismo en algún año futuro desconocido.

NOTA: De acuerdo con el propósito del experimento, se requiere que usted no comparta ningún tipo de información (verbal, escrita, gestos, etc.) con los demás participantes. Por favor respete estas reglas, ya que son importantes para el valor científico del experimento.

Si lo requiere puede hacer preguntas aclaratorias al personal encargado del experimento.

¡Muchas gracias por participar en este juego y de lo mejor de usted!

Treatment 3:

INSTRUCCIONES

PRECAUCIÓN: ¡No toque el equipo hasta que se le indique!

En este juego, Usted va a jugar el papel de un productor de electricidad. Cada año, Usted decide cuanta capacidad nueva quiere ordenar (centrales eléctricas). Las órdenes se hacen por medio de ofertas en una subasta de licencias para construir nueva capacidad.

Su objetivo es maximizar sus beneficios acumulados. Usted es uno de los cinco productores de electricidad en un mercado y no sabe quiénes son sus competidores, ni cómo se desempeñan individualmente. Las centrales eléctricas tienen una vida útil 16 años y tardan 4 años en construirse, es decir, si Usted decide construir una central hoy, dispondrá de ella dentro de 4 años y le durará 16 años a partir de ese momento. Las ganancias anuales están dadas por la producción multiplicada por la diferencia entre el precio y los costos unitarios, menos el número de nuevas licencias adquiridas multiplicadas por su precio.

$$Ganancias = Prod * (Precio - Costos\ unit) -* Nuevas\ licencias * \ Precio\ licencia$$

Los costos unitarios son constantes e iguales a 1 (dinero experimental/unidad). Las nuevas licencias reducen los beneficios si la subasta genera un precio positivo para las licencias. Si la subasta genera un precio negativo para las licencias, los beneficios aumentarán. Piense en este último caso como si el gobierno estuviese subsidiando licencias.

La capacidad de cada jugador no puede ser negativa y debe estar por debajo de 20 unidades. Piense en este límite superior como una regulación gubernamental para mantener un mínimo de competencia en el mercado. Cada año, la capacidad para producir electricidad está dada por licencias entregadas en años anteriores. La utilización de la capacidad es siempre el 100% para todos los jugadores y toda la electricidad producida por los cinco productores se consume cada año.

El gobierno determina la cantidad total de nuevas licencias cada año. La cantidad es configurada de tal manera que cada año el total de nuevas licencias sea igual al total de la capacidad que se ha vuelto obsoleta. Esto significa que la capacidad total en el mercado se mantiene constante en el tiempo. Puesto que suponemos que no hay crecimiento de la demanda a través del tiempo, el precio de la electricidad también se quedará constante e igual a 1 (dinero experimental/unidad). Esto significa que las ganancias anuales sólo dependen del número y precio de las nuevas licencias.

Cada año se subastan nuevas licencias. Esto se hace mediante una gráfica de oferta donde se especifica el número de nuevas licencias que le gustaría recibir para diferentes precios. Usted puede manipular la gráfica moviendo el cursor sobre la gráfica, haciendo clic y arrastrando. Los precios de las licencias varían entre valores negativos (subsidios) y valores positivos. La gráfica de oferta debe ser definida de tal manera que usted pide menos licencias a medida que el precio aumenta y su oferta por un precio de 2.4 debe ser cero. Si estos requisitos no se cumplen, el programa le pedirá que corrija la gráfica.

Cada año, el gobierno toma todas las gráficas de oferta y asigna nuevas licencias de manera que la cantidad total de nuevas licencias sea igual a la cantidad de capacidad que se vuelve obsoleta. Todos los jugadores terminan pagando (o recibiendo) el mismo precio (o subsidios) por las nuevas licencias. Cada jugador recibe la cantidad de nuevas licencias que él o ella ha especificado por el precio de equilibrio resultante. Nuevas Licencias conducen automáticamente a pedidos por nueva capacidad. Después de cuatro años, las nuevas licencias se suman a la capacidad existente. La capacidad dura durante dieciséis años y es reduce automáticamente cuando se desechan las centrales antiguas.

Los gerentes anteriores de su empresa han recibido nuevas licencias y han invertido una cantidad constante de 0.625 unidades por año, durante mucho tiempo. Las 5 empresas son iguales, con los mismos costos unitarios y la misma capacidad inicial. El mercado comienza con una capacidad total inicial de 10 unidades para cada empresa y una capacidad total de mercado de 50 unidades.

TENGA CUIDADO DE NO PRESIONAR "aceptar las decisiones" a menos que realmente lo desee. Después de haber pulsado "aceptar las decisiones", su decisión para ese año en particular ya no puede ser cambiada.

1. Mire la información disponible para la empresa y el mercado.

2. Dibuje con el cursor su gráfica de oferta. El programa no permite que pida más cantidad cuando el precio aumenta (error lógico), ni que pida una cantidad mayor a cero cuando el precio es 2.4 (precio máximo). Tenga en cuenta que tiene que tomar una decisión activa cada año. Si no

realiza ningún cambio en la gráfica de oferta, su decisión se tomará como si fuera igual que el año anterior, ya que su gráfica de oferta anterior no es borrada automáticamente.

3. Pulse "aceptar las decisiones".

4. Espere hasta que todos los participantes del mercado hayan tomado sus decisiones de oferta para el año en curso y recibir información de las ofertas el próximo año. Escriba su número de licencias asignadas en la hoja de papel de reporte.

5. Comience en el punto 1 de nuevo. El juego continuará hasta que se detenga por sí mismo en algún año futuro desconocido.

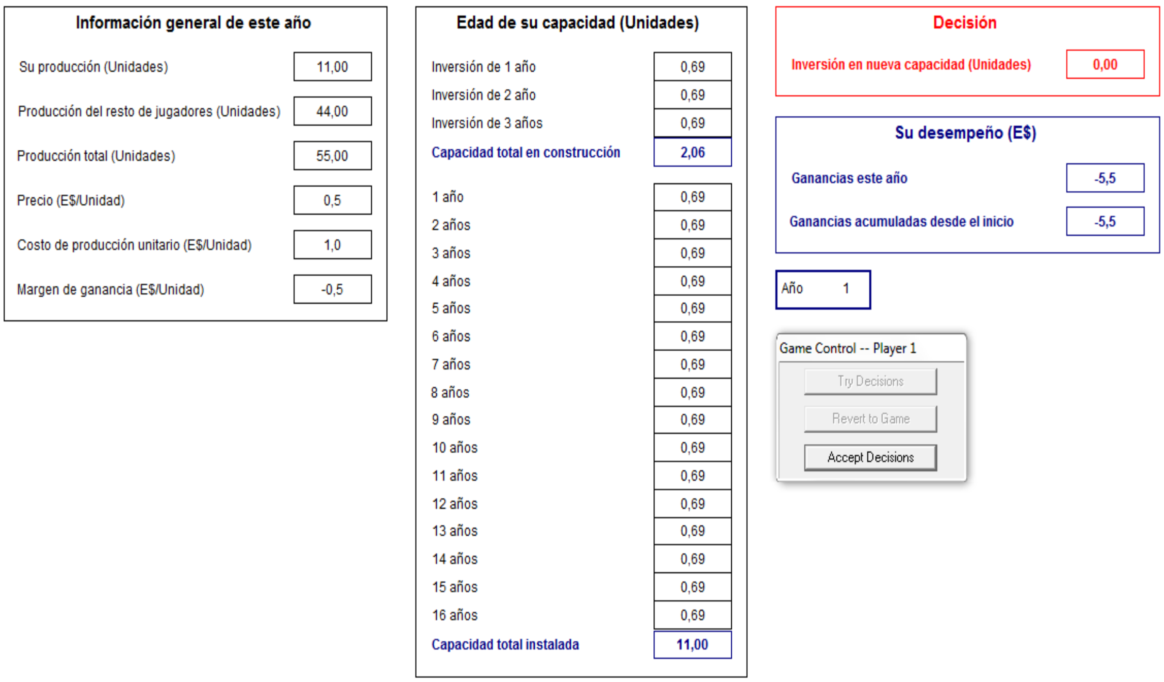
NOTA

De acuerdo con el propósito del experimento, se requiere que usted no comparte ningún tipo de información (verbal, escrito, gestos, etc.) Por favor respeta estas reglas, ya que son importantes para el valor científico del experimento. Usted puede pedir aclaración preguntas.

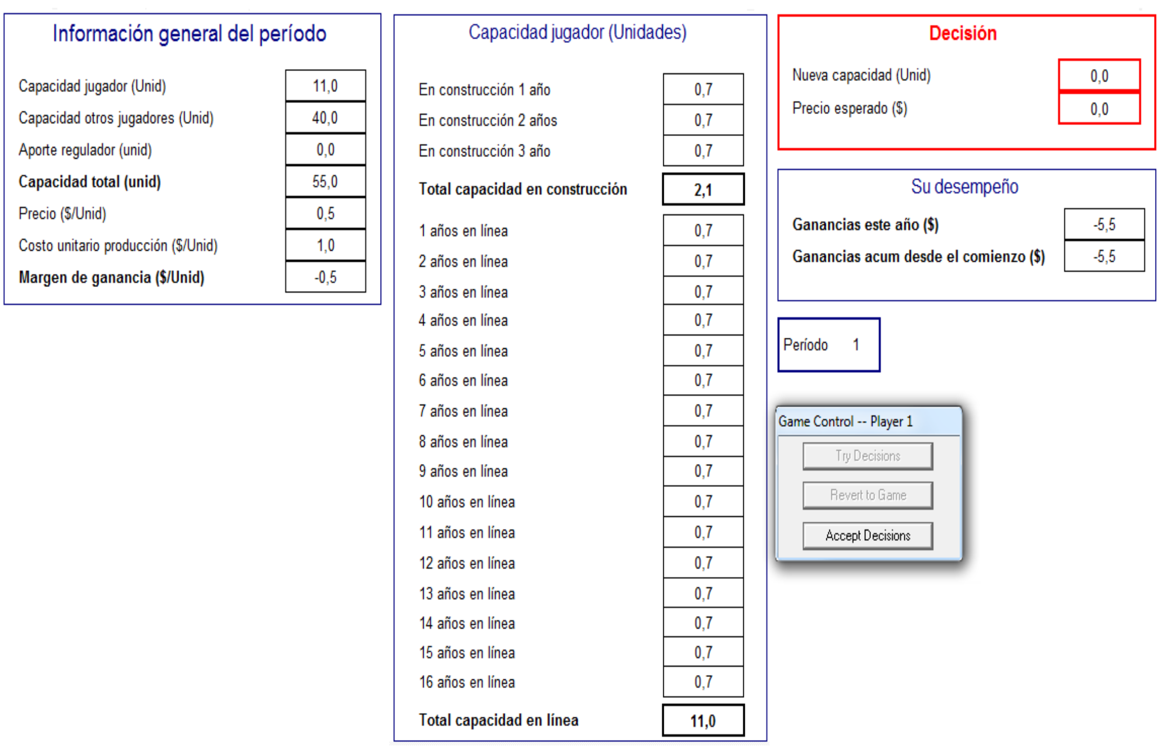
¡Gracias por participar en este juego y lo mejor de Usted!

APPENDIX 3: Software interfaces (in Spanish)

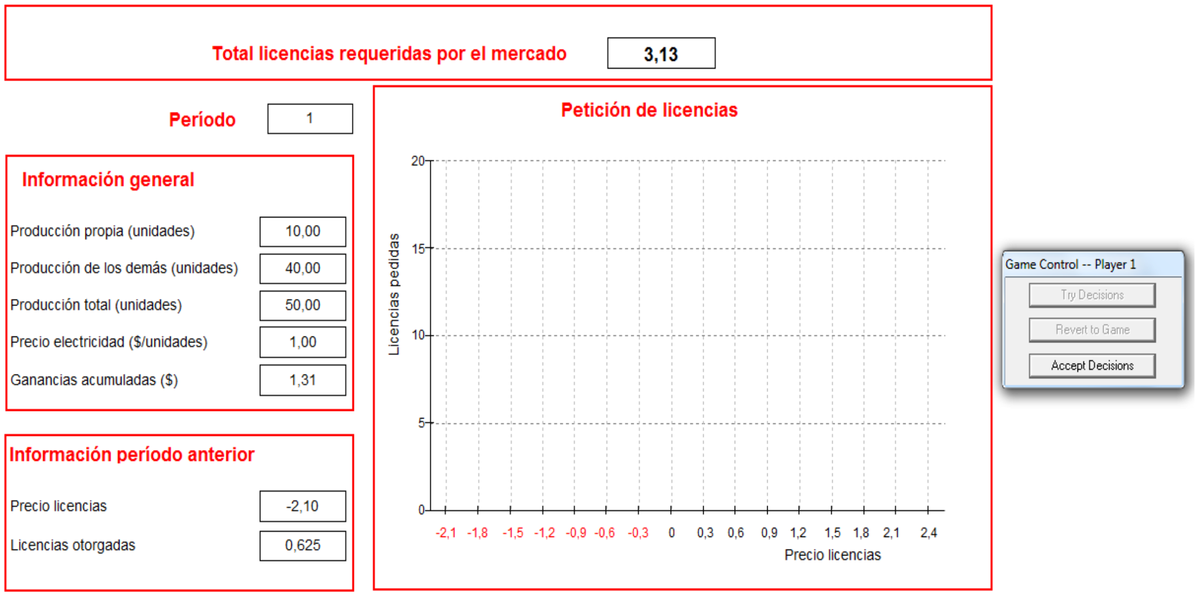
Treatment 1:



Treatment 2:



Treatment 3:


Total licencias requeridas por el mercado
3,13
Período
1
Información general
Producción propia (unidades)
10,00
Producción de los demás (unidades)
40,00
Producción total (unidades)
50,00
Precio electricidad ($/unidades)
1,00
Ganancias acumuladas ($)
1,31
Información período anterior
Precio licencias
-2,10
Licencias otorgadas
0,625
Petición de licencias
Licencias pedidas
20
15
10
5
0
-2,1 -1,8 -1,5 -1,2 -0,9 -0,6 -0,3 0 0,3 0,6 0,9 1,2 1,5 1,8 2,1 2,4
Precio licencias
Game Control -- Player 1
Try Decisions
Revert to Game
Accept Decisions