AN EXPERIMENTAL STUDY OF INVESTMENT INCENTIVES MECHANISMS IN THE ELECTRICITY INDUSTRY

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Abstract

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Very Preliminary Version

Energy-only markets tend not to produce the adequate incentives to suppliers to engage the right amount of investment in the right type of technology and in the right location in the network to satisfy a reliability standard at least cost[1]. Market failures in energy spot market typically result in price spikes that are too infrequent and temporary to motivate efficient investment in new capacities as would market theory expect. It suggests finding alternatives to these "energy-only markets" situation where there is no additional incentive mechanism to the price of the energy spot market to guide investment behaviour. In fact, here are various so-called "capacity mechanisms" which aim at replacing the investment incentives that are provided by price spikes with a more stable incentive that relies on the reduction of investment risks. However, in the market design arena, there is still no consensus today on the best way to proceed, as reflected by the different designs of capacity mechanisms that have been applied in practice and the debates on new mechanisms that are still going on among academics (De Vries 2004; Vazquez et al. 2002; Perrez Arriaga et al. 2006).

This paper aims at assessing the efficiency properties of one of these mechanisms: the "forward capacity market" (hereafter FCM) initially proposed by Cramton and Stoft (2006) and Joskow (2006) and recently applied in New England[2]. Cramton and Stoft (2006) propose a forward capacity market design in which each year, an auction is held to buys enough capacity, both existing and new, to provide adequate capacity C^* for the year starting three years from that date. Existing capacity are purchased for one year and new capacity are given four-year contracts. Both new and existing units are paid through an auction-clearing price that is generally be set by the need for new capacity. Existing capacity receives this price for one year, and new capacity for four years. To ensure efficient selection by investors and efficient performance of all capacity, the contracts include a pay-for-performance mechanism, to make sure that prices are high enough to induce adequate capacity. They argue that the benefits of the forward-capacity-market approach are notably in the control of resource

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[1] An efficient electricity system is one where the probability of electricity shortages and the resulting service interruptions remains near the social optimum. The social cost of capacity shortage is very high.

[2] http://www.iso-ne.com/markets/othrmkts_data/fcm/index.html

adequacy, the minimum cost of new capacity, the reduced risk premiums and a fair price and good retirement signals for existing capacity. Overall they propose a market design with spot prices that restored to their proper level but fully hedged. Because load is required to purchase an adequate level of capacity, suppliers receive a price for that hedged capacity sufficient to induce them to invest. Consequently, these physically-based hedges sell for much more than typical energy-only forward contracts, and thereby restore the missing money problem for adequate capacity.

We use the experimental methodology to produce data on the efficiency of this mechanism and to gather empirical regularities on producer's behaviours regarding investment in new capacities. We create two situations in the lab: an energy-only market situation (hereafter "all market" situation, AM) that we compare to a situation with a forward capacity market (FCM). Laboratory experiments are a complementary tool to analytical models to help inform on market design issues. A number of experimental researches have been conducted on power market design issues. They concern the general architecture of power market (Backerman, et al., 2000), the effect of the demand participation in wholesale market (Jullien, et al., 2008, Rassenti, et al., 2002) the capture of rents (Jullien, et al., 2008, Rassenti, et al., 2002) and the impact of specific market rules and auction mechanisms comparing sealed-bid *versus* continuous double auction (Denton, et al., 2001), or uniform *versus* discriminatory auctions (Abbink, et al., 2003). This paper ought to contribute to this literature by enhancing our knowledge on the functioning of forward capacity markets.

We construct our experimental environment, using smart computer assisted markets. Our experimental design is simple, and reproduces an industry structure with 4 producers that are in competition to sell energy in the energy spot market and that also compete on capacities in a forward capacity market when it exists, . Practically, the capacity market is the occasion for a seller to commit himself (today) to sell units in the energy markets (in the future). To do so, he has to sell capacities: Selling capacity is his commitment to offer energy in the energy market. By doing so, if he is successful in his offers to do so, then he can count on future profits that are rather stable and sure. Thereby he can invest with a lesser level of risk than if no capacity market existed. Moreover, the capacity market serves the regulator to solve the energy availability issue in the energy spot market, especially in peak periods. After committing to sell capacities, producers can invest and then compete in the marketplace. Practically, our experiments are figuring a three stages process with a forward capacity market, then an investment stage and then an energy market with multiple periods.

In order to evaluate the effect of market structure on individual investment behavior we consider two competitive situations: one with 4 symmetric incumbent producers and one with 1 incumbent and 3 potential new entrants. We question whether the market structure as an impact on both individual behaviors and market efficiency. We examine the effects of the forward capacity market on the pattern of both energy prices and capacity prices and on the incentives to invest (both in terms of type of plants (baseload or peakload) and volume of investment). Our main result is to show that capacity markets are efficient in giving adequate individual incentives to invest as they lead to an aggregate investment in capacities close to the needed level in peak and extra peak demand periods. They also conduce to lower energy market prices in peak and extra peak demand compared with situation when such capacity markets do not exist.

The paper is organized as follow. In section 1, we present and justify the experimental design and procedure, i.e. the characteristics of the market participants (portfolio of generation units, individual supply curve) and the market institution (the FCM and the EOM). In section 2, we present our results regarding the global efficiency of the two mechanisms, the patterns of market. We conclude in section 3.

1. Experimental design and procedure

Our experimental design reproduces the competition to sell and to invest in energy under two different market designs. In what we call the *All market design*, we figure the “energy-only markets’ where no specific incentives other than the price of energy are given to drive individual behaviors to sell and to invest in new capacities. Then the *Capacity Market design* figure the role of a forward capacity market before taking investment decision and energy pricing decision. We alternatively name that forward capacity market the reserve market

The experiments are decontextualized[3]. Participants in the experiment trade two types of good: the “good X” which is sold in the X-market in stage 3 and the “reserves of X” which are sold in the reserve market in stage 1 (forward). Reserves of X are the quantities of X that a producer commits to sell in the product market in stage 3 if they are bought in stage 1.

Each experiment last a certain number of rounds. A round is either composed of two or three stages depending on the experimental Treatment. Treatments are defined according to two dimensions: the institution (the rules of the games) and the competitive situation.

Concerning the institution, there are two situations: the “All Market” (AM) situation in which the only investment incentives mechanism is the product market itself and a forward capacity market (FCM) situation. Stage 1 corresponds to the FCM, stage 2 to the investment decision and stage 3 to the good market. Stage 3 is composed of 4 successive market periods.

	AM treatment	Forward capacity market treatment FCM
Phase 1	Ø	X
Phase 2	X	X
Phase 3	X	X

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[3] This means that in the instruction read to the participants, we avoid any explicit parallelism with reality.

1. *Participants and decisions*

Participants to the experiment are producers[4]. Producers are characterized by a cost function and an initial endowment in terms of producing capacity. They have to take two types of decision: **a decision to sell** X and/ or reserve of X and a **decision to invest** in producing capacity. To be able to produce units of X, they need to have enough producing capacity. They all compete in the energy market. In the FCM they also compete in the reserve market.

a) Selling X in stage 3 and/ or reserve of X in stage 1

Producers compete to sell the good X. There are two ways to sell the good:

- In the reserve market (in stage 1) which consists to committing itself to propose to sell a given quantity of good on the good-market in stage 3
- In the X-market in stage 3 only.

To be able to sell the good a producer has to pass through the X-market in stage 3.

b) Investment decision in stage 2

The decision to invest in producing capacity is taken in stage 2. There are two types of technology to produce the good: technology B (for baseload) which is characterized by a high fixed cost component and a low variable cost and technology P (for peaking) which is characterized by a low fixed cost and a high variable cost.

Fixed cost is presented as the cost to buy a factory and it is proportional to the size of the factory and independent from the level of sales. The variable cost (unit cost) is proportional to the level of sales (increasing function communicated to the participants in the instruction, cf. annex 1).

	Technology B	Technology P
Fixed cost	300	100
Unit cost	$a_b q + b_b q^2$ $avec\ a_b = 0\ et\ b_b = 0{,}1$	$a_p q + b_p q^2$ $avec\ a_p = 80\ et\ b_p = 0{,}15$
Marginal cost	$2b_b q$	$2b_p q$

2. *Sequences of a round*

- **Stage 1 : forward reserve market**

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[4] We have chosen not to include consumers although in the theoretical models they are assumed to participate to the forward capacity market together with the producer. Selling capacity means for consumers committing to reducing their consumption in case of shortage of production.

In the *AM treatment*, this stage does not exist. In the FCM treatment, participating to this stage is not compulsory: producers are not obliged to sell reserves, i.e. to commit themselves if they sell these reserves at this stage to propose the same volume in the X-market in stage 3. The volume of reserves needed by the market operator for each round is fixed and equal to **300 units.**

Producer can submit various offers (quantity/ unit price). The price is caped at **300ECU**[5] in the reserve market. Furthermore, if the producer succeed to sell units in the reserve market, the maximum price he will get for these units in the X-market is **115 ECU** : it means that the units that are committed in the reserve market and sold in the X-market are caped in the X-market. Even if the X-market price is above 115, the producer will be paid 115 for the units that were committed in the reserve market (this is equivalent to the *strike price* in the reliability option mechanism, Perez Arriaga et al. 2006).

If a producer offers less in the X-market than what he has sold in the reserve market, he will have to pay a penalty of 200 per unit (not proposed).

The auction used in the forward reserve market is a sealed bid first price auction. Bids are accepted in an increasing order of price up to the required level of reserves (fixed to 300 units during all the experiment): the price of reserves is the one submitted by the last accepted bid. In case of *ex aequo*, all bids are accepted proportionally to the quantity offered.

If there is not enough bids to satisfy the 300 units required, they are all accepted, no matter the price given that the price cap (300) applies.

Assume that the 4 producers have submitted the following bids :

	Unit price	Quantity	Cumulated quantity
Producer 1	**45**	**80**	**80**
Producer 2	**60**	**100**	**180**
Producer 2	**80**	**90**	**270**
Producer 3	**92**	**50**	**320**
Producer 4	**92**	**100**	**420**
Producer 1	**110**	**40**	**460**

The required reserve quantity is 300. Bids are accepted in the following way:

	Unit price	Quantity	Accepted quantity	Cumulated accepted quantity
Producer 1	**45**	**80**	**80 (100%)**	**80**

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[5] ECU= Experimental Currency Unit

Producer 2	**60**	**100**	**100 (100%)**	**180**
Producer 2	**80**	**90**	**90 (100%)**	**270**
Producer 3	**92**	**50**	**10 (20% out of 50)**	**280**
Producer 4	**92**	**100**	**20 (20% out of 100)**	**300**
Producer 1	**110**	**40**	**0 (0%)**	**300**

The reserve price for the round is 92 ECU. Two producers have bidden at that price, their proposition will be partially accepted (proportionally to the quantity they have offered).

Producers will receive the following payments :

	Unit price	Quantity	Accepted quantity	Payment for reserves
Producer 1	**45**	**80**	**80 (100%)**	**80*92 = 7 360 ECU**
Producer 2	**60**	**100**	**100 (100%)**	**100*92 = 9 200 ECU**
Producer 2	**80**	**90**	**90 (100%)**	**190*92 = 17 480 ECU**
Producer 3	**92**	**50**	**10 (20% de 50)**	**10*92 = 920 ECU**
Producer 4	**92**	**100**	**20 (20% de 100)**	**20*92 = 1840 ECU**
Producer 1	**110**	**40**	**0 (0%)**	**0 ECU**

Stage 2 : Investment decision

A producer decides to invest in order to increase its available generating capacity. He can invest in technology B or technology P. It is optional, producers can rely on their initial endowments. However, they need to have at least as much quantity as what they sell in the X-market. When they decide to invest they already know their initial supply function based on their initial endowment. They also know the level of demand on the X-market (with certainty if it is a low demand period and with a given probability distribution if it is a high demand period, cf. below). Finally, they know how many units they have sold in the reserve market, i.e how many units they will have to offer in the X-product. They also know how many units the other producers have sold in the reserve market, i.e. how many units they should offer in the X-market. They are thus capable to evaluate the level of tension in this market.

Stage 3 : the market of product X (X-market)

Each round is composed of 4 X-market periods following the demand cycle: low, high, low, high.

- The low demand level is certain and constant : **100 units.**
- The high demand level is uncertain:
  - with a probability 50% it is equal to **200 units** (high demand) ;

- with probability 50% it is equal to 300 units (extra-high demand).

The total initial endowment in generating capacity of technology B is enough to satisfy low demand with no need for new investment. On the contrary, during high demand period, producers require generating capacity of technology P except in a situation where there has been enough investment of type B during stage 2.

X-market price is caped, it cannot exceed **150ECU.** The auction used in the X-market is a sealed bid first price auction. If there is not enough offers to satisfy demand (similar to lost-load situation in real world) the X-market price is fixed to 150ECU.

The profits of a producer depend on his commitment in the reserve market:

- For the quantity committed in the reserve market he receive a maximum price of 115ECU
- If the X-market price is above 115ECU, the price he will be paid for the units committed in the reserve market is still 115ECU. For the other units, sold in the X-market but not committed the maximum price he can be paid is 150ECU.
- If producer doesn't fulfill its commitment, he is penalized for each unit committed but not available in the X-market[6] (200ECU per unit committed and not available).

The cost incurred by the producer correspond to the sum of fixed cost[7] (which depend on the level of generating capacity) and variable costs (which depend on the sales in the X-market).

Profits per round

	Gains	Costs
Stage 1	+ reserve price (per unit of reserve sold)	
Stage 2		- sum of fixed costs (depending on the initial endowment and investment)
Stage 3	+ sales of product X (for the 4 periods)	- variable costs of producing (depending on the sales) - Penalty (if commitment not fulfilled)

3. *Competitive structure*

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[6] This means that the producer did not even make an offer in the X-market no matter the price.

[7] Fixed costs are fairly distributed over the 4 periods of X-market.

The competitiveness of the structure is characterized by the number of producers and the initial endowments on the supply side and the level of demand on the demand side.

There are two types of situations. 1/ A situation in which 4 producers have the same initial endowment (symmetric treatment SYM) and 2/ a situation in which one producers has all the initial endowment while the other three (*de facto* new entrants) have no initial endowment (asymmetric treatment, ASYM). New entrants have to invest in stage 2 in order to be able to sell in stage 3.

1. Symmetric situation (SYM) with needed investment (need for 140 units to satisfy extra-high demand 300 and 40 units to satisfy high demand 200)

Sym

Initial endowment producer 1	B 30 ; P 10
Initial endowment producer 2	B 30 ; P 10
Initial endowment producer 3	B 30 ; P 10
Initial endowment producer 4	B 30 ; P 10

2. Asymmetric situation (ASYM) with needed investment (need for 140 units to satisfy extra-high demand and 40 for high-demand)

ASym

Initial endowment producer 1	B 120 ; P 40
Initial endowment producer 2	B 0 ; P 0
Initial endowment producer 3	B 0 ; P 0
Initial endowment producer 4	B 0 ; P 0

4. *Calculation of the optimal solution*

To determine the equilibrium of the game, we develop a theoretical model, and present in this section its principal characteristics. First (i) we draw the general assumptions of the model, then (ii) we describe the game itself, (iii) the resolution of the game and finally (iv) the parameters used to run the experimental sessions and the equilibrium solution.

(i) General assumptions

The model is a three stages model. In stage 1 generators commit themselves on capacities in the capacity market. In stage 2 generators invest in peak and baseload capacities. And in stage 3, generators sell their capacities in a four period market for energy.

The demand in the market for energy is cycling from low level to high level. More precisely, periods one and three are low demand periods, known with certainty. Periods two and four are high demand periods. The high level of demand is uncertain: the demand can either be “high” with a 50 percent probability or “extra-high” otherwise.
The four generators are in a Cournot competition in stage 1 and 3 of the game.

(ii) Description of the game

Let’s describe more precisely the three stages of the game.

- *Stage 1: commitment in the capacity market*

In the stage, the total capacity that needs to be bought by the regulator is fixed. It corresponds to the maximum anticipated level of demand in the future energy market stage. Generators have the opportunity to sell capacities to the regulator in this stage. To do so they must submit offers to sell in a sealed bid auction. Offers to sell correspond to a quantity and price proposition. The price corresponds to the expected premium or to the minimal revenue they expect to get in order to cover the total cost of producing the units they are ready to commit. Note that in the energy market - stage 3 – the realized premium is measured by the difference between the energy market price and the point of reference for the marginal cost as defined by the regulator. In high level demand periods, this point of reference is the marginal cost of peak units. By comparing the capacity market price, and the difference between energy market price and the cost of reference, the regulator can measure if any extra revenue or rent is extracted by a generator in the capacity market. If it is the case, this extra revenue is deduced from the profits of the generator by the regulator. In other words inframarginal rents on stage 1capacities are not possible.

To determine the quantity to offer in the capacity market, each generator maximized its profits made of (i) the profits he gets in the auction when sells his capacities and (ii) the expected profits to be made in the energy market thanks to his commitment in the capacity market. Precisely, each produces maximized his profit in the following form:

$$\max_{e_c} \quad \mathrm{Prim_{opt}} \cdot \mathrm{e_c} + \mathrm{E_w}\left(\sum_i \mathrm{Pr}of_{i,c}\left(e_c, e_{c'}, K_c, K_{c'}\right)\right) \tag{1}$$

sc.

$$\mathrm{e_c} \le K_c \tag{2}$$

$$\sum_{\mathrm{c}} \mathrm{e_c} \le Q \tag{3}$$

Given, the generator *c*, his competitor *c’*, the period *i*, with *i = 1,2,3,4*, *w* the index of uncertainty on the future peak demand level, $\mathrm{Prim_{opt}}$ the premium asked by the latest offer to sell in the auction i.e. the market price of the auction, $\mathrm{Pr}of_{i,c}$ the future profit of *c* that depends on his commitments, $\mathrm{e_c}$ the quantity offered and accepted in the auction, K_c the maximum production capacity of producer *c*, Q the quantity asked by the regulated and E the expected value. The first constraint of equation (1) says that the commitment must not exceed the anticipated total capacity of the generator, where the second constraint says that the sum of the capacities committed by all the generators must not exceed the total capacities commitment asked (anticipated and fixed) by the generator.

The premium asked by each producer is of the following form:

$$\Pr im_c = \max\left(\mathrm{E}_{\mathrm{W}}\left(\sum_i (P_i^{'} - Cm) \right); \mathrm{E}_{\mathrm{W}}\left(\sum_i (CT_i \; - Cm) \right) \right) \tag{4}$$

With $P_i^{'}$ the future price of energy in market period i – that corresponds to the per unit revenue of the generator if he does not make commitments in the capacity market, Cm the marginal cost of the latest unit accepted in the energy market, and CT_i the total unit cost of the unit engaged in the capacity market.

- *Stage 2: investment decision*

In stage 2, each generator has to decide on the production capacity he seeks to invest in. There are two types of technology: the baseload technology (called the B technology) and the peakload technology (P technology).

The investment depends on the commitment made in stage 1, and will a constraint for the selling of units in the stage 3 energy market.

A generator maximized his expected profits :

$$\max_{u_{c,B}, u_{c,P}} \quad \mathrm{E}_{\mathrm{W}}\left(\sum_i \Pr of_{i,c}\left(e_c^*, e_{c^{'}}^*, K_c, K_{c^{'}} \right) \right) \tag{5}$$

s.c.

$$K_c = K_{c,init} + u_{c,B} + u_{c,P} \tag{6}$$

with $u_{c,B}$ the investment in base load technology, $u_{c,P}$ the investment in peak load technology, e_c^* the capacity commitment of the capacity market by generator *c*, $e_{c^{'}}^*$ the capacity commitments by all the other generators in the capacity market, $K_{c,init}$ the initial capacity endowment of generator *c*.

All the generators are informed on the quantity commitment in the stage 1 capacity auction. The optimal investment decision in stage 2 depends on the stage 1capacity commitment. Therefore multiple investment scenarios are possible. Resolving backward, the optimal investment decisions can be determined given different assumption on the commitments made by producers in stage 1.

- *Stage 3: energy market periods*

Given his commitment in the capacity market, each generator decides in stage 3 on the quantity he seeks to sell in the market for energy. There exist two different levels of demand in this market: (i) a low demand level that corresponds to a situation where the installed capacities to produce are not constraint, and (ii) the peak demand level when the commitments made in the capacity market must be satisfied otherwise exposing the generator to high penalty.

The base load- peak load cycle is repeated one time, leading to four market periods total. The generators decide simultaneously on the quantity they wish to sell, resolving individually the following programs:

- Low demand profit maximizing program:

$$\max_{q_{c,B},q_{c,P}} \quad \mathrm{P}.(q_{c,B}+q_{c,P}) \ - \mathrm{C_{c,B}}(q_{c,B}) \ - \mathrm{C_{c,P}}(q_{c,P}) \tag{6}$$

sc.

$$q_{c,B} \le K_{c,B} \tag{7}$$

$$q_{c,P} \le K_{c,P} \tag{8}$$

$$\sum_c q_{c,P} + q_{c,B} \le D_B \tag{9}$$

where $q_{c,B}$ is the baseload quantity proposed by *c* in the energy market, $q_{c,P}$ the peakload quantity proposed by *c* in the energy market, $K_{c,B}$ the total baseload capacity (B technology) of generator *c*, $K_{c,P}$ the total peakload capacity (P technology) of generator *c*, and D_B the low demand level.

The market price in low demand periods is given by:

$$P_B = \begin{cases} \mathrm{Cm_{opt}} & si \ \sum\limits_c q_{c,P} + q_{c,B} = D_B \\ P_{cap} & si \sum\limits_c q_{c,P} + q_{c,B} < D_B \end{cases} \tag{10}$$

with $\mathrm{Cm_{opt}}$ the marginal cost of the last accepted unit, P_{cap} the price cap, and given the following quadratic variable cost function of respectively baseload (11) and peakload (12) capacities.

$$\mathrm{C_{c,B}}(q_{c,B}) = \mathrm{a_b}.q_{c,B} + b_B.(q_{c,B})^2 \tag{11}$$

$$\mathrm{C_{c,P}}(q_{c,P}) = \mathrm{a_P}.q_{c,P} + b_P.(q_{c,P})^2 \tag{12}$$

We suppose that in the energy market the generators offer their marginal cost for each type of technology. The market price corresponds to the last unit accepted to satisfy the demand. In case of disequilibrium between the supply and the offer, producers are paid a fixed price cap (p_{cap} in (10)). Note that the total cost of investment is deduced form his profits.

- High demand profit maximizing program:

$$\max_{q_{c,B},q_{c,P}} \quad \mathrm{Min(S,P)}.(q_{c,B,e}+q_{c,P,e}) \ + \mathrm{P}.(q_{c,B,ne}+q_{c,P,ne}) \\ - \mathrm{C_{c,B}}(q_{c,B}) \ - \mathrm{C_{c,P}}(q_{c,P}) - \mathrm{Pen}.(\mathrm{e_c^*} - q_{c,B,e} - q_{c,P,e}) \tag{13}$$

sc.

$$q_{c,B,e} + q_{c,P,e} \leq \mathrm{e}_{\mathrm{c}}^{*} \tag{14}$$

$$q_{c,B,e} + q_{c,B,ne} \leq K_{c,B} \tag{15}$$

$$q_{c,P,e} + q_{c,P,ne} \leq K_{c,P} \tag{16}$$

$$\sum_{c} q_{c,P,e} + q_{c,B,e} + q_{c,P,ne} + q_{c,B,ne} \leq D_P \tag{17}$$

$$(q_{c,B,ne} + q_{c,P,ne}).(\mathrm{e}_{\mathrm{c}}^{*} - q_{c,B,e} - q_{c,P,e}) = 0 \tag{18}$$

With $q_{c,B,e}$ the baseload quantity sold by *c* that corresponds to his commitment in the capacity market, $q_{c,P,e}$ the peakload quantity sold by *c* that corresponds to his commitment in the capacity market, $q_{c,B,ne}$ the additional baseload quantity sold by *c* after satisfying his commitment, $q_{c,P,ne}$ the additional baseload quantity sold by *c* after satisfying his commitment, D_P the high demand level, that either be “high” or “extra-high”.

The profits of a generator in peak demand period is the sum of four elements:

- The revenue from his commitment in stage 1 capacity market. He is paid the minimum price between the market price and the strike price (S) that corresponds to the marginal point of reference cost.
- The revenue for the selling of additional units, once his commitment is satisfied. The price P is given by (10).
- The total variable cost of production.
- The penalty (Pen) for any quantity offer in the energy market that is below his commitment in the capacity market $(\mathrm{e}_{\mathrm{c}}^{*} - q_{c,B,e} - q_{c,P,e})$.

Note that constraint (18) imposed to generators to satisfy their commitment in order to offer additional units and benefits the market price.

(iii) Resolution of the game

The dynamic game is resolved backward searching for closed-loop equilibria.

- Stage 3 equilibrium

For a given installed capacity ($K_{c,B}, K_{c,P}$) and a given commitment in capacity (e_c) wad calculate the Nash equilibrium given the demand level, using the mixed complementarity problem method.

In baseload period, the total installed capacity in base load technology is larger than the demand. The optimal capacity and price are the following:

$$q^{*}{}_{c,B} = \begin{cases} \dfrac{D_B}{c} & si \ \dfrac{D_B}{c} \leq K_{c,B} \\ K_{c,B} & si \ \dfrac{D_B}{c} > K_{c,B} \end{cases} \tag{19}$$

$$q^{*}{}_{c,P} = 0 \tag{20}$$

In peak demand periods, 10 different scenarios can be assumed given the capacity installed and committed, and leading to different solutions. These scenario are presented in Annex 2.

Scenario 1 : $K_{c,B} < e_c$ and $\sum_c K_{c,B} < D_P < \sum_c e_c$

Solution : $q^{*}_{c,P,e} = \min\left(\frac{D_P - \sum_c K_{c,B}}{c} ; K_{c,P} \right)$, $q^{*}_{c,B,e} = K_{B,i}$ and $q^{*}_{c,P,ne} = q^{*}_{c,B,ne} = 0$.

Scenario 2 : $\sum_c e_c \geq D_P$ and $\sum_c K_{c,B} \geq D_P$

Solution : $q^{*}_{c,B,e} = \min\left(\frac{D_P}{c} ; K_{c,B} \right)$, $q^{*}_{c,P,e} = q^{*}_{c,P,ne} = q^{*}_{c,B,ne} = 0$

Scenario 3 : $\sum_c e_c = D_P$

Solution : $q^{*}_{c,B,e} = \min\left(e_c ; K_{c,B} \right)$ and $q^{*}_{c,P,e} = \max\left(0 ; e_c - K_{c,B} \right)$

Scenario 4 : $\sum_c K_{c,B} < \sum_c e_c < D_P \leq \sum_c K_c$

Solution : $q^{*}_{c,B,e} = K_{c,B}$; $q^{*}_{c,P,e} = e_c - K_{c,B}$;

$q^{*}_{c,P,ne} = \min\left(\frac{D_P - \sum_c e_c}{c} ; K_{c,P} - q^{*}_{c,P,e} \right)$ and $q^{*}_{c,B,ne} = 0$

Scenario 5 : $\sum_c e_c = \sum_c K_{c,B} < D_P \leq \sum_c K_c$ et $e_c = K_{c,B}$

Solution : $q^{*}_{c,P,e} = q^{*}_{c,B,ne} = \frac{K_{c,B}}{2 + \frac{2.b_P}{2.b_b + b_P}}$; $q^{*}_{c,B,ne} = K_{c,b} - q^{*}_{c,B,ne}$

et $q^{*}_{c,P,ne} = \frac{2.b_b + b_p}{b_p} . q^{*}_{c,P,e}$

Scenario 6 : $\sum_c e_c \leq \sum_c K_{c,B} < D_P \leq \sum_c K_c$ and $e_c \neq K_{c,B}$

Solution : $q^{*}_{c,B,e} = \frac{K_{c,B} - \left(\frac{b_b + b_P}{b_b} \right) . \left(e_c - K_{c,B} \right)}{3 + \frac{b_P}{b_b}}$ si ≥ 0

$q^{*}_{c,B,ne} = K_{c,B} - q^{*}_{c,B,e}$; $q^{*}_{c,P,e} = e_c - K_{c,B} + q^{*}_{c,B,ne}$ and $q^{*}_{c,P,ne} = \frac{2.b_b + b_p}{b_p} . q^{*}_{c,P,e}$

Scenario 7 : $\sum_c e_c < D_P \leq \sum_c K_{c,B} \leq \sum_c K_c$

Solution : $q^{*}_{c,B,e} = e_c$; $q^{*}_{c,P,e} = q^{*}_{c,P,ne} = 0$ and $q^{*}_{c,B,ne} = \min\left(\frac{D_P - \sum_c e_c}{c} ; K_{c,B} - e_c\right)$

Scenario 8 : $\sum_c e_c < \sum_c K_c < D_P$

Solution : $q^{*}_{c,B,e} = \frac{\frac{b_b}{b_P}.K_{c,B} - K_{c,P} + 2.e_c}{2.\left(\frac{b_b}{bp} + 1\right)}$; $q^{*}_{c,B,ne} = K_{c,B} - q^{*}_{c,B,e}$; $q^{*}_{c,P,e} = e_c - q^{*}_{c,B,e}$

And $q^{*}_{c,P,ne} = K_{c,P} - q^{*}_{c,P,e}$

Scenario 9 : $\sum_c K_c < \sum_c e_c < D_P$

Solution : $q^{*}_{c,P,e} = K_{c,P}$; $q^{*}_{c,B,e} = K_{c,B}$ and $q^{*}_{c,P,ne} = q^{*}_{c,B,ne} = 0$

Scenario 10 : $e_c = 0$

Solution : equilibrium as determied in baselod periods.

- Stage 2 equilibrium

Given the optimal solution of the stage 3, we can deduce the total expected profit for a generator form his selling in the energy market:

$$\mathrm{E}_{\mathrm{W}}\left(\sum_i \Pr of_{i,c}\left(e_c, e_{c'}, K_c, K_{c'}, q^{*}_{c,P,e}, q^{*}_{c,B,e}, q^{*}_{c,P,ne}, q^{*}_{c,B,ne}\right)\right)$$

Given the capacity commitment at stage 1 we can determine the Nash equilibrium of the investment game. Solving program (5) and (6) and assuming that the commitments correspond to the quantity asked by the regulator, the unique and Pareto dominant Nash equilibrium is :

$$u^{*}_{c,P} = e_c - K_c \text{ and } u^{*}_{c,B} = 0$$

Then we calculate the Nash equilibrium for every scenario.

- Stage 1 equilibrium

Given the optimal offers in the energy market and the optimal investment determined in function of the capacity commitment at stage 1, we can determine the equilibrium commitment solving program (1)-(4).

The rational decision for each producer consist in offering the maximum capacity in the capacity market in order to capture the premium he ask (4) and that corresponds at least to the revenue he could obtain in the energy market if he did not participate to the capacity market. Then we suppose that at the equilibrium:

$\sum_c e^*_c = Q$ and then $u^*_{c,P} = \max(0; e_c - K_c)$ and $u^*_{c,B} = 0$

We deduce that the objective function in program (1)-(4) is a monotonic and continuous function, leading to the existence and the unique Nash equilibrium.

In the All market treatment experiment, only two stages exist with individual decision to invest and to sell capacities in the energy market. The resolution of the game is made using the stage described above and making the assumption that $e_c = 0$.

(iv) Parameters for the experiment and equilibrium solution

The equilibrium of the game is calculated according to four scenarios.

Scenario	**Notation**
Capacity market / Symmetric structure	FCM/Sym
Capacity market / Asymmetric structure	FCM/Asym
All-Market / Symmetric structure	AM/Sym
All-Market / Asymmetric structure	AM/ASym

The parameters for the experiments are the following.

Baseload Fixed cost	300
Baseload variable cost	$a_b q + b_b q^2$ avec $a_b = 0$ et $b_b = 0{,}1$
Baseload marginal cost	$2b_b q$
Peakload fixed cost	100
Peakload variable cost	$a_p q + b_p q^2$ avec $a_p = 80$ et $b_p = 0{,}15$
Peakload marginal cost	$2b_p q$
Initial endowment generators (1/2/3/4)	symmetric (1: B30,P10 / 2: B30,P10 / 3: B30,P10 / 4: B30,P10) asymmetric (1 : B120, P40/ 2 : B0, P0/ 3 : B0, P0/ 4 ; B0, P0)
Low demand level	100
High demand level	200
Extra high demand level	300
Limit offers in the capacity market	[0,300]
Penalty	200
Price cap in the enrgy market	150
Maximum price for committed capacities	115
Market price if the supply is inferior to the demand	150
Exchange rate	1€ = 1000ECU
Initial fee	20€

For each senario the equilibrium of the game is the following:

	FCM/Sym	FCM/Asym	AMSym	AMASym
Auction premium	100	100	---	---

Capacity asked in stage 1	300	300	---	---
Total capacity	300	300	199	199
Demand in low periods	100	100	100	100
Demand in « high » periods	200	200	199	199
Demand in « extra-high » periods	300	300	199	199
Market price in low demand	5	20	5	20
Market price in “high” demand periods	106	106	150	150
Market price in “extra-high” demand periods	113.5	115	150	150
Engagement/ producer 1	75	195	---	---
Engagement/ producer 2	75	35	---	---
Engagement/ producer 3	75	35	---	---
Engagement/ producer 4	75	35	---	---
Investment/ producer 1	75 (pointe)	35(pointe)	10*(pointe)	10*(pointe)
Investment/ producer 2	75 (pointe)	35(pointe)	9(pointe)	9(pointe)
Investement/ producer 3	75 (pointe)	35(pointe)	9(pointe)	9(pointe)
Investment/ producer 4	75 (pointe)	35(pointe)	9(pointe)	9(pointe)

* There are 4 Nash equilibria : a player c invest 10 units and the competitors 9units. It is thrue if we assume that investment take a unitary value. In the other case, there is no Nash equilibrium. This assumption does not affect the results.

2. Results

The experiments were run in the experimental laboratories of the GATE (Lyon) and of GAEL (Grenoble), using a dedicated market-software developed with the experimental software Regate (Internet Based Software for Experimental Economics of the GATE). Undergraduate students were recruited from business school (EM Lyon), engineering schools (Ecole Centrale de Lyona nd Ecole Nationale de Génie Industriel, INPG) and economics departments of the two universities.

All-market sessions are conducted the following way: instructions are distributed and read loudly to all participants. Participants can raise questions of understanding during the reading, if any. At the end of the reading they are asked to answer an understanding questionnaire. There are few trial periods with no financial incentives just to make sure they have fully understood the rules.

Then, subjects participate to various rounds (up to the end of the experimental session which last three hours, it has been announced to them at the beginning). At the beginning of each round, each participant is allocated to a group of 4 players. These groups (3 or 4 depending on the sessions) are randomly reshuffled at the beginning of each round. Given the configuration of the laboratory, it is possible to maintain a good level of anonymity between the participants. We thus can assume that participant do not know with certainty with which persons he is associated.

The environment of the Foward Capacity Market (FCM) is too complex to be explained to the participant and to get exploitable data during the granted time. We thus decided to conduct FCM sessions only with « experienced » participants, i .e. participants who have participated to a session dedicated to the learning of FCM rules or participants who have already participated to AM session. The switch from AM experimental environment to the FCM experimental environment has proven to be relatively easy.

Each session last 3 hours maximum. The average hourly payment per participant is XXX Euro.

Time	**Treatment**	**Location**	**# Group**	**# Trial period**	**# Period with incentive**	**Number of observation**
29/05/08	**FCM_ASym**	**Lyon**	**3**	**2**	**4**	**12**
14/05/08	**FCM_Sym**	**Lyon**	**3**	**2**	**6**	**18**
6/05/08	**FCM_Sym**	**Lyon**	**2**	**1**	**10**	**20**
7/05/08	**AM_Sym**	**Lyon**	**2**	**2**	**10**	**20**
6/03/08	**FCM_Sym**	**Lyon**	**3**	**1**	**4**	**12**
8/04/08	**FCM_Sym**	**Grenoble**	**3**	**1**	**3**	**9**
28/04/08	**FCM_Sym**	**Grenoble**	**3**	**1**	**5**	**15**
29/04/08	**FCM_Sym**	**Grenoble**	**3**	**1**	**5**	**15**
5/06/08	**AM_ASym**	**Lyon**	**3**	**2**	**11**	**33**

Results are presented according to the successive stages: 1/ first the data concerning the forward capacity market, 2/ then the investment decision (volume and type of technology) and finally 3/ data concerning the X-product market.

1. Forward capacity market

a) Quantity

The demand in this market is fixed to 300 units (enough to satisfy the extra-high level of demand in the X- market).

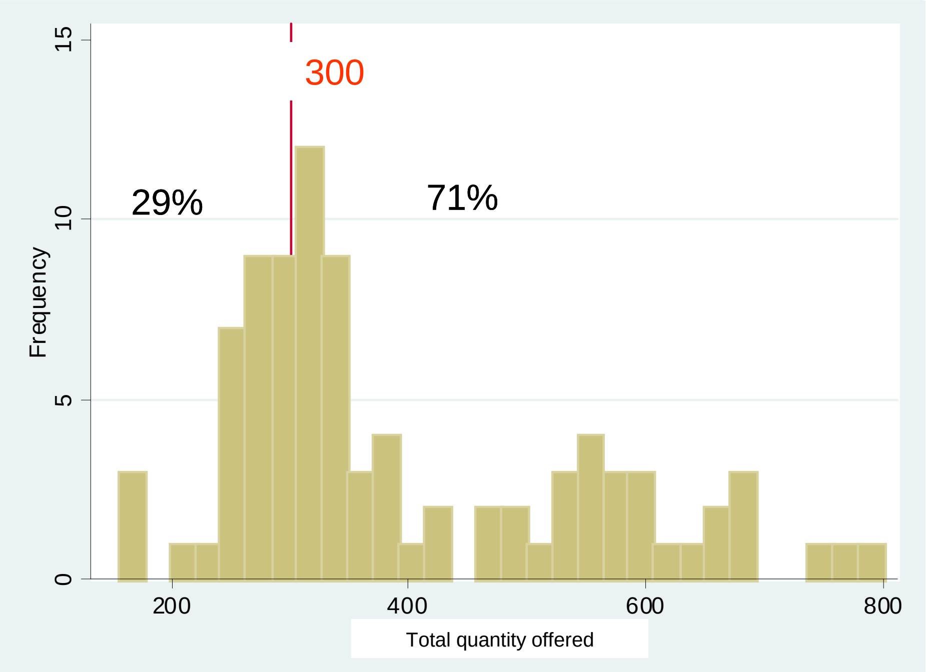

Figure 1. Quantity offered in the reserve market for all the FCM-Sym sessions

For more than two-third of the periods, the quantity offered by all the producers is above the quantity needed (300 units). Looking the data more into details, one can notice that above all it is during the rounds that offered quantity are lower that demand. It can be interpreted as a transitory learning phenomena.

Finding 1. quantity offered in the reserve market is higher than demand in this market in the Sym treatments.

Evidence: For 71% of observations, quantity offered by producers is higher than what is needed. This proportion increases with the experience (and the resulting learning) of participants. Periods with less than 250 units offered represent less than 7% of the observations.

At the individual levels, behaviors are different according to the participants. In figure 2, we show individual propositions (in terms of quantity offered to the reserve market) for all the FCM-Sym sessions.

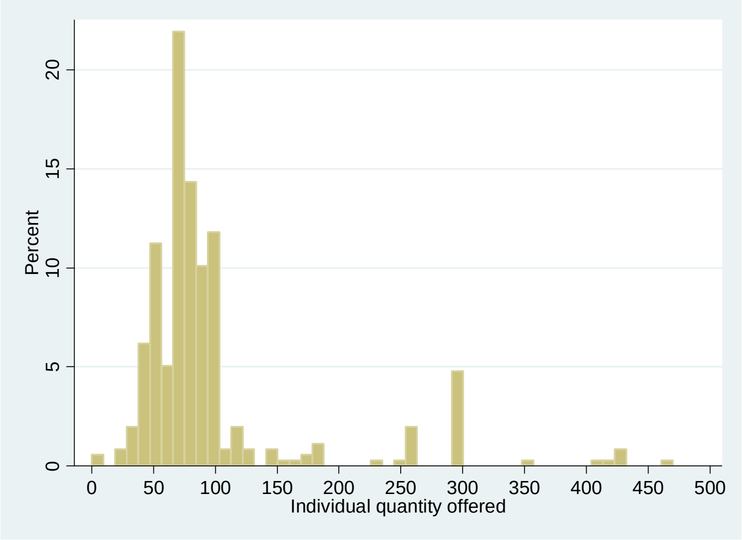

Figure 2. Individual offers distribution (volume) , FCM-Sym

Individual offers above 100 units represent only 20% of the sample. For 80% of the individual offers which are inferiors or equal to 100units we have found the following distribution:

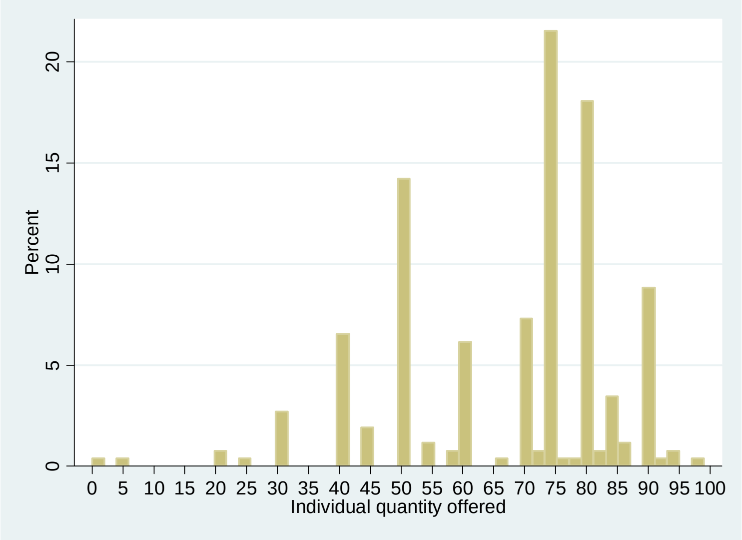

Figure 3. individual offers distribution below 100 units, FCM-SYm

It seems that producers spontaneously choose to individually offer a quarter of the total demand (¼ of 300 units, i.e. 75 units). As a matter of fact, 32% of observations are between 70 and 80 units.

Finding 2. Competition in volume in the reserve market is low. Producers spontaneously limit their offer to ¼ of the total demand which lead to a relatively egalitarian distribution among producers.

Evidence: individual offers which are superior to ¼ of the demand represent only 52% of our observations.

This result is rather surprising given that there is no cost for bidding in the reserve market. It may be explained by the fact that producers want to reduce competition in the market while reducing risk at the individual level. This result has to be linked to the price analysis in this market.

b) Market price and individual price strategy in the reserve market

The equilibrium price in the reserve market is 100 ECU (cf. above the equilibrium). Prices observed for all the SCM-Sym session are given in the figure bellow.

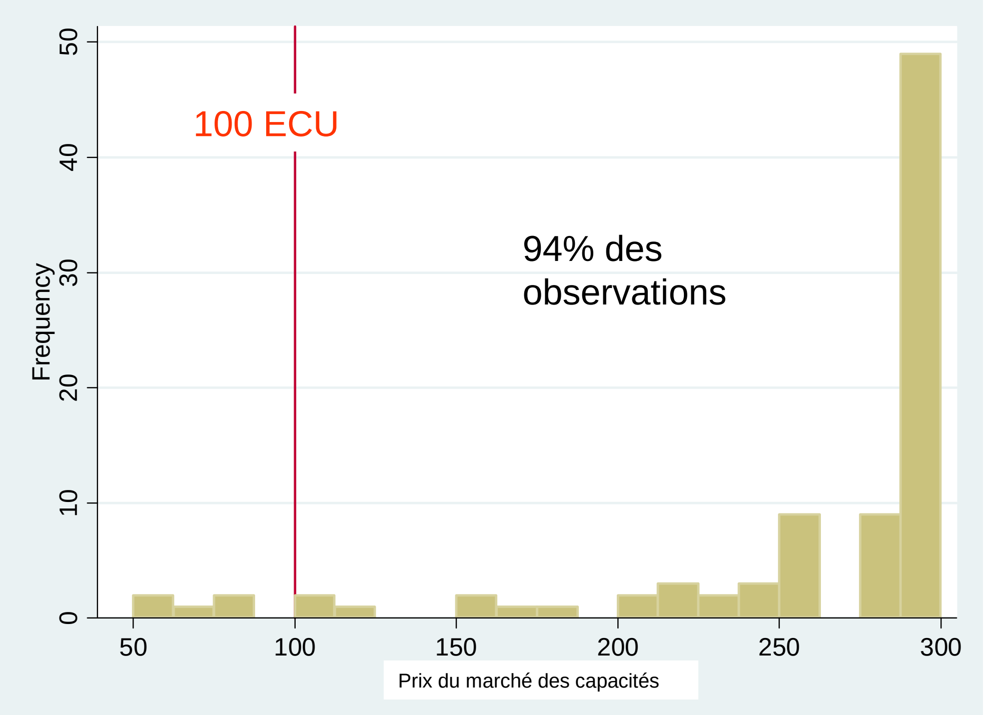

Figure 4. Observed prices in the reserve market in FCM-Sym treatment.

Observed prices in the reserve market are clearly above the equilibrium price.

Finding 3. The reserve market price is significantly above the expected competitive price. For half of the observations, the market price is equal to the price cap (300).

Support : For 94% of the rounds, the market price is above the competitive price.

This result can be interpreted as tacit collusion among producers which thus confirm the results concerning the spontaneous reduction of quantities offered to the market.

Finding 4. The high level of reserve market price result from tacit collusion among producers Le prix de marché élevé sur le marché des capacités résulte d'une entente tacite entre les producteurs

Support : For 61% of the observations, producers propose a price above 290 ECU.

2. *Investment decision*

The optimal investment decision is 160 Units of technology P (cf above).
In figure 7, we have show the distribution of investment levels in the various treatment (FCM-Sym, FCM-ASym, AM-Sym, AM-ASym).

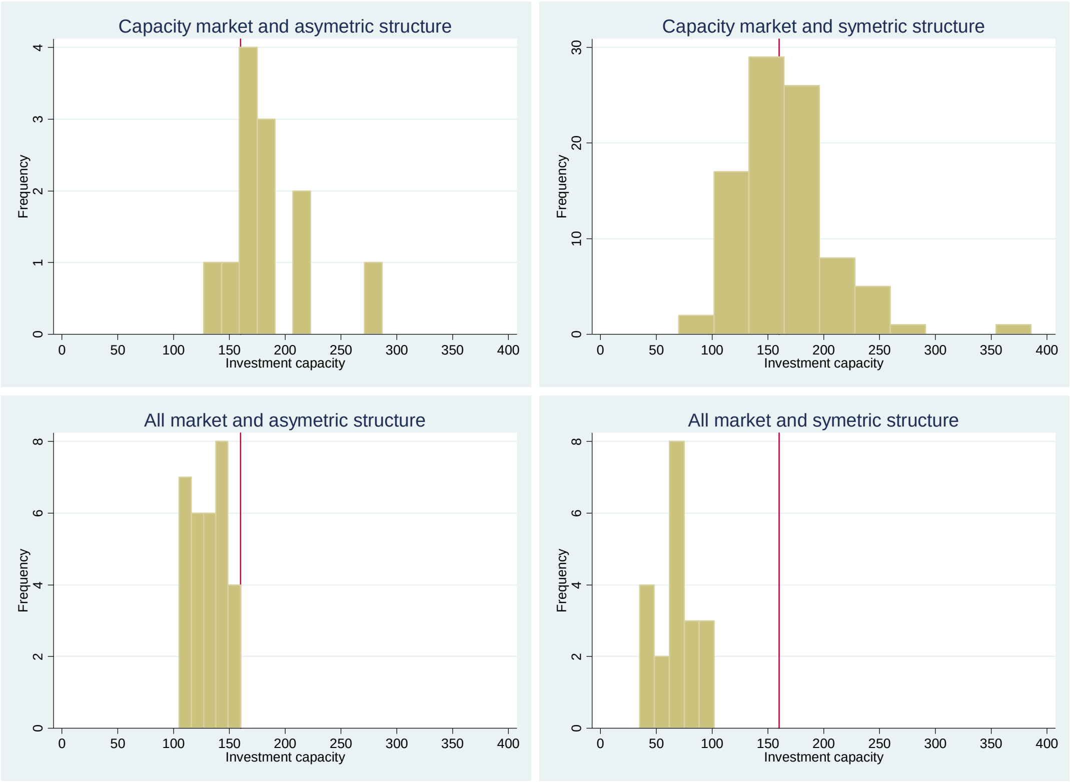

Figure 5. Level of investment in stage 2 by treatment

In the All Market situation there is under-investment notably under the Sym treatment (average investment level 85 units). Under the ASym the average investment level equal 131 units.
In the FCM, there is over-investment notably under the ASym treatment.

To be able to compare the aggregate level of investment, we have estimated the following econometric model :
Data are analyzed as independent data considering the reshuffling of producers within each round. The number of rounds already realized is considered as a explanatory variable to be able to take into account the learning effect of participant.

$INV_t^{Total} = \beta_0 + \beta_1 D_{FCM-ASym} + \beta_2 D_{AM-ASym} + \beta_3 D_{AM-SSym} + \beta_4 t^2 + \varepsilon$

avec INV_t^{Total} l'investissement observé à la période t

$D_{FCM-ASym}$ variable dummy, telle que $D_{FCM-ASym} = 1$ pour une période conduite avec le traitement FCM - ASym et 0 sinon

$D_{AM-ASym}$ variable dummy, telle que $D_{AM-ASym} = 1$ pour une période conduite avec le traitement AM - ASym et 0 sinon

D_{AM-Sym} variable dummy, telle que $D_{AM-Sym} = 1$ pour une période conduite avec le traitement AM - Sym et 0 sinon.

Model 1. MEasure of the impact of the treatment and the number of period on the total investment (reference treatment FCM-Sym)

The results of estimation are reported in the following table

$$INV_t^{Total} = \beta_0 + \beta_1 D_{FCM-ASym} + \beta_2 D_{AM-ASym} + \beta_3 D_{AM-Sym} + \beta_4 t^2 + \varepsilon$$

	Coef	**Std. Err.**	**z**	**P > | z |**	**[95% Conf. Inteval]**	
β_0	166,7294	4,539226	36,73	0,000	157,7588	175,7
β_1	17,8502	11,79858	1,51	0,132	-5,466553	41,16695
β_2	-30,74562	8,491327	-3,62	0,000	-47,52647	-13,96478
β_3	-92,86526	9,806788	-9,47	0,000	-112,2458	-73,48476
β_4	-,1328345	,121488	-1,09	0,276	-,3729232	,1072542

Number of obs = 152

Adj R-squared = 0.4357

Table 1. Estimation of the impact of the treatment and the number of round (leaning effect) on the level of investment (reference : FCM-Sym)

The estimations show that the investments are not statistically different under the asymmetric treatment (FCM_Asym). However, we observe a statistically significant underinvestment in the periods of the sessions of the All market treatment (AM-Sym et AM-ASym). Moreover, the non significance of parameter β_4 can be interpreted as an absence of learning effect. The level of investment measure by parameter β_0 in the treatment of reference whs that the investment is not statistically different from the investment asked by the regulator. In the absence of a capacity market, the underinvestment is larger when generators are symmetric compared to the situation when they are asymmetric.

The main result concerning the total investment is the following:

Finding 5. Using the FCM mechanism leads the correct level of investment. On the contrary, in the AM situation, the level of investment is not sufficient to have the adequate level of production for extra-high demand period.

Evidence : In the AM situation, the level of investment is significantly below the optimal level. There is on average a lack of 30 units in the ASym treatment and 90 units in the Sym treatment.

The other important aspect concerning investment decision is the type of technology. Given the experimental design, investment should be exclusively on technology P. In figure 8, we represent the investment according to the technology for the FCM situation both for the Symmetric and the Asymmetric treatments.

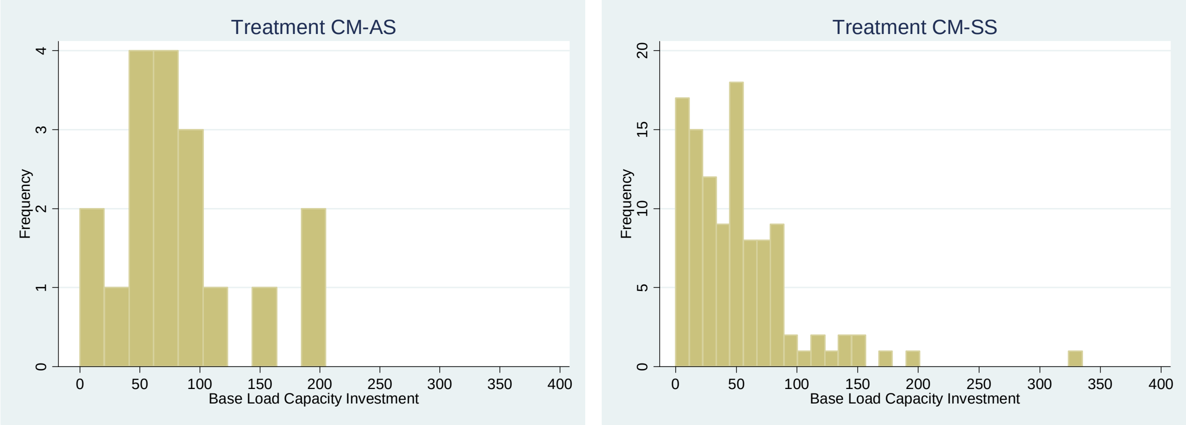

Figure 6. Base load capacity investment for the FCM situation

As shown above, producers do invest in base load technology which is under-optimal (they should invest exclusively in technology P). It might be due to the fact that the optimal investment decision is not easy to compute for the participants. It can also be explained by the fact that they do not have a strong pressure to find the optimal investment decision given the level of payment they get in the reserve market. Indeed, the observed prices in the reserve market equal the fixed costs of technology B (300).

The initial objective of the market mechanisms is the give enough incentives to invest in production capacities in order to be able to cover exceptional peak levels of demand. We've just seen that the All market treatment leads to an insufficient level of investment that does not cover the extra peak demand. More systematically, we report in the following table the frequency of failures to cover the extra peak demand level, for each treatment and type of periods.

	Low Demand	High Demand	Extra-high Demand
CM-AS	0%	0%	14%
CM-SS	1%	1%	31%
AM-AS	0%	10%	63%
AM-SS	0%	47%	96%

The frequency of failures to cover the extra high demand is significantly lower in the absence of a capacity market. It is true for Extra-high demand periods and also for High demand periods. The observed failures under the capacity market treatment correspond to the periods where the commitment in capacities is inferior to the demand. Otherwise, a large majority of generators, they offer capacities that corresponds to their level of commitment in the capacity market. The reduction of the capacities offered in the energy market by generators in the All market treatment highlights their strategy to benefit from the cap price of the experimental design when the supply is insufficient to satisfy the demand.

3. *Energy market prices*

To begin with, it is useful to recall the market prices are capped at 250 ECU in the All market treatment. A cap price exist in the Capacity market treatment at 150ECU for produces who are engaged in the capacity market. The main statistical results concerning energy market prices (average, standard deviation and number of observation) are given in the following table.

	Low Demand	High Demand	Extra high Demand
CM-AS	24,3	86,7	122,5
	(29,1)	(32)	(26)
	24	*10*	*14*
CM-SS	26,9	86,2	136
	(23,3)	(36,5)	(18,5)
	178	*97*	*81*
AM-AS	37,5	194,7	249,8
	(46,7)	(68,7)	(0,51)
	62	*30*	32
AM-SS	44,1	191,3	244,8
	(14,5)	(77,9)	(27)
	44	*17*	27

Table. Average market price per period and per level of demand (standard deviation and *number of observations*).

The distribution of energy market prices observed in the energy market for the four treatment in periods of low demand, high demand and extra high demand is presented in the following graphics.

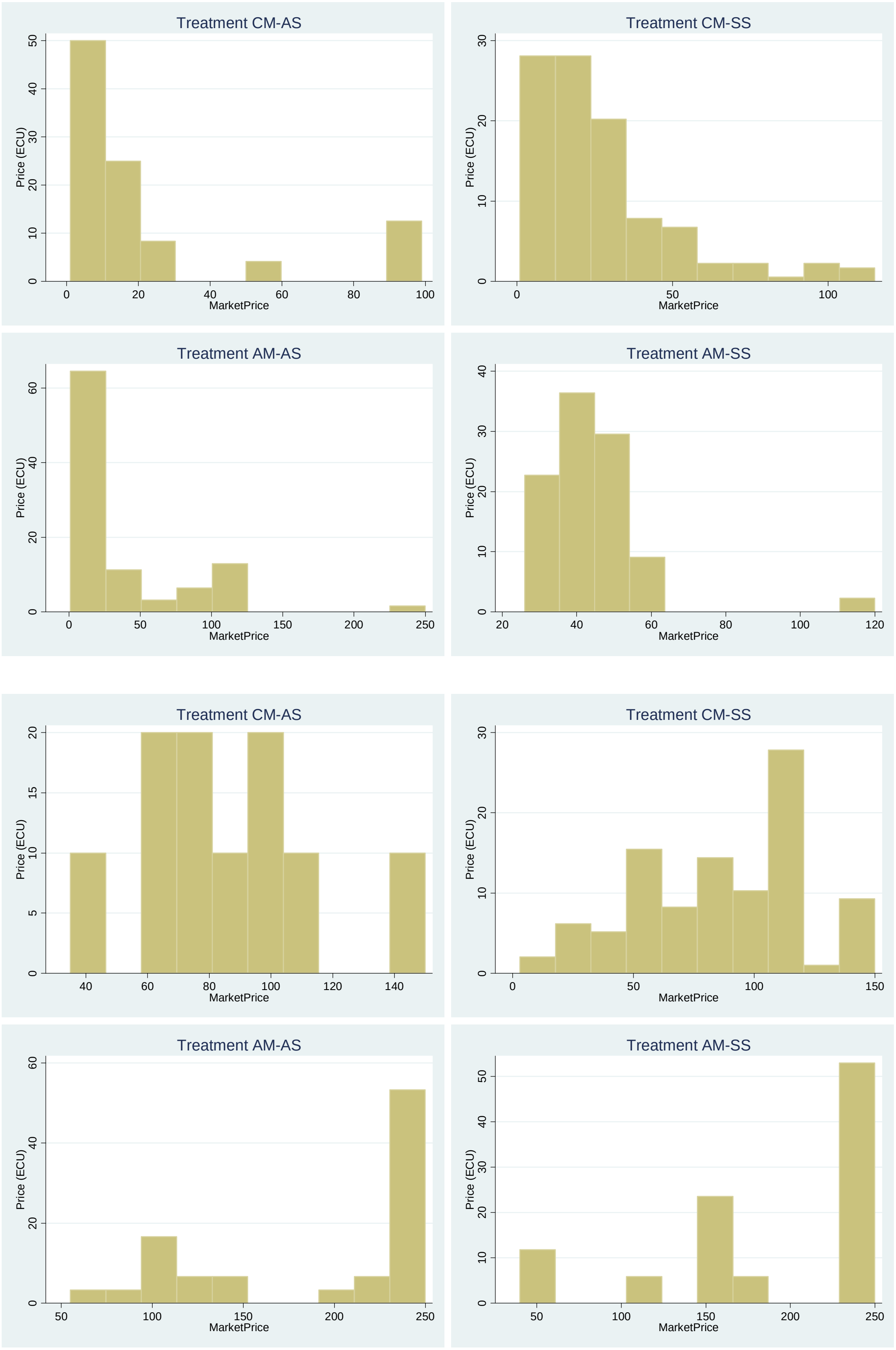

Figure 7. Energy market prices distribution.

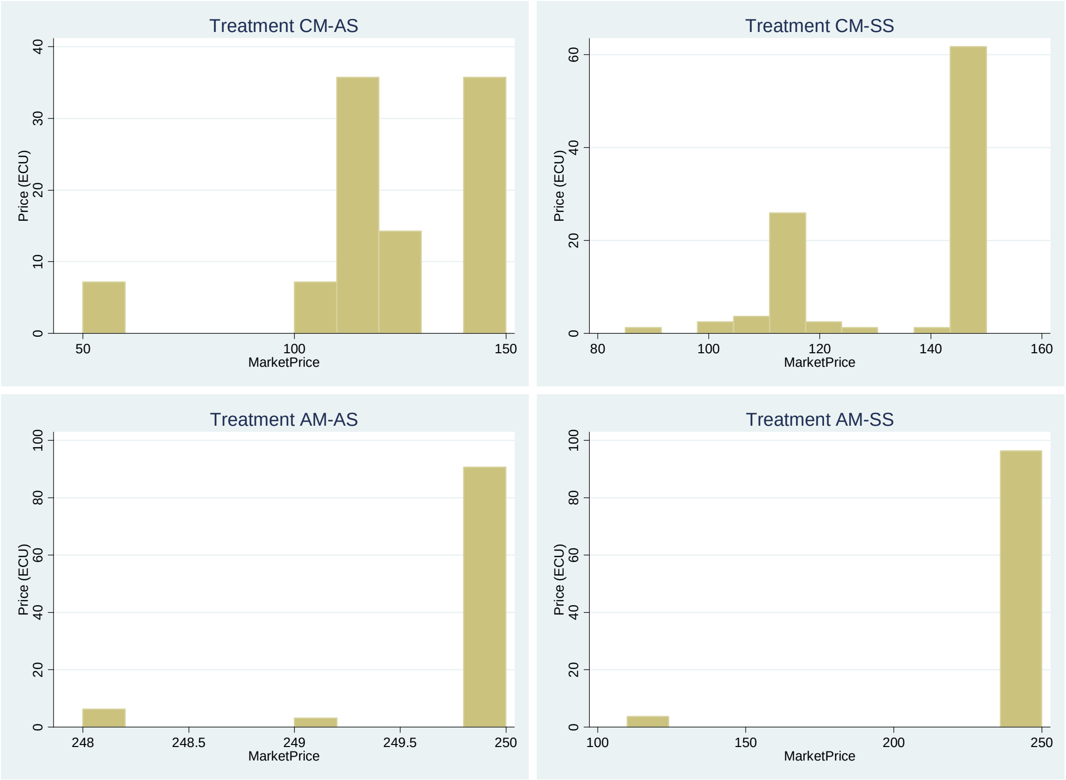

Figure 8. Energy market prices distribution.

The average market prices and their distribution show that capacity markets significantly reduce market prices in extra high demand periods. This result is a direct consequence of the price cap designed in the capacity market, with market price lower than the 150ECU price cap. However in the All market treatment, market prices are close to the 250ECU price cap.

The market prices observed in periods of high demand are rather surprising. In fact, in the All market treatment we observe rather high market prices with an average of 190ECU. This result is a direct consequence of the price cap imposed in the market when the supply is shorter than the demand. The strategy by generator to reduce their offer in order to benefit from the price cap appears to be successful. This strategy if often observed. We may propose a explanation for this behavior. The underinvestment leads to quasi systematic shorten of the supply in high and extra high demand periods. The resulting profit at the price cap gives an incentive to generators to try to duplicate this scenario in high demand periods.

However, market price are rather low in high demand periods in the capacity market treatment. On average, they are inferior to the marginal cost of reference for peak units.This result might be explained by the over investment in baseload capacity that drive energy market prices close to the corresponding marginal cost of this technology.

Finding 6. The introduction of a capacity market leads to a significant reduction of markets prices in periods of high and extra high demand.

Support : A non-parametric test leads to reject the assumption of the absence of difference between energy market prices with and without capacity market at a 1% level of confidence. The result is true for symmetric and asymmetric market structure treatments.

3. Conclusions

Laboratory experiments were used to investigate the behavioral properties of a forward capacity market design in order to conduce to investment in new technology in power markets. The results show that such capacity markets give adequate private incentives to invest in new technologies and induce market competition in the energy market that leads to lower market prices in peak and extra peak demand periods, compared to experimental situation when such market do not exist. This promising result suggest not to base incentives to invest and the sole energy markets. It calls also for a regulation of the functioning of capacity market with an adequate definition of price caps to regulate individual incentives.

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Annex 1: Cost function for technology P

Peak technology P					Technology P					Technology P				
Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost	Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost	Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost
1	100	100	100,3	100,3	51	100	5100	115,3	5498	101	100	10100	130,3	11645
2	100	200	100,6	200,9	52	100	5200	115,6	5613	102	100	10200	130,6	11776
3	100	300	100,9	301,8	53	100	5300	115,9	5729	103	100	10300	130,9	11907
4	100	400	101,2	403	54	100	5400	116,2	5846	104	100	10400	131,2	12038
5	100	500	101,5	504,5	55	100	5500	116,5	5962	105	100	10500	131,5	12170
6	100	600	101,8	606,3	56	100	5600	116,8	6079	106	100	10600	131,8	12301
7	100	700	102,1	708,4	57	100	5700	117,1	6196	107	100	10700	132,1	12433
8	100	800	102,4	810,8	58	100	5800	117,4	6313	108	100	10800	132,4	12566
9	100	900	102,7	913,5	59	100	5900	117,7	6431	109	100	10900	132,7	12699
10	100	1000	103	1017	60	100	6000	118	6549	110	100	11000	133	12832
11	100	1100	103,3	1120	61	100	6100	118,3	6667	111	100	11100	133,3	12965
12	100	1200	103,6	1223	62	100	6200	118,6	6786	112	100	11200	133,6	13098
13	100	1300	103,9	1327	63	100	6300	118,9	6905	113	100	11300	133,9	13232
14	100	1400	104,2	1432	64	100	6400	119,2	7024	114	100	11400	134,2	13367
15	100	1500	104,5	1536	65	100	6500	119,5	7144	115	100	11500	134,5	13501
16	100	1600	104,8	1641	66	100	6600	119,8	7263	116	100	11600	134,8	13636
17	100	1700	105,1	1746	67	100	6700	120,1	7383	117	100	11700	135,1	13771
18	100	1800	105,4	1851	68	100	6800	120,4	7504	118	100	11800	135,4	13906
19	100	1900	105,7	1957	69	100	6900	120,7	7625	119	100	11900	135,7	14042
20	100	2000	106	2063	70	100	7000	121	7746	120	100	12000	136	14178
21	100	2100	106,3	2169	71	100	7100	121,3	7867	121	100	12100	136,3	14314
22	100	2200	106,6	2276	72	100	7200	121,6	7988	122	100	12200	136,6	14451
23	100	2300	106,9	2383	73	100	7300	121,9	8110	123	100	12300	136,9	14588
24	100	2400	107,2	2490	74	100	7400	122,2	8233	124	100	12400	137,2	14725
25	100	2500	107,5	2598	75	100	7500	122,5	8355	125	100	12500	137,5	14863
26	100	2600	107,8	2705	76	100	7600	122,8	8478	126	100	12600	137,8	15000
27	100	2700	108,1	2813	77	100	7700	123,1	8601	127	100	12700	138,1	15138
28	100	2800	108,4	2922	78	100	7800	123,4	8724	128	100	12800	138,4	15277
29	100	2900	108,7	3031	79	100	7900	123,7	8848	129	100	12900	138,7	15416
30	100	3000	109	3140	80	100	8000	124	8972	130	100	13000	139	15555
31	100	3100	109,3	3249	81	100	8100	124,3	9096	131	100	13100	139,3	15694
32	100	3200	109,6	3358	82	100	8200	124,6	9221	132	100	13200	139,6	15833
33	100	3300	109,9	3468	83	100	8300	124,9	9346	133	100	13300	139,9	15973
34	100	3400	110,2	3579	84	100	8400	125,2	9471	134	100	13400	140,2	16114
35	100	3500	110,5	3689	85	100	8500	125,5	9597	135	100	13500	140,5	16254
36	100	3600	110,8	3800	86	100	8600	125,8	9722	136	100	13600	140,8	16395
37	100	3700	111,1	3911	87	100	8700	126,1	9848	137	100	13700	141,1	16536
38	100	3800	111,4	4022	88	100	8800	126,4	9975	138	100	13800	141,4	16677
39	100	3900	111,7	4134	89	100	8900	126,7	10102	139	100	13900	141,7	16819
40	100	4000	112	4246	90	100	9000	127	10229	140	100	14000	142	16961
41	100	4100	112,3	4358	91	100	9100	127,3	10356	141	100	14100	142,3	17103
42	100	4200	112,6	4471	92	100	9200	127,6	10483	142	100	14200	142,6	17246
43	100	4300	112,9	4584	93	100	9300	127,9	10611	143	100	14300	142,9	17389

44	100	4400	113,2	4697	94	100	9400	128,2	10740	144	100	14400	143,2	17532
45	100	4500	113,5	4811	95	100	9500	128,5	10868	145	100	14500	143,5	17676
46	100	4600	113,8	4924	96	100	9600	128,8	10997	146	100	14600	143,8	17819
47	100	4700	114,1	5038	97	100	9700	129,1	11126	147	100	14700	144,1	17963
48	100	4800	114,4	5153	98	100	9800	129,4	11255	148	100	14800	144,4	18108
49	100	4900	114,7	5268	99	100	9900	129,7	11385	149	100	14900	144,7	18253
50	100	5000	115	5383	100	100	10000	130	11515	150	100	15000	145	18398

Annex 1: cost function for technology B

Technology B					Technology B					Technology P				
Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost	Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost	Unit.	Fixed unit cost	Cumulated fixed cost	Variable cost of the unit	Total Variable cost
1	300	300	0,2	0,2	51	300	15300	10,2	265,2	101	300	30300	20,2	1030
2	300	600	0,4	0,6	52	300	15600	10,4	275,6	102	300	30600	20,4	1051
3	300	900	0,6	1,2	53	300	15900	10,6	286,2	103	300	30900	20,6	1071
4	300	1200	0,8	2	54	300	16200	10,8	297	104	300	31200	20,8	1092
5	300	1500	1	3	55	300	16500	11	308	105	300	31500	21	1113
6	300	1800	1,2	4,2	56	300	16800	11,2	319,2	106	300	31800	21,2	1134
7	300	2100	1,4	5,6	57	300	17100	11,4	330,6	107	300	32100	21,4	1156
8	300	2400	1,6	7,2	58	300	17400	11,6	342,2	108	300	32400	21,6	1177
9	300	2700	1,8	9	59	300	17700	11,8	354	109	300	32700	21,8	1199
10	300	3000	2	11	60	300	18000	12	366	110	300	33000	22	1221
11	300	3300	2,2	13,2	61	300	18300	12,2	378,2	111	300	33300	22,2	1243
12	300	3600	2,4	15,6	62	300	18600	12,4	390,6	112	300	33600	22,4	1266
13	300	3900	2,6	18,2	63	300	18900	12,6	403,2	113	300	33900	22,6	1288
14	300	4200	2,8	21	64	300	19200	12,8	416	114	300	34200	22,8	1311
15	300	4500	3	24	65	300	19500	13	429	115	300	34500	23	1334
16	300	4800	3,2	27,2	66	300	19800	13,2	442,2	116	300	34800	23,2	1357
17	300	5100	3,4	30,6	67	300	20100	13,4	455,6	117	300	35100	23,4	1381
18	300	5400	3,6	34,2	68	300	20400	13,6	469,2	118	300	35400	23,6	1404
19	300	5700	3,8	38	69	300	20700	13,8	483	119	300	35700	23,8	1428
20	300	6000	4	42	70	300	21000	14	497	120	300	36000	24	1452
21	300	6300	4,2	46,2	71	300	21300	14,2	511,2	121	300	36300	24,2	1476
22	300	6600	4,4	50,6	72	300	21600	14,4	525,6	122	300	36600	24,4	1501
23	300	6900	4,6	55,2	73	300	21900	14,6	540,2	123	300	36900	24,6	1525
24	300	7200	4,8	60	74	300	22200	14,8	555	124	300	37200	24,8	1550
25	300	7500	5	65	75	300	22500	15	570	125	300	37500	25	1575
26	300	7800	5,2	70,2	76	300	22800	15,2	585,2	126	300	37800	25,2	1600
27	300	8100	5,4	75,6	77	300	23100	15,4	600,6	127	300	38100	25,4	1626
28	300	8400	5,6	81,2	78	300	23400	15,6	616,2	128	300	38400	25,6	1651
29	300	8700	5,8	87	79	300	23700	15,8	632	129	300	38700	25,8	1677
30	300	9000	6	93	80	300	24000	16	648	130	300	39000	26	1703
31	300	9300	6,2	99,2	81	300	24300	16,2	664,2	131	300	39300	26,2	1729
32	300	9600	6,4	105,6	82	300	24600	16,4	680,6	132	300	39600	26,4	1756
33	300	9900	6,6	112,2	83	300	24900	16,6	697,2	133	300	39900	26,6	1782
34	300	10200	6,8	119	84	300	25200	16,8	714	134	300	40200	26,8	1809
35	300	10500	7	126	85	300	25500	17	731	135	300	40500	27	1836
36	300	10800	7,2	133,2	86	300	25800	17,2	748,2	136	300	40800	27,2	1863
37	300	11100	7,4	140,6	87	300	26100	17,4	765,6	137	300	41100	27,4	1891
38	300	11400	7,6	148,2	88	300	26400	17,6	783,2	138	300	41400	27,6	1918
39	300	11700	7,8	156	89	300	26700	17,8	801	139	300	41700	27,8	1946
40	300	12000	8	164	90	300	27000	18	819	140	300	42000	28	1974
41	300	12300	8,2	172,2	91	300	27300	18,2	837,2	141	300	42300	28,2	2002
42	300	12600	8,4	180,6	92	300	27600	18,4	855,6	142	300	42600	28,4	2031

43	300	12900	8,6	189,2	93	300	27900	18,6	874,2	143	300	42900	28,6	2059
44	300	13200	8,8	198	94	300	28200	18,8	893	144	300	43200	28,8	2088
45	300	13500	9	207	95	300	28500	19	912	145	300	43500	29	2117
46	300	13800	9,2	216,2	96	300	28800	19,2	931,2	146	300	43800	29,2	2146
47	300	14100	9,4	225,6	97	300	29100	19,4	950,6	147	300	44100	29,4	2176
48	300	14400	9,6	235,2	98	300	29400	19,6	970,2	148	300	44400	29,6	2205
49	300	14700	9,8	245	99	300	29700	19,8	990	149	300	44700	29,8	2235
50	300	15000	10	255	100	300	30000	20	1010	150	300	45000	30	2265