Price Cap or Price Spike?

An Experimental Investigation of the electricity market

Elforsk rapport 13:72

Chloé Le Coq

December 2013

ELFORSK

Price Cap or Price Spike?

An Experimental Investigation of the electricity market

Elforsk rapport 13:72

Chloé Le Coq

December 2013

Some words from Market Design

The Market Design research programme has been operating for more than 10 years. Over the time the focus has shifted from the national to the Nordic and, in certain cases, to the European level. This emphasis will continue over the next three years, with the European perspective dominating.

In this report, Chloé Le Coq presents the results from a laboratory experiment, which was designed to test the efficiency properties of price caps on wholesale electricity markets. A total of 94 students participated in the experiment, which was conducted at the University of Nottingham as well as at the New Economic School in Moscow. In addition, 28 professionals directly involved in the electricity market also participated in our experiment. The main finding is that a price-cap regulation has an impact not only on market prices but also on market performance.

More information about the Market Design Research program, finished reports and conference documentation can be found at www.marketdesign.se.

Johan Linnarsson,
Secretary of the Market Design programme

Stockholm, December 2013

Preface

The primary aim of this project is to determine whether or not price-cap regulation reduces the risk of price spikes. The project's purpose is twofold: (i) to provide empirical evidence on the effect of price caps in a controlled laboratory market, and (ii) to create an interactive tool making it possible for electricity market participants to analyze their particular market.

These turned out to be two very challenging goals and I wish to extend my gratitude to all of the people who have been involved in the various stages of this project.

First, I would like to begin by saying that this report is based upon an ongoing study I am conducting together with Henrik Orzen from the University of Mannheim, in which we examine how market design, specifically in electricity markets, impacts competition.

Moreover, I have greatly benefited from many discussions with Peter Fritz of Sweco, Pär Holmberg from IFN and Magnus Thorstensson from Svensk Energi, who acted as members of my reference group for the Market Design program. I also had many interesting discussions with electricity market actors and I would like to thank them all, in particular those who participated in the experimental sessions. I would also like to thank Roman Bobilev and Kristaps Donzon for their work as research assistants.

Finally, I most gratefully acknowledge the financial support given by Elforsk and Konkurrensverket making this research possible.

Sammanfattning

Pristak kan såväl motverka höga och volatila priser som hämma investeringsincitamenten. Denna rapport presenterar resultat från ett elmarknadsexperiment som testar effekterna av pristak utifrån ett samhällsekonomiskt perspektiv.

Verkliga elmarknader inspirerade experimentets utformning. Fyra subjekt representerade elproducenter som konkurrerade i upprepade auktioner där efterfrågan var helt oelastisk och volatil. Subjekten tog två typer av beslut. Först bestämde de hur många kapacitetsenheter som skulle vara tillgängliga på marknaden. Därefter lämnade de vid upprepade tillfällen utbudsfunktioner som angav hur många enheter de var villiga att leverera till ett visst pris. Subjekten deltog antingen i en behandling med ett lågt eller ett högt pristak och var tvungna att erbjuda priser lägre än pristaket. De hade dock ingen skyldighet att producera med full kapacitet. Deltagarna var studenter men även fackmän verksamma inom elbranschen.

Den främsta slutsatsen är att pristaksregleringar inte enbart påverkar marknadspriserna utan även marknadens funktionssätt. Ett högt pristak förbättrar resursallokeringen (och därmed energiförsörjningssäkerheten) men hämmar produktionseffektiviteten (kostnaderna minimeras inte). Givet jämförbara marknadsvillkor, blev dessutom marknadspriset oftare lika med pristaket i behandlingen med ett lågt pristak. Ökningen i pristaket innebar alltså inte att marknadspriserna ökade fullt lika mycket.

Summary

Price cap are one of the regulatory tools to attain low and non-volatile prices, yet they may inhibit adequate investment levels. This report presents the results from a laboratory experiment, which was designed to test the efficiency properties of price caps on wholesale electricity markets.

Several "real world" features of the electricity market inspire our experimental design. In our setup, four subjects representing electricity generators, interact in repeated multi-unit auctions where they compete as suppliers. The demand is perfectly inelastic and volatile. Our subjects must make two types of decisions. Initially, they must decide upon a total capacity to make available to the market. Then they submit repeatedly multi-step supply functions, i.e. schedules of quantities and prices specifying how much they are willing to supply for a given price. They cannot offer their units above a maximum price, exogenously given in the experiment. On the other hand there is no obligation to produce at full capacity. Subjects participate in different treatments with different price caps. Moreover the participants were students but also professionals working in the electricity industry.

Our main finding is that price-cap regulation has an impact not only on market prices but also on market performance. Imposing a relatively high price cap improves allocative efficiency (i.e. energy supply security) but reduces productive efficiency (costs are not minimized). Moreover we find that the price cap, for similar market conditions, is reached more often with relatively low price cap level. We conclude therefore that an increase in price cap does not fully translate into a one to one increase in market prices.

Innehåll

1 Why are we looking at a price-cap regulation?

This research project comprises experimental investigations in the laboratory of the electricity market. The aim of this analysis is to better understand the efficiency properties of price caps. In particular, we focus on the fact that price-cap regulation may provide low and non-volatile prices yet curtail adequate investment levels. Choosing between price spikes and a price cap is therefore a key issue for electricity market design as well as for many other types of markets.

Before proceeding to the core of the report, which includes methods and results, we will briefly discuss the reasoning behind why we are looking into price-cap regulation.

Firstly, price-cap regulation is a well spread phenomenon even in electricity markets. The fact that price spikes are heavily debated in the media is perhaps one of the main reasons for price-cap regulation. Such regulation most often applies to a specific market such as retail, transmission or wholesale. Moreover, the exact formulae and timing of the price-cap regulation differ across markets. In this report, we focus on the price-cap regulation applied in wholesale markets.

Secondly, there is a clear trade-off between price spikes and price caps. Policymakers have always stressed the importance of creating incentives for adequate investment in electricity generation yet also require low, non-volatile prices. Price cap is a regulatory tool used to achieve the latter of these objectives, however, it may curtail adequate investment levels. Without regulatory intervention, adequate market investment levels are reached only as a direct result of price spikes. Price spikes may be deemed efficient, as their occurrence is a sign of scarcity and signal that generation capacity is in short supply, thereby encouraging investments.

Thirdly, despite the extensive use of price-cap regulation in the electricity sector, the literature on this topic is scarce. The efficiency properties of electricity market design can be studied in different ways.

The theoretical approach has mainly focused on the strategic behaviour of the generators in the wholesale electricity market. (For a recent overview see Genc and Reynolds, 2011 or Frutos and Fabra, 2012). The majority of these studies assume a market reserve price. This literature usually argues that a maximum price, per se, impacts the market price’s level. With the exception of Fabra, von der Fehr and de Frutos, (2011) and Holmberg and Newbery, (2010), this literature does not discuss whether or not a price cap impacts upon market efficiency.

As far as we are aware, there is no empirical study on this issue for the electricity market. An empirical analysis of the efficiency properties of a price cap would require actual data on firms’ cost structure. The difficulty to obtain such data may explain the absence of an empirical study.

Electricity market design has been studied using the experimental approach but we are aware of only two studies on price-cap scheme. These studies focus primarily on how price caps differ according to the generators, (Kiesling and Wilson, 2007) and on non-binding price caps, (Vossler et al., 2009). Similar to the pioneer study by Isaac and Plott, (1981) but focusing on electricity markets, this report considers different price cap levels, which are applicable to all market participants. Unlike the previous studies, we investigate the effect of price caps in the context of uniform-price auctions where the subjects choose their capacities and subsequently compete in prices. Under these conditions, the fact that each generator may become pivotal – each generator's capacity is required to meet the demand – turns out to be crucial for the outcome. (See also Brandts et al., 2013, concerning this issue.)

We now proceed to the next section where the expected theoretical effects of price-cap regulation are discussed. We then explain, in detail, our experimental strategy, (section 2) and discuss our result, (section 3). The final section offers some concluding remarks.

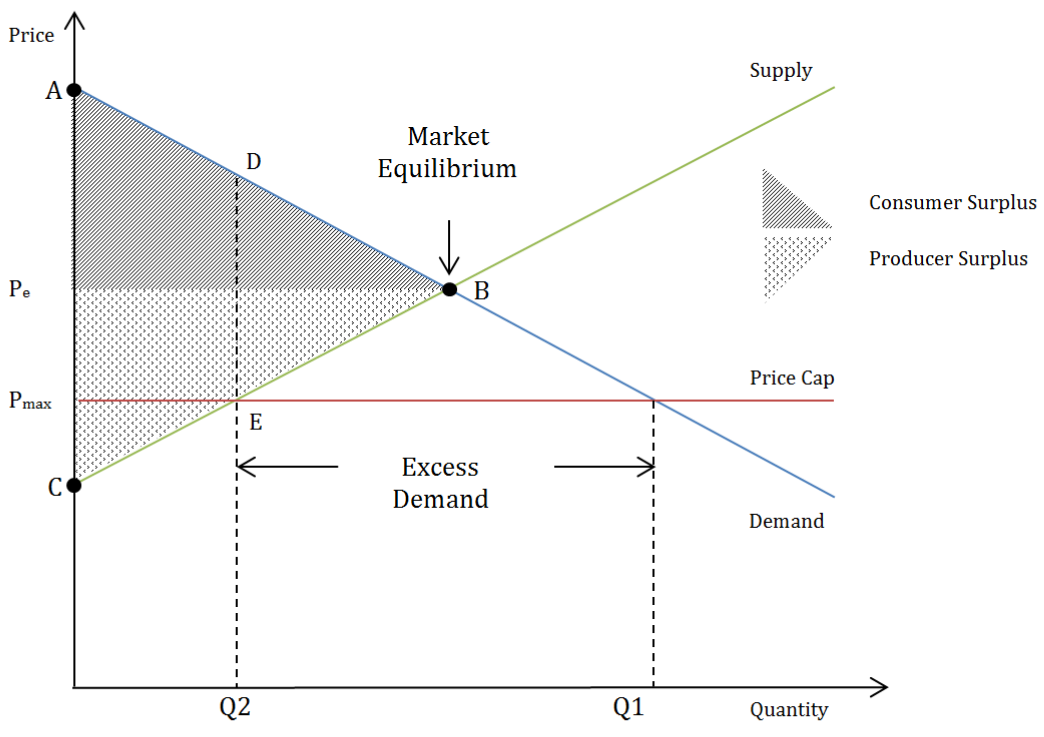
2 What can be expected from a price-cap regulation?

This section discusses the possible effects of price-cap regulation in electricity markets. Imposing a cap on the market price will undoubtedly affect market outcomes. The relationship of price cap levels to suppliers' capacity and price choices depends not only on the price cap level but also on the market structure itself.

2.1 Price Cap Level and Capacity Choice

Figure 1 illustrates how imposing a price cap, (P max), on the market reduces the quantity available thus creating an excess demand, (from Q1 to Q2).

Figure 1 Price Cap and Market Clearing Price



A price-cap regulation also has welfare implications. Depending upon the exact form of demand and supply, the consumer surplus may increase (from ABP_e to $ADEP_{max}$ in Figure 1). The producer surplus will decrease from CBP_e to CEP_{max}. Note also that a price-cap regulation only has an effect if the equilibrium market price (P_e in the figure) exceeds the price cap. Otherwise, the market outcome remains unchanged. Thus:

Prediction 1 A price cap reduces supplied quantity and generates excess demand unless the cap exceeds the market-clearing price. In this case, the market outcome remains unchanged.

Note that the setup described in detail in Section 3 includes two different scenarios or "treatments". In the Low Cap treatment the price cap is such that it would not be socially beneficial to build the last unit in order to meet the demand. Such is not the case in the High Cap treatment. Hence by design, we should expect a capacity shortage in the Low Cap treatment but not in the High Cap treatment.

2.2 Price Cap Level, Market Price and Price Bidding

In most electricity markets, generators sell on the spot market competing in a uniform-price auction. At a given time of the day, the generators submit a multi-step supply function, i.e. a schedule of quantities and prices specifying how much they are willing to supply for a given price. Subsequently, the market operator collects all the submitted schedules, constructs a market supply curve. The market price, at which all transactions take place, corresponds to the intersecting point of the market supply curve and the demand.

Moreover, it is often the case that generators face convex cost function, i.e. marginal production cost increases with additional units (see Borenstein, Bushnell and Wolak, 2002 for empirical evidence).

Many markets impose a price cap, i.e. a maximum bidding price. The effect price cap has on the market price depends upon several factors, including the demand and the capacity available in a particular market and time period. As in other markets, the price bid strategy and therefore, the market-clearing price depends upon the number of generators being able to supply the entire demand.

To simplify the analysis we examine three different cases: a constrained market, an unconstrained market, and a tight market. This report does not contain a formal analysis of such theoretical predictions (see Le Coq and Orzen, 2013 for the full analysis) rather it discusses different equilibrium outcomes in order to provide some insight.

A *constrained market* is the first scenario that we consider. In this type of market, all generators' capacities are necessary in order to collectively serve the demand. (Note that the demand may exceed the total available capacity). In this case the equilibrium market price equals the price cap. All generators bidding the price cap is an equilibrium.

An *unconstrained market* is the second scenario that we consider. An unconstrained market occurs when at least one generator is not needed to supply the entire demand. Such situation may arise either when the demand is low or when many generators have some high capacity. In this case, the equilibrium market price is the competitive price, i.e. it equals the marginal cost (of the last dispatched unit).

Based on these two cases, we make the following prediction:

Prediction 2 ***A price cap is (not) binding if the market is (un)constrained.***

The third scenario is that of a *tight market* in which the demand is such that at least one generator is pivotal. A generator is *pivotal* if he has a monopoly power on its residual demand i.e. that portion of the market demand that cannot be supplied by the other generators. So, during a *tight market*, even the highest bidder sells a share of the demand. It can be shown that, at the equilibrium one (pivotal) generator bids the price cap while the other (pivotal and non pivotal) generators bid a sufficiently low price in order to make it unprofitable for the price-setting generator to undercut (see Fabra et al. 2006). We have conveniently labelled this sufficiently low price, the *limit price*. Note that the exact formulation of the *limit price* depends upon the demand level, the price cap and the installed capacity of the price-setting generator (see Le Coq and Orzen, 2013 for a detailed analysis).

Finally, because of the uniform-price auction, the highest bidder will only serve its residual demand at the price cap. All the other generators are price takers and will sell all their capacity at the price cap.

Prediction 3 ***With a tight market, the price cap is binding with one generator charging the price cap and selling its residual demand. Non-price setting generators bid a price up to the*** **limit price** ***and sell their entire capacity.***

When the market is tight and there are at least two pivotal suppliers, a coordination problem may arise: each generator is better off when another generator offers the price cap. In the "theoretical" equilibrium, mis-coordination never occurs. This reasoning motivates the following prediction:

Prediction 4 ***Despite the coordination problem that may occur in a tight market, bidding behaviour is similar in both treatments.***

In the experiment however, the subjects are likely to find it difficult to coordinate and single out which generator should take on the role of bidding the price cap. The cost of mis-coordination whereby no generator offers the price cap increases with the cap and the individual capacity. Such cost may therefore affect the generators' bidding strategy, and such effect may differ between treatments and generator's capacity.

3 Testing the Price Cap Effect in the laboratory

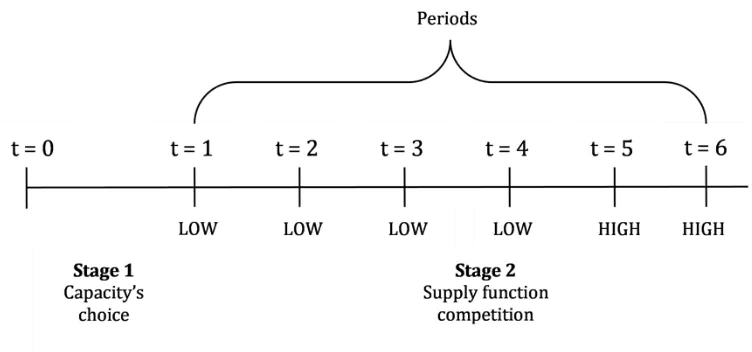
We used the experimental method in order to study the efficiency properties of price-cap regulation. We created a controlled environment that included several "real world" features of the electricity market. Participants in this experiment played the roles of generators and were required to make decisions about their generating capacity and price bids. The level of maximum price allowed, varied in this controlled environment. Using this approach, we were able to observe how participants reacted to a change in price cap. Moreover, cost structure, capacities, price choices were perfectly known and recorded and this made it possible to study the efficiency properties of a price-cap regulation.

We now proceed by describing in detail the experiment that we designed.

Each participant received information about the tasks that they were expected to perform, how much they were to be paid, which depended upon their performance, and made aware of the general rules of the game. Finally, each participant was allocated to an experimental market of four subjects.

The experiment consisted of a number of rounds and periods. There were 10 rounds and each round consisted of 6 periods, (See Figure 2). The demand level could be low, meaning 7, 8, or 9 units, or it could be high, meaning 23, 24, or 25 units. The exact demand level was only revealed at the beginning of each period.

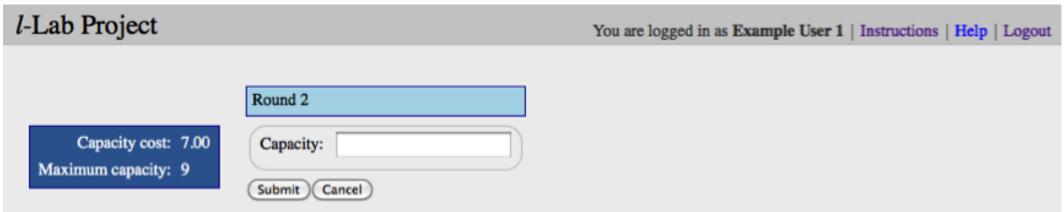
Figure 2 Timing of one round



3.1 Stage 1: Capacity choice

At the beginning of each round (**Error! Reference source not found.** in Figure), the subjects chose the generating capacity they wished to have available for the next 6 periods. The number could be anywhere from 0 to 9. Note that within a round of six periods, the capacity remained unchanged. Moreover there is a fixed cost (equals to 7) for each unit produced by a subject.

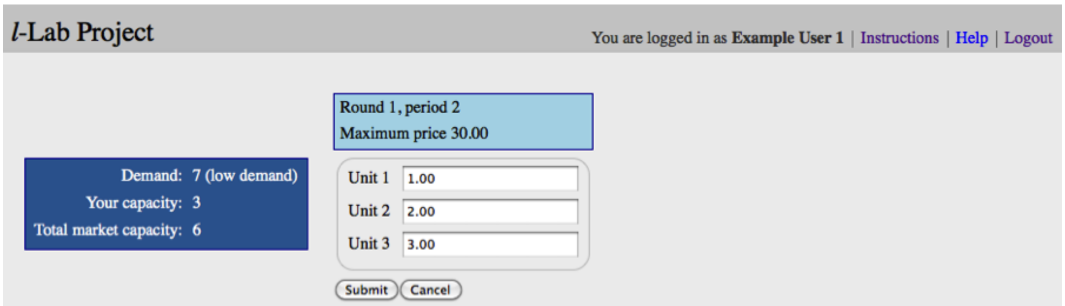
The computer screen at **Error! Reference source not found.** appears as uch:



3.2 Stage 2: Price Choices

At the beginning of each period, (Stage 2 in Figure 2), the exact level of demand was revealed. Subjects then submitted a supply function. That is to say that they submitted a quantity-price schedule seeing that each unit was associated with a particular price. A unit may be viewed as a power plant. A generator chose a price bid for each unit as she has set (See Stage 1).

The computer screen for the price decision appears as such:

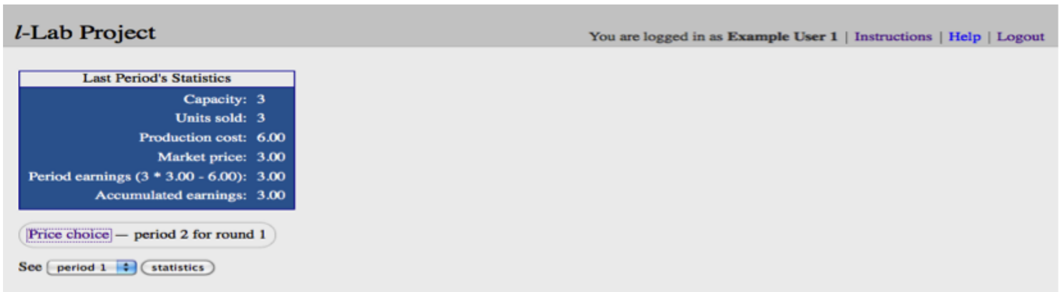


Note that, in addition to the fixed cost of 7, which was previously paid in Stage 1, the subjects were required to pay a production cost for all dispatched, or sold, units but not for any other units. To be more precise, the cost of the first unit, if dispatched, was 1, the second unit, if dispatched, was 2, the cost of the third unit, if dispatched, was 3, and so on. The exact number of units that were to be dispatched was revealed in Stage 3.

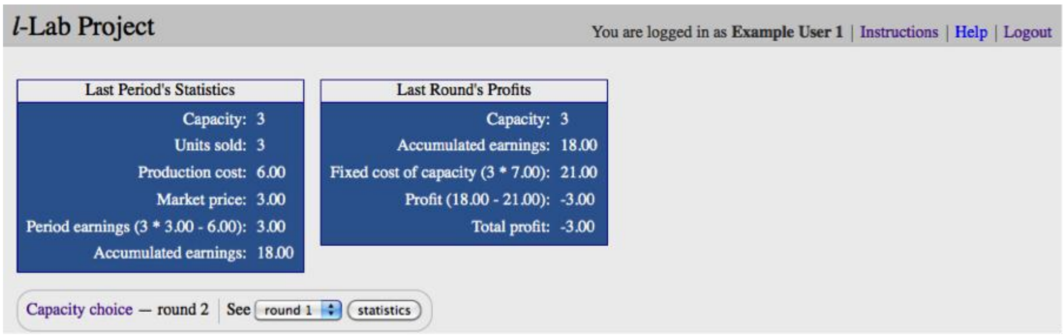
3.3 Stage 3: Market Price and Earnings

After all the bids were submitted, the computer program ranked them from the lowest to the highest and aggregated the individual schedules in order to obtain a market supply function. The intersecting point of this supply function with the completely inelastic demand determined the period's market price.

At the end of each period the screen displayed the Market Price, how many units the subject had sold and how much profit she had made.
There is no information concerning the other generators' individual choices.



At the end of each round, the computer screen displayed the subject's profit as well as the previous period's statistics.



The subjects participated in one out of two possible treatments either with Low or High price caps. In the Low Cap treatment, the price cap was equal to 15 and in the High Cap treatment it was equal to 30. Each subject participated in exactly one session, compiled of 10 rounds (or 60 periods) and each session was either Low Cap or High Cap.

The experimental design described above, enabled us to compare the market participants' bids in accordance to the size of their price caps.

Running the experiment A total of 94 students participated in the experiment, which was conducted at the University of Nottingham as well as at the New Economic School in Moscow. In addition, 28 professionals directly involved in the electricity market also participated in our experiment. Note also that during all sessions, subjects were paid according to their performance, which was measured by the profit they retained at the completion of all ten rounds.

Experimental game programing. One cumbersome of part of this project was to ensure that the experimental game could be technically up and running with participants in action. In order to achieve this, we needed a computer program that would follow the design outlined above. This part of the project was much more time consuming than expected and we were forced to program twice.

Initially, we programmed the experiment using Z-tree software, which is specifically designed for experiments in economics. (For more information on this software see here). In our setup, the subjects were randomly assigned to an experimental market each made up of four participants. Hence, many experimental markets were up and running simultaneously during each session and with several participants making multiple choices at the same time. We were consequently forced to find an alternative type of software.

We recruited Kristaps Dzonsons of *k*-Consulting to carry out this task. A new software interface was subsequently designed using the C-language software, which is ISC-licensed and portable between modern UNIX systems. Thus, the *l-lab* game was created and made available on line.

Firstly, this software package is capable of managing thousands of players and is unaffected by the number of choices the subjects must make. Secondly, this programming allows the experiment to be conducted via the Internet. And finally, the *l-lab game* can be modified or expanded in order to study other important issues related to the electricity market e.g. green energy, congestion costs, or demand-side bidding.

4 Results of the Price Cap Effect in the Laboratory

This section presents the results from the implementation of the experiment described in Section 3. Note that each subject was participating in a market made up of four generators, which remained unchanged for the duration of the session. Moreover, the appointed market was one of two possible treatments. They participated in either the Low Cap treatment, in which the price cap was set to 15 or the High Cap treatment in which the price cap was 30.

Based upon a pairwise comparison of the treatments, we begin by discussing the performance of the two price caps in terms of allocative and productive efficiency. We later discuss how the two price caps may have affected bidding behaviour. It becomes clear in the next subsection that we cluster the data at different levels. Depending upon the question we are addressing, data may be clustered at the market level, the demand level, the individual level or the unit level.

4.1 Price Cap Level and Market Outcome

4.1.1 Individual and Market Capacity Over Time

Our subjects proved to have a higher production rate when participating in the High Cap treatment. This is confirmed when we look at the distribution of individual choice capacity (See Figure 3). Consistent with Prediction 1, participants tended to supply less in the Low Cap treatment, approximately 5 or 6 units as compared to the High Cap, which supplied 6 or 7 units on average.

This result is also consistent with our prediction if we are to assume that the consumers' reservation price is equal to the highest price cap of 30, i.e. consumers are inelastic up to this price and then they switch off. We can easy show that it may not be socially optimal to built unit 25 (unit 7 if we assume symmetric capacity choices) the final unit produced during maximum demand. In fact, only a price cap above 17.5 would make unit 25 socially beneficial and should therefore be avoided in the Low Cap treatment.

XX illustrates the capacity choices in both treatments by indicating total capacity for each market and each round. The different levels of demand are marked in red and correspond to either the case of low demand where 7, 8, or 9 units are requested or in the case of high demand where 23, 24, or 25 units are requested.(For a detailed description of the game, see Section 3).

Figure 3 Individual capacity over time, per treatment

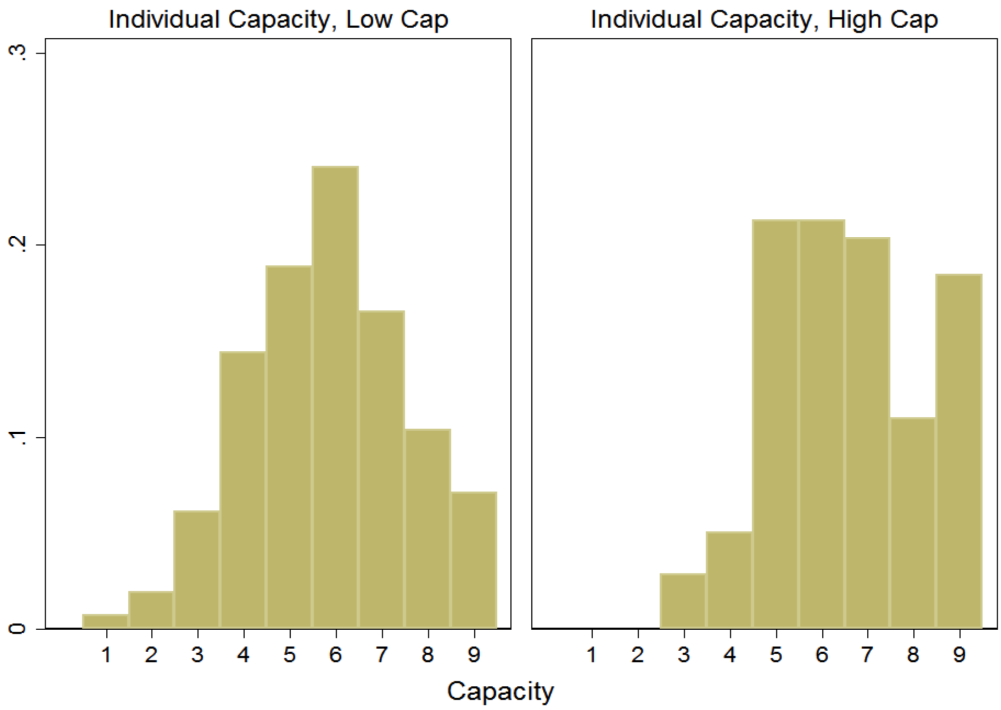
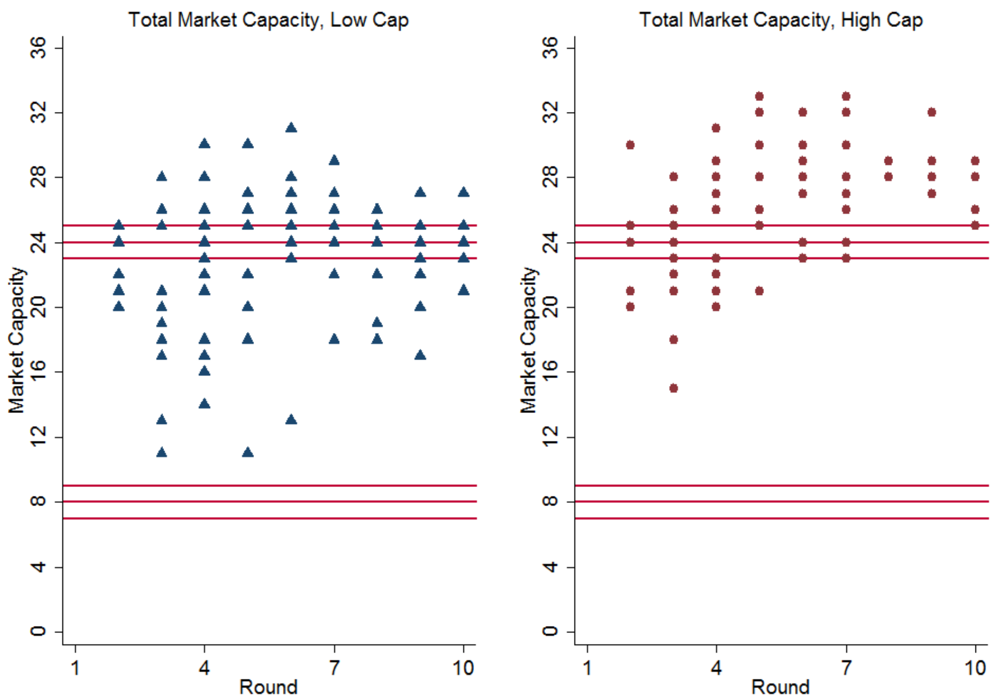


Figure 4 Market capacities over time, per treatment



Some learning appears to take place during the course of the experiment. In the Low Cap treatment, total market capacities tend to converge to the high demand levels, where by contrast in the High Cap treatment total market capacities exceed the highest demand level, even in the last rounds.

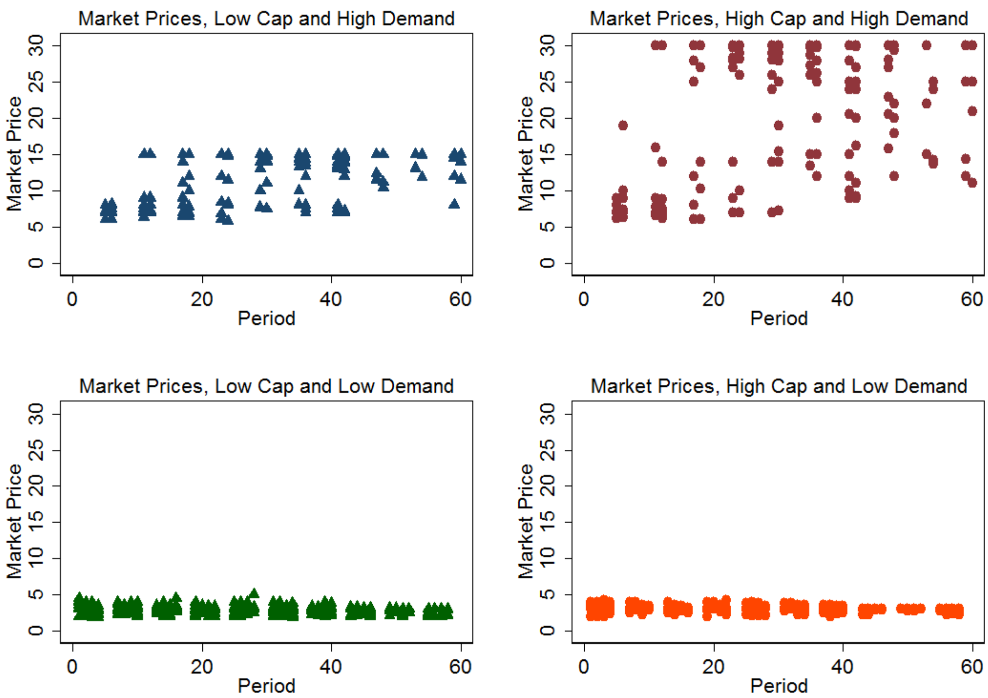
4.1.2 Spot market prices over time

Figure 5 illustrates the market prices by market and round using all four scenarios of low or high caps in relation to low or high demand.

There is no difference between the two treatments when demand is low. Average prices and their variability between treatments are comparable. Consistent with Prediction 2, prices are very close to marginal cost when demand is low.

In contrast, prices and their variability are higher during periods with high demand. The pattern in Figure 5 may suggest that some learning took place; i.e. that the subjects managed to bid the price cap more often as they gained experience in the market. Prices are higher in the High Cap treatment than in the Low Cap treatment, which is consistent with Prediction 2.

Figure 5 Market prices and demand, per treatment



4.2 Price Cap level and productive inefficiency

Here we examine how the change in the price cap affects productive efficiency. In the experimental design, marginal costs rise from unit to unit for each individual generator; it therefore prove more efficient for all generators to produce the same quantities (or at most one unit difference). Productive inefficiencies arise if any generators produce and sell substantially more than others, as these extra units would have been produced at a lower cost had there been a central planner deciding how many units were to be produced by each generator. Any deviation from this "efficient dispatch" is damaging in welfare terms.

Figure 6 and Figure 7 illustrate this additional cost as well as the share of markets with efficient outcomes. The additional cost corresponds to the difference between total production costs (in a given market and a given period), and the lowest possible total cost of production that could have been achieved by central planner. Here we assume that with central planner, investments are chosen optimally. Such a difference is labeled "the additional costs incurred".

Figure 6 Productive Inefficiency as measured by the additional costs incurred
LOW DEMAND & PRICE CAP

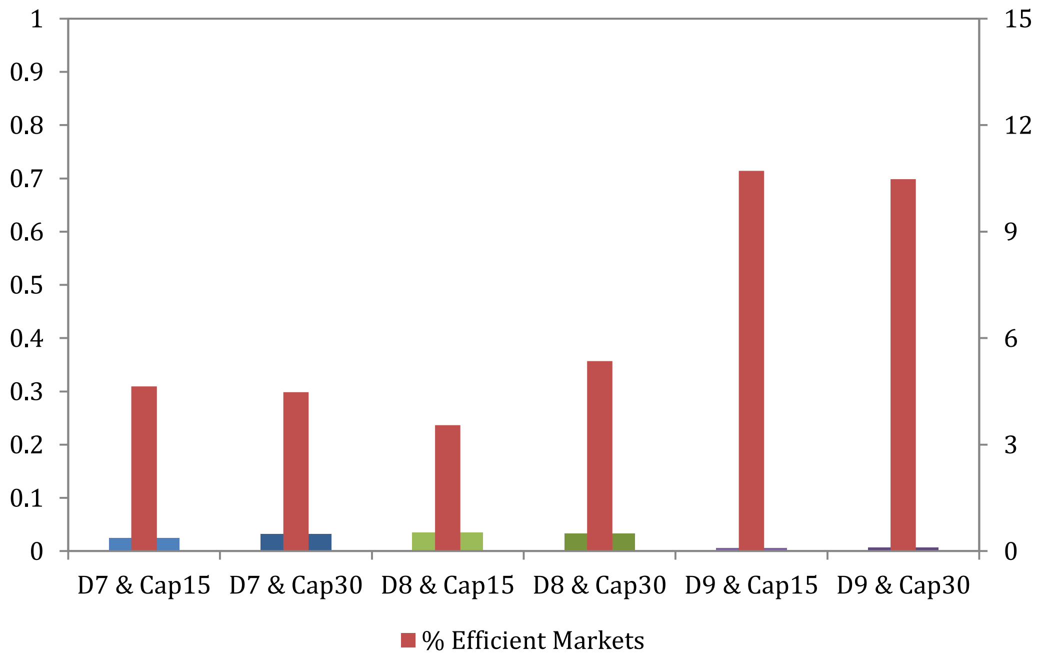
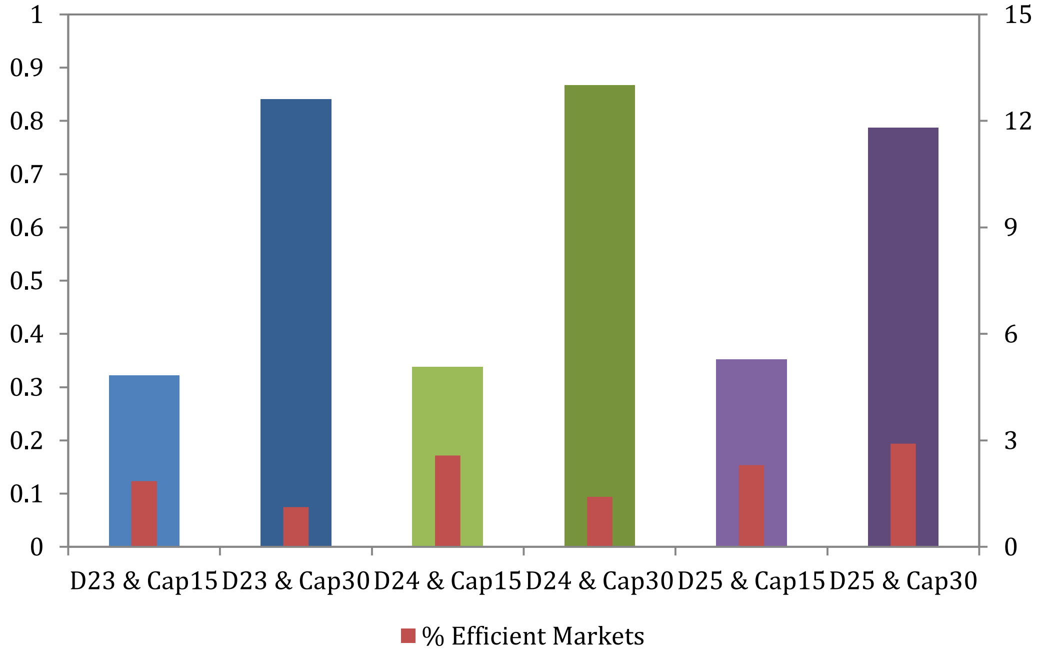


Figure 7 Productive Inefficiency as measured by the additional costs incurred
HIGH DEMAND & PRICE CAP



When demand is low, the inefficiencies are low: i.e. the market is competitive and all generators perform more or less equally. Moreover, during periods of low demand, the inefficiencies seem to decrease over time. A very different picture emerges during periods of high demand. In this case, inefficiencies are quite substantial. Furthermore costs are also substantially higher in the High Cap treatment.

This finding implies that a high price cap increases productive inefficiency as the additional costs incurred are much higher than with a low price cap.

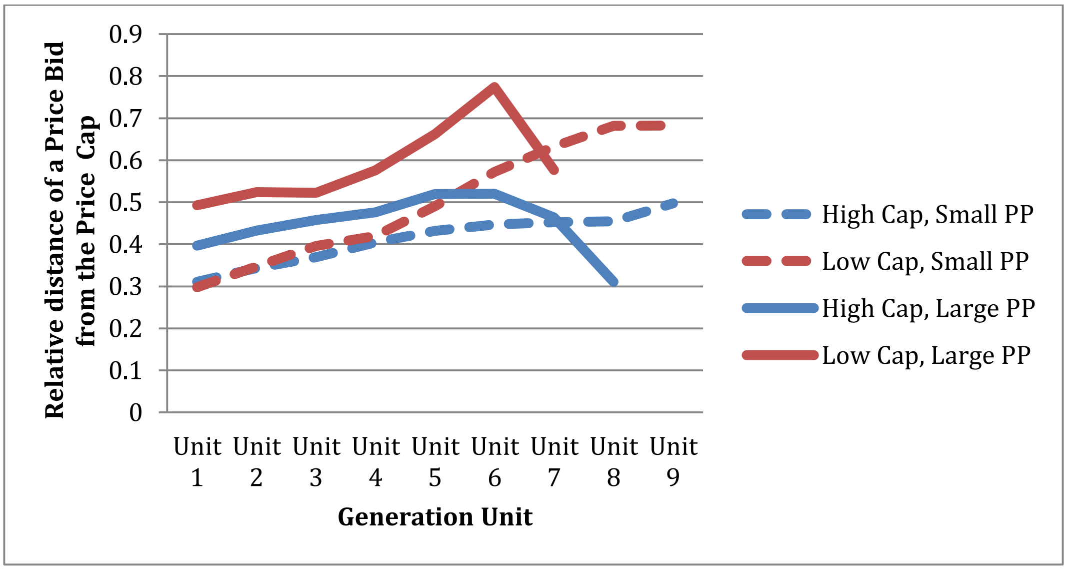
4.3 Price Cap level and Bidding Curve

In order to better understand how changing in the price cap affects bidding price behaviour, we have constructed a “representative” bidding curve for each treatment by running an Ordinary Least-Squares (OLS) regression. Such regression allows us to estimate the linear relationship between the price bid (chosen by each participant), and the existing price cap. Since the level of the price cap varies, we estimated the relative distance between the price cap and the price bid associated with a specific unit. More precisely, the dependent variable corresponds to the relative price bid ([price cap-price bid]/price cap), for each capacity unit. We then ran a linear regression, controlling the identity of the participant, the market, the level of demand, market excess capacity, if any, and the asymmetry between generators. The last variable was approximated by a Gini coefficient, which measures the deviation from an equal capacity distribution amongst generators. This regression considers cases where in equilibrium the market price should be equal to the price cap but where the participants face a coordination problem. That is to say, we only consider capacity configuration and demand levels where there is a pivotal supplier.

We divided the data according to the generators' *pivotal power* (PP). The pivotal power is commonly measured by the RSI (Residual Supply Index), where for each generator, RSI= (market capacity minus total capacity of the other generators)/ demand. Note that a low RSI corresponds to a relatively high market power. We estimate a bidding curve for two different groups of generators. The first group is composed of generators with a large pivotal power (i.e. their RSI being among the 25% of the lowest ones). The other generators belong to the group with low pivotal power. We estimated different bidding curves for the two groups.

The estimated bidding curves are shown in Figure 8. Each point estimate was calculated for each unit of production with the maximum number of units being 9. The vertical axis displays each unit of capacity unit and indicates the relative difference between the estimated price bid and the price cap.

Figure 8 Bidding under different price caps



The bidding curves in Figure 8differ with the price cap and the pivotal power. Regardless of the price cap, generators with small PP offered relatively lower price bids, for the first five of their units, than the generators with large PP did. Their price bids only increased with their final units. This way of bidding has also been observed in different power exchanges and is referred to as "Hockey-Stick Bidding" (see Holmberg and Newbery, 2010).

The estimated bidding curve for a representative generator with large PP differs in the two treatments. The curves' distance from the price cap and the shape of the curve itself are particular to each treatment. In the Low Cap treatment, generators with large PP bid closer to the price cap as compared to the way they bid in the High Cap treatment. Moreover, in the Low Cap treatment, such generators drastically increased his/her price bid for the 5th and 6th units; units that are, theoretically, likely to be the final units dispatched in the market. This appears not to be the case in the High Cap treatment. This finding is therefore inconsistent with Prediction 4; i.e. bidding behaviour is similar across treatments. One possible explanation for this may be that the coordination problem is more difficult to resolve with a higher cap and generators with large PP tend to play more "cautious".

4.4 Running experiment with professionals

Running the experimental sessions with participants from the electricity market was another challenge we faced during this project. It did, however, enable us to compare the strategies used by students contra the practitioners. As we describe below, we found quite a significant difference in strategies. Unfortunately the pool of practitioners is too small to generalize our findings.

While the project was still on-going, we contacted many of the Swedish and French electricity market participants. It was, however, quite difficult to convince practitioners to participate. The main reason being that the first Z-tree version of the programming was difficult to employ outside a "regular" laboratory setup. Using Z-tree outside the laboratory required authorization from the IT-support of the company directly involved in the experiment. Some practitioners, e.g. Vattenfall or the French Energy Commission, were interested in running the experiment but were forced to decline our offer once their It-support departments denied permission to run the software.

After the *I-lab* game was available online, we were, however, able to run experimental sessions at the consultant company Sweco, Energy Markets Inspectorate and with the Market Design Board. We present here the results from the three experimental sessions run with the High Cap Treatment.

Figure 9 and Figure 10 provide the quantity choice and the price choice by market for the High Cap treatment. The practitioners' capacity choice is different from the students' capacity choice as reported in Figure 4. On average, practitioners offer small capacities and subsequently, they tend to offer the price cap more often than the students do. (See Figure 5).

Figure 9 Market capacities over time (High Cap treatment & Practitioners)

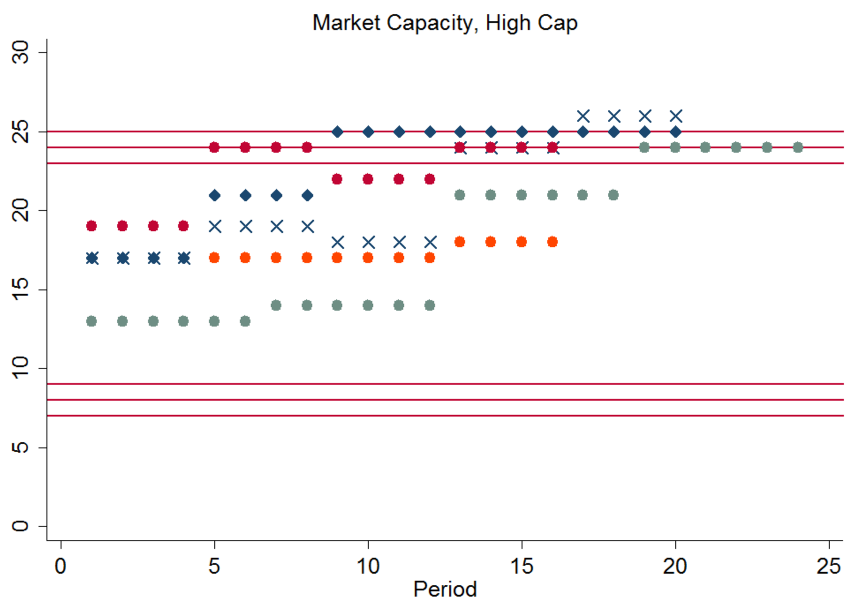
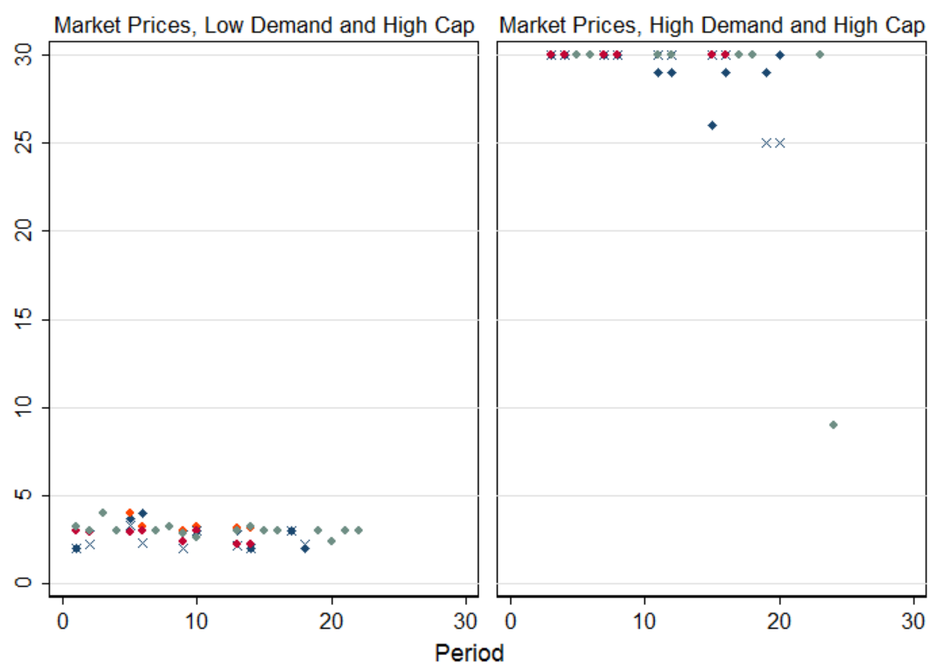


Figure 10 Price bids over time (High Cap treatment & Practitioners)



One possible explanation for the difference in capacity choices between practitioners and students may be that practitioners better understand the game. They seem to be taking into account that each unit they invest in has a fixed cost regardless of whether or not it is dispatched. Hence, any over-investment would be costly.

We also run one session of Low Cap treatment, but the number of participants was too small be reported here. Interestingly however, our main finding (i.e. different bidding behaviour with different price cap levels) seems to be confirmed here.
It is, however difficult to generalize this result when we consider the size of the practitioners' sample. Running the experiment on a larger scale is necessary in order to draw any meaningful conclusions.

5 Concluding remarks

This project is a part of the general debate on the security of electricity supply, which has been taking place ever since the wave of deregulation of electricity sectors. We used experimental methods to investigate the relationship between prices, market power and capacity investments in electricity markets with inelastic demand. We considered two regimes that differ in terms of the price cap levels. We found that the level of the price cap is significant for market outcomes as it impacts not only market prices but also market performance. Imposing a relatively high price cap improves allocative efficiency: i.e. energy supply security, yet reduces productive efficiency which to say that costs are not minimized. Interestingly, we found that the price cap for similar market conditions is reached more often in the Low Cap treatment rather than in the High Cap treatment. We therefore conclude that raising the price cap does not fully translate into a one to one increase in the electricity price.

This last result may have an interesting implication for the price-cap regulation. It should be possible to design an "optimal" price-cap regulation that would induce "reasonable" market prices and levels of energy supply security. The exact formula for such price-cap regulation remains has yet studied. This could prove to be an interesting avenue for future research.

Another avenue for future research would be to study the impact of price caps when electricity is traded between two countries. In 2010 the FERC pushed to raise the price cap in the Western Electricity Coordinating Council (WECC) spot market to align it with the price cap already in place in the California Independent System Operator Corporation (CAISO) spot market. The effect of this measure is, however, unclear and requires further research. It is also interesting from a European and Nordic perspective, as the electricity markets in Europe and in the Nordic countries have become increasingly integrated.

Finally, comparing the effect of price-cap regulation with alternative tools to avoid price spikes is a logical way for us to pursue our research question. The introduction of capacity markets may change the effects of price caps. It is often argued that the capacity market is able to compensate for any lack of investments, which price caps may create and may thereby ensure security of supply.

6 References

Brandts, J., Reynolds, S.S. and Schram, A., (2013). Pivotal Suppliers and Market Power in Experimental Supply Function Competition. *The Economic Journal*

Borenstein, S., Bushnell, J. and Wolak, F., (2002). Measuring Market Inefficiencies in California's Wholesale Electricity Industry. *American Economic Review,* 92 (5).

de Frutos, M.A. and Fabra, N., (2012). How to Allocate Forward Contracts: the Case of Electricity Markets. *European Economic Review,* 56 (3).

Fabra, N., von der Fehr, N.H. and de Frutos, M.A., (2011). Market Design and Investment Incentives. *Economic Journal*, 121 (557).

Fabra, N., von der Fehr, N.H. and Harbord, D., (2006). Designing Electricity Auctions. *Rand Journal of Economics*, 37 (1).

Genc, T.S. and Reynolds, S.S., (2011). Supply Function Equilibria with Capacity Constraints and Pivotal Suppliers. *International Journal of Industrial Organization*, 29 (4).

Holmberg, P. and Newbery, D., (2010). The Supply Function Equilibrium and its Policy Implications for Wholesale Electricity Auctions. *Utilities Policy*, 18.

Isaac, R.M. and Plott, C.R., (1981). Price Controls and the Behavior of Auction Markets – an Experimental Examination. *American Economic Review*, 71:448-459.

Kiesling, L. and Wilson, B., (2007). An Experimental Analysis of the Effects of Automated Mitigation Procedures on Investment and Prices in Wholesale Electricity Markets. *Journal of Regulatory Economics*, 31 (3).

Le Coq, C. and Orzen, H., (2013). Bidding Under a Price Cap – Evidence from an Electricity Market Experiment. SITE Working Paper.

Vossler, C.A., Mount, T.D., Thomas, R. and Zimmerman, R., (2009). An Experimental Investigation of Soft Price Caps in Uniform Price Auction Markets for Wholesale Electricity. *Journal of Regulatory Economics*, 36 (1).

ELFORSK

SVENSKA ELFÖRETAGENS FORSKNINGS- OCH UTVECKLINGS - ELFORSK - AB

Elforsk AB, 101 53 Stockholm. Besöksadress: Olof Palmes Gata 31
Telefon: 08-677 25 30, Telefax: 08-677 25 35
www.elforsk.se