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## Capacity Mechanisms and Effects on Market Structure

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# Capacity Mechanisms and Effects on Market Structure

## - Preliminary Version -

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### Abstract

Liberalized electricity markets are characterized by fluctuating price-inelastic demand of non-storable electricity, often defined by a substantial market share held by one or few incumbent firms. These characteristics have led to a controversial discussion concerning the need for and the design of capacity mechanisms, which combine some form of capacity payments with price caps in the spot market. The purpose of this study is to understand the effects of capacity mechanisms on the market structure. We consider a model with a dominant firm and a competitive fringe and investigate the impact of price caps and capacity payments on investment incentives and market concentration. While lower price caps reduce the potential for the exercise of market power in static models, we find that in the dynamic model with endogenous investments, lower price caps result in an increase in market concentration, the frequency of capacity withholding and the profits of the dominant firm.

**Keywords:** Electricity Markets, Market Design, Market Structure, Capacity Mechanisms, Competitive Fringe

**JEL codes:** L11, L51, L94, D47

## 1 Introduction

The need for and the design of capacity mechanisms have been controversially discussed during recent years. Researchers as well as policymakers are con-

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cerned that there might be not sufficient investment incentives for adequate generation capacity in the wholesale market.<sup>1</sup> As the European Commission (2012) summarizes, “ensuring generation adequacy in electricity markets has become an increasingly visible topic in the policy discussion”. The reason for the concerns and the subsequent debate about capacity mechanisms is often based on the following line of arguments: Electricity markets are characterized by a fluctuating price-inelastic demand and limited storage possibilities, which can cause high price volatility and facilitate the exercise of market power.<sup>2</sup> Therefore price caps or related measures are often proposed or are already implemented to reduce the potential of market power in the spot market. However, binding price caps reduce spot market revenues and may therefore lead to a lack of investments in the long term. This problem is often referred to as the "missing money" problem and intensively discussed in the economic literature, e.g. by Hogan (2005), Cramton and Stoft (2006) or Joskow (2008). For these reasons, capacity mechanisms have been introduced or are currently debated in many liberalized electricity markets. Typically, capacity mechanisms consist of some form of capacity payments in combination with price caps or similar measures to address the missing money and the market power problem.

The purpose of this paper is to analyze the effects of capacity mechanisms on the market structure. In many electricity markets, the market structure is given by a small group of large incumbent firms (or a single firm) which competes with many small competitive firms. We investigate such markets using a model with fluctuating price-inelastic electricity demand in which a single dominant firm faces a competitive fringe of small firms that can freely enter the market and act as price taker. Investments take place at a first stage and afterwards firms sell electricity at the spot market. We analyze how the level of price caps and different capacity mechanisms affect the market structure specified by the resulting market shares and profits of the dominant firm and competitive firms and the frequency of capacity withholding in the spot market.<sup>3</sup> The focus is on three common forms of capacity mechanisms: procurement auctions, subsidies and strategic reserve.<sup>4</sup>

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<sup>1</sup>See for example Joskow (2008), Cramton and Stoft (2005), Finon and Pignon (2008).

<sup>2</sup>Market power in electricity markets has been studied, for example, by Borenstein et al. (2002) and Wolfram (1999).

<sup>3</sup>Besides price caps other control methods to reduce market power and price volatility exist, e.g. reliability options or bid caps on the spot market, see Cramton and Stoft (2008); Joskow (2008). All these methods have in common that they lead to a reduction of the generators' profits in times of scarcity. For our analysis only this impact is important, therefore we do not distinguish between the different methods.

<sup>4</sup>Capacity markets with procurement auctions are introduced in many electricity mar-

We find the following main result that robustly holds for different forms of capacity mechanisms: If the price cap decreases, the market share and profits of the dominant firm increase and also the frequency of capacity withholding in the spot market increases. This means that even though lower price caps reduce the potential for static market power exertion and the total capacity can be fixed by a capacity mechanism, there is a robust counter-veiling force that a reduction of price caps increases market concentration. The main intuition is as follows: When fixing a target level of total capacity, a lower price cap means that energy market revenues decrease and a larger fraction of firms revenues must come from the capacity mechanism. This shift in revenue streams relatively benefits the dominant firm compared to the competitive fringe. The reason is as follows: The dominant firm has on average a lower capacity utilization in peak price periods due to the fact that it holds back capacity to increase spot market prices. Therefore the average revenues per capacity on the spot market of the dominant firm are lower than those of the competitive firm. On the other hand, the dominant firm and a competitive firm benefit equally from the capacity payments.

The effects of price caps on investments, market outcomes and market power have been studied by Zoettl (2011) and Fabra et al. (2011). Zoettl (2011) analyses the impact of reduced scarcity prices on investment decisions of strategic firms in base load and peak load technologies. He shows that an appropriately set price cap can increase investments in peak load capacity without reducing base load investments. Fabra et al. (2011) extend the analysis of Fabra et al. (2006) by analysing strategic investment incentives in electricity markets in a duopoly model. They compare the impact of uniform-price vs. discriminatory auction formats and price caps on investment incentives. They find that although prices are lower in discriminatory auctions the aggregated capacity is the same for both auction formats. Grimm and Zoettl (forthcoming) analyze strategic investment decisions and compare different spot market designs. They find that investment incentives decrease if spot markets are designed in a more competitive fashion. All those contributions do not consider capacity mechanisms. Another main difference of our model is that we consider a competitive fringe with free entry.

The remainder is structured as follows: In section 2 we describe the model and discuss the main results for a capacity auction. Section 3 illustrates robustness of the results for different capacity mechanisms. Section 4

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kets in the US as well as in Central and South America. Examples are given by the Forward Capacity Market (ISO New England), the Reliability Pricing Model (PJM), the Colombia Firm Energy Market. Strategic reserves are used in Sweden and Finland. Capacity subsidies are paid in Spain and Portugal.

concludes. Proofs are relegated to an appendix.

## 2 The Model

We consider a model with a strategic dominant firm  $m$  and a competitive fringe  $f$  consisting of many small firms that act as price takers. There are two stages. In the first stage firms perform long term capacity investments. In the second stage firms compete in the electricity spot market, which is characterized by price-inelastic fluctuating electricity demand.

At the investment stage the dominant and fringe firms built up their capacities  $x_m$  and  $x_f$ . The structure of the investment game varies between the different capacity mechanisms described below. The fixed costs per unit of capacity (including investment cost and fixed operation cost) are denoted by  $k_m$  and  $k_f$ , respectively. We allow the dominant firm to have a fixed cost advantage due to expert knowledge or economies of scale, i.e.  $k_m \leq k_f$ . Variable per unit costs of electricity generation are identical for all firms and denoted by  $c$ .

### 2.1 Spot Market

We first describe the spot market and characterize its outcome. Electricity demand is given by a non-negative random variable  $D$  with distribution function  $G$  and a continuously differentiable density function  $g$ . There is a maximum level of demand, which we normalize to 1. We assume that  $g(D)$  is strictly positive for all  $D \in [0, 1]$ . One can interpret  $G$  as the distribution of demand over a large number of hours in which spot market competition with given capacities takes place.

After observing realized demand, the dominant firm chooses an output level  $q_m$  with  $q_m \leq x_m$ .<sup>5</sup> If the sum of fringe capacity and the dominant firm's chosen output exceeds total demand  $D$ , competition by fringe firms will drive the spot market price down to the variable costs  $c$ . Otherwise, electricity is scarce and a maximal price  $\bar{P} > c$  is reached.<sup>6</sup>  $\bar{P}$  corresponds either to a price cap determined by the regulation or to the value of lost load (VOLL) which indicates the amount customers are willing to pay to avoid a

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<sup>5</sup>We would obtain the same results if the dominant firm can offer supply functions that specify price-quantity schedules.

<sup>6</sup>We assume that if electricity supply exceeds total demand, there is a partial black-out. The network operator cuts off exactly so many consumers from electricity supply that total consumption equals the given supply.

power outage. Written compactly, the spot market prices satisfy

$$P = \begin{cases} \bar{P} & \text{if } D \geq q_m + x_f \\ c & \text{if } D < q_m + x_f. \end{cases} \quad (1)$$

When demand is below the total capacity of the competitive fringe  $x_f$ , the spot market price always equals the variable generation costs  $c$ . The dominant firm then cannot influence the price level. When demand exceeds the fringe capacity, the dominant firm always has an incentive to withhold so much capacity that scarcity drives the price up to  $\bar{P}$ , i.e. it then optimally chooses

$$q_m = \min \{D - x_f, x_m\}.$$

For fixed  $x_f$ , the equilibrium prices in the spot market are therefore independent of the dominant firm's capacity  $x_m$  and given by

$$P = \begin{cases} \bar{P} & \text{if } D > x_f \\ c & \text{if } D \leq x_f. \end{cases}$$

Positive spot market profits are only achieved in periods with a peak price  $P = \bar{P}$ . To avoid uninteresting case distinctions, we will henceforth restrict attention to the case that  $x_f + x_m \leq 1$ .<sup>7</sup> The expected variable spot market profits per capacity unit of the dominant firm and the competitive fringe are given by

$$\pi_m^s = (\bar{P} - c) \left( (1 - G(x_f + x_m)) + \frac{1}{x_m} \int_{x_f}^{x_f + x_m} (D - x_f) dG(D) \right) \quad (2)$$

$$\pi_f^s = (\bar{P} - c) (1 - G(x_f)). \quad (3)$$

We denote by

$$\phi_m = \mathbb{E}_D \left[ \frac{q_m}{x_m} | D > x_f \right]$$

the average capacity utilization (capacity factor) of the dominant firm in periods with peak price. We can then compactly write its expected spot market profits as

$$\pi_m^s = (\bar{P} - c) (1 - G(x_f)) \phi_m. \quad (4)$$

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<sup>7</sup>In our model, there will be no need for a regulator to design a capacity mechanism that yield a total capacity above the maximum demand.

If fringe capacity is below the maximum demand, there are always some demand realizations, in which capacity withholding is optimal for the dominant firm, which implies

$$\phi_m < 1.$$

In contrast, the fringe firms will always utilize their whole capacity in peak price periods. Hence, while the dominant firm benefits from capacity withholding in the spot market, a fringe firm benefits even more from it. We therefore directly find

**Proposition 1.** *If  $x_m > 0$  and  $0 < x_f < 1$ , the dominant firm's expected spot market profits per capacity unit are strictly below those of a fringe firm and satisfy*

$$0 < \pi_m^s = \phi_m \pi_f^s.$$

## 2.2 Investments and Capacity Auctions

We assume that the regulator wants to impose a spot market price cap  $\bar{P}$  but at the same time wants to ensure a reliability level  $\rho$ , which shall measure the probability that no black out due to insufficient supply takes place, i.e.

$$\rho \equiv \Pr(D \leq x_m + x_f).$$

In our model, fixing a reliability level is equivalent to fixing a total capacity

$$x_T \equiv x_m + x_f.$$

We investigate a market design in which the desired capacity  $x_T$  is procured in an auction that yields a uniform capacity payment to each firm that is willing to provide capacity. Capacity procurement auctions exist in many electricity markets in the USA as well as in Central and South America. Examples are given by the Forward Capacity Market (ISO New England), the Colombia Firm Energy Market (see, e.g. Cramton (2006) or Cramton (2007)). We consider a multi-unit descending-bid auction. Ausubel and Cramton (2006) discuss this auction type and its application for capacity procurement. The auctioneer starts by announcing a high initial capacity payment (auction price) that is offered for each unit of capacity. At each price level, firms simultaneously announce the capacities they are willing to build. The price is continuously decreased as long as the offered supply of capacity exceeds the demand  $x_T$ .<sup>8</sup> At any given price, firms can at most

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<sup>8</sup>It is a common simplification in theoretical models to assume that prices are decreased in a continuous fashion, even though in real world auctions discrete bid decrements are prevailing.

offer the capacity that they offered at a higher price, i.e. offered capacity levels must weakly decrease during the auction. The resulting uniform capacity payment will be the infimum of those auction prices at which offered capacity was at least as high as demand.<sup>9</sup> Consider an auction outcome with capacities  $x_m$  and  $x_f$  and capacity payments  $z$ . A fringe firm's expected profits per capacity unit, including spot market profits, fixed cost and capacity payments, are then given by

$$\pi^f = (\bar{P} - c) (1 - G(x_f)) - k_f + z.$$

Hence, fringe profits are zero whenever fringe capacity and capacity payments satisfy the following relationship

$$z = k_f - (\bar{P} - c) (1 - G(x_f)). \quad (5)$$

Consistent with the assumption that fringe firms act as price takers and there is free entry, we assume that for any offered capacity payment  $z$  during the auction, total fringe supply will be such that the zero profit condition (5) exactly holds. As capacity payments decrease during the auction also the offered fringe capacity will decrease. Figure 1 illustrates this zero profit curve as a fringe supply curve for different capacity payments.

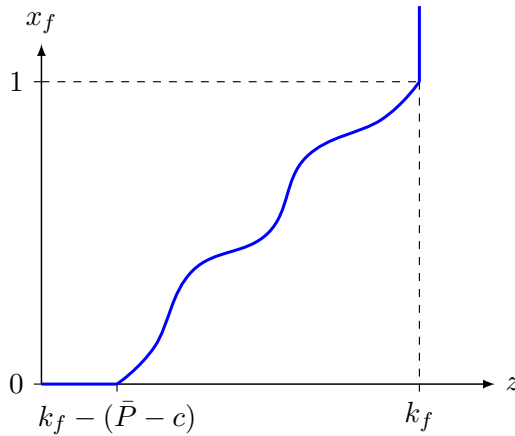


Figure 1: Illustration of the fringe's zero profit curve

If the dominant firm bids in all rounds some constant capacity  $x_m \in [0, 1]$ , we have the following auction outcome: the dominant firm gets the capacity

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<sup>9</sup>In case of excess supply at this price, capacity will be randomly allocated.

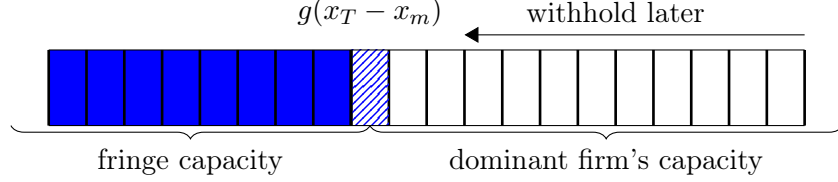


Figure 2: Illustrating the effect of a marginal capacity expansion of the dominant firm

$x_m$ , the fringe capacity is  $x_f = x_T - x_m$  and the capacity payments  $z$  are determined by the zero profit curve (5). Given the competitive bidding of the fringe firms, the dominant firm has no alternative bidding strategies that could implement different auction outcomes than those simple strategies of bidding a constant  $x_m$ . By substituting the values for  $z$  and  $x_f$ , the dominant firm's expected total profits

$$\Pi^m = (\pi_m^s + z - k_m) x_m$$

can be written as a function of the desired level of  $x_m$ . The dominant firm simply maximizes these profits over  $x_m$ . The derivative of this profit function can be written as <sup>10</sup>

$$\frac{\partial \Pi^m}{\partial x_m} = (k_f - k_m) - g(x_T - x_m)(\bar{P} - c)x_m. \quad (6)$$

For an intuitive interpretation for this derivative consider Figure 2. Each box shall illustrate a small capacity unit. The shaded box illustrates the small capacity unit that will be transferred from the fringe to the dominant firm if the dominant firm marginally increases its capacity. If the dominant firm performs capacity withholding in the spot market, let us assume w.l.o.g. that it first withholds capacity units that are more to the right in the Figure 2. Since the newly acquired capacity unit is the last unit that is withheld, the dominant firm makes with it approximately the same expected spot market profit than the competitive fringe did. Since the dominant firm has a fixed cost advantage of  $k_f - k_m$  for building the unit, its total profits for this unit are by this amount larger than they were for a fringe firm. Since the fringe firm's per unit profits determine the size of the capacity payments, the term  $k_f - k_m$  in  $\partial \Pi^m / \partial x_m$  captures this excess profit of the dominant firm.

<sup>10</sup>See the appendix for a derivation.

The remaining term in  $\partial\Pi^m/\partial x_m$  captures a negative effect of capacity expansion on the dominant firm's profits due to the fact that the expansion will decrease the auction price. Consider the case that realized spot market demand will be just slightly above the new fringe capacity, so that the dominant firm will withhold the newly acquired capacity. The density  $g(x_T - x_m)$  can be interpreted as a measure for the "probability" of this event. The fringe firms then make a spot market profit of  $(\bar{P} - c)$  per unit, which they would not have made if the dominant firm had not expanded its capacity. This increase in fringe firms' expected spot market profits translates into a lower auction price, which reduces the capacity payments for all  $x_m$  inframarginal capacity units of the dominant firm.

An optimal capacity choice balances these two effects. However, without imposing further, quite strong, assumptions on the demand function, the dominant firm's profit function is not in general concave. This means the first order condition of a zero derivative is not sufficient for an optimal capacity choice and we cannot rely on the implicit function theorem for comparative statics. Nevertheless, using methods of monotone comparative statics (Milgrom (2004)), we can establish the following general result.

**Proposition 2.** *If a fixed total capacity  $x_T$  is procured in a multi-unit descending-bid auction, the dominant firm's total profits  $\Pi^m$ , as well as its capacity  $x_m$  and market share, and the frequency of capacity withholding in the spot market are decreasing in the price cap  $\bar{P}$ .*

In addition to the discussion above, the following intuition may be helpful for understanding this result. Ceteris-paribus, a reduction of the price cap reduces the spot market profits of both the fringe firms and the dominant firm. Yet, average spot market profits of fringe firms are reduced by a larger amount than the profits of the dominant firm, since fringe firms have larger capacity utilization in periods with peak prices. The reduction of spot market profits of fringe firms will be offset by higher payments in the capacity auction so that the zero profit condition for fringe firms still holds. Since the dominant firm and the competitive fringe benefit equally from the increased capacity payments, there is a net benefit for the dominant firm from the shift to a lower price cap.

Basically, the fact that the dominant firm will hold back capacity in the spot market has a negative effect on its total profits once the effect on capacity payments is accounted for. Indeed, it would be optimal for the dominant firm if it could commit not to withhold any capacity at all: it can then benefit most strongly from its fixed cost advantage. The larger is the price cap and the dominant firm's market share, the larger will be the

difference between average spot market profit per capacity unit of a fringe firm and the dominant firm. Moreover, the effect of a *marginal* capacity expansion on profit differences is increasing in the price cap. Therefore, larger capacities are more desirable for the dominant firm when the price cap is low.

### Example - Uniformly Distributed Demand

We illustrate the outcome of the game for the simple case that the demand  $D$  is uniformly distributed on  $[0, 1]$ . Interestingly, the dominant firm's equilibrium capacity is then independent of the total capacity  $x_T$  and simply given by the ratio of fixed cost advantage to the difference of price cap and variable costs,

$$x_m^* = \frac{k_f - k_m}{\bar{P} - c}.$$

This means that for a fixed price cap  $\bar{P}$  market concentration falls if a higher reliability level  $\rho$  and thus a higher total capacity  $x_T$  is desired. This result does not necessarily extend to more general demand functions, however. The dominant firm's profits are given by

$$\Pi^m(x_m) = \frac{(k_f - k_m)^2}{\bar{P} - c}.$$

### Welfare

In our model a higher market share of the dominant firm corresponds to a larger welfare level. That is because of the following reasons: i) the total capacity is fixed, ii) due to the inelastic electricity demand there are no deadweight losses from capacity withholding, and iii) the dominant firm has a cost advantage over the competitive fringe. This welfare result is important to keep in mind.

However, there could be negative impacts of higher market concentration that are beyond the scope of our simple model. For example, if we would extend the model for uncertainty in predicted electricity demand, capacity withholding may have negative externalities on consumers and network operators. If demand is underestimated, capacity withholding may cause blackouts or requires excessive procurement of balancing energy from network operators. Since a higher market concentration leads to a higher frequency of capacity withholding, welfare effects are then less clear cut. Furthermore, we illustrate in the following subsection that a lower price cap

gives the dominant firm stronger incentives for anti-competitive practices that increase fixed costs of fringe firms.

### Raising Rivals' Costs

Assume at an initial stage, the dominant firm has the opportunity to conduct anti-competitive, e.g. creating entry barriers, that raise the fixed cost of fringe firms. See Salop and Scheffman (1983) for a classical treatment on raising rivals' costs. The dominant firm can pick an intensity level  $a \in [0, \bar{a}]$  of anti-competitive practices and the resulting fringe firm's fixed cost shall be given by

$$k_f = k_m + \Delta + a.$$

The parameter  $\Delta$  measures a natural fixed cost benefit of the dominant firm. For simplicity, we assume that demand is uniformly distributed and that the dominant firm has quadratic costs of anti-competitive practices

$$\psi(a) = \gamma a^2.$$

The dominant firm's total expected profits as a function of the sabotage intensity then satisfy

$$\Pi^m = \left( \frac{(\Delta + a)^2}{\bar{P} - c} - \gamma a^2 \right).$$

By solving for the optimal level of  $a$ , we directly find the following result:

**Proposition 3.** *The equilibrium intensity of anti-competitive practices  $a$  is decreasing in the price cap.*

*Proof.* By solving the FOC

$$\frac{\partial \Pi_m}{\partial a} = \frac{1}{P - c} 2(a + \Delta) - 2\gamma a = 0$$

and accounting for corner solutions, we find that the dominant's firm optimal level of anti-competitive practices  $a^*$  is by

$$a^* = \begin{cases} \frac{\Delta}{(P-c)\gamma-1} & \text{if } (P-c)\gamma > 1 \\ \bar{a} & \text{otherwise.} \end{cases}$$

The result follows immediately. □

### 3 Alternative Capacity Mechanisms

This section studies the robustness of our results by considering two alternative capacity mechanisms: subsidies and strategic reserves.

#### 3.1 Subsidies

Assume that before investments take place the regulator fixes a uniform capacity subsidy  $s$  to encourage sufficient capacity levels. The regulator fixes a price cap  $\bar{P}$  and chooses the subsidy such that the resulting equilibrium capacity  $x_f^*$  and  $x_m^*$  will add up to a target level of total capacity  $x_T$ .

The total profits per unit of capacity for a fringe firm are given by

$$\pi_f = \pi_f^s - k_f + s. \quad (7)$$

We assume that fringe firms enter the market until profits are driven down to zero. This zero profit condition can be written as

$$s = k_f - (\bar{P} - c) (1 - G(x_f^*)). \quad (8)$$

For  $s < k_f$  this condition uniquely determines the fringe capacity  $x_f^*$  which is increasing in the per unit subsidies  $s$ . As in the auction case, the fringe's equilibrium capacity does not depend on the dominant firm's capacity  $x_m$ . That is because the dominant firm will always withhold sufficient capacity to drive prices up to  $\bar{P}$  when  $D > x_f^*$ . Consequently, it does not matter whether the dominant firm invests before, at the same time, or after the competitive fringe: the resulting equilibrium capacities will be the same.

The dominant firm's equilibrium capacity  $x_m^*$  maximizes total profits  $\Pi^m$  given the fringe's equilibrium capacity  $x_f^*$  and the previously fixed subsidy  $s$ . In contrast to the auction, the capacity payments are no longer a function of the dominant firm's capacity choice. The dominant firm's first order condition is given by

$$\frac{\partial \Pi^m}{\partial x_m} = (\bar{P} - c) (1 - G(x_f^* + x_m^*)) - (k_m - s) = 0. \quad (9)$$

The term  $k_m - s$  simply describes the net cost of an additional capacity unit. The term  $(\bar{P} - c) (1 - G(x_f^* + x_m^*))$  captures the following simple effect of a marginal capacity expansion on spot market profits. In situations, in which demand exceeds the total capacity, the additional marginal unit is sold with a markup of  $\bar{P} - c$ .

Independent of the form of the demand distribution  $G$ , the dominant firm's expected profits are strictly concave in  $k_m^*$ . Hence the fringe's zero profit condition and the dominant firm's first order condition uniquely determine equilibrium investments for any given pair of subsidies  $s$  and price cap  $\bar{P}$ . It follows from (9) that for any fixed total capacity  $x_T < 1$  the subsidies  $s$  must increase if the price cap  $\bar{P}$  decreases. In the special case of a 100% reliability level, i.e.  $x_T = 1$ , subsidies must always be equal to the dominant firm's fixed cost  $k_m$ .<sup>11</sup>

Even though the dominant firm's first order condition is quite distinct from the one in the auction case, we find qualitatively the same comparative static results with respect to the price cap.

**Proposition 4.** *If the regulator uses subsidies  $s$  to fix a reliability level  $\rho \in [0, 1]$ , the dominant firm's total profits  $\Pi^m$ , as well as its capacity  $x_m$  and market share, and the frequency of capacity withholding in the spot market are decreasing in the price cap  $\bar{P}$ .*

The intuition for this result is similar as in the auction case. The regulator must compensate a reduction in the price cap by a higher subsidy level. The dominant firm benefits from that shift of spot market revenues to capacity subsidies, since it has a lower capacity utilization at peak prices than fringe firms.

### 3.2 Strategic Reserves

Strategic reserves are generation capacity controlled by a regulator who only uses it in case of a supply shortage and when spot market prices rises above a previously determined trigger price. In some liberalised electricity markets, strategic reserves exists in addition to the energy-only market.<sup>12</sup> The strategic reserve can be used to implement a desired reliability level without using capacity payments. Assume the trigger price of the strategic reserve is equal to the price cap  $\bar{P}$  and the regulator procures a strategic reserve of size  $x_r$  that shall satisfy  $x_r + x_f^* + x_m^* = x_T$  for a specified total capacity level. The strategic reserve shall only used in case of shortage and shall not push prices below the cap  $\bar{P}$ , i.e.

$$q_r = \min\{x_r, \max\{0, D - q_f - q_m\}\}.$$

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<sup>11</sup>Yet, for  $s = k_m$ , the dominant firm is indifferent between all capacity levels. Clearly, an auction is advantageous for targeting a specific capacity goal.

<sup>12</sup>For example, strategic reserve exists in Sweden and Finland.

Given this usage policy, the strategic reserve then does not influence the distribution of spot market prices. Correspondingly, the equilibrium investments and profits of the dominant firm and the competitive fringe are independent of the size of the strategic reserve. The equilibrium capacities  $x_m^*$  and  $x_f^*$  are given by the solution of the zero profit condition (8) and first order condition (9) of the previous subsection for the case of a zero subsidy  $s = 0$ . We find the following limit result for changes in the price cap.

**Proposition 5.** *Consider an energy-only market with strategic reserves and the limit  $\bar{P} \rightarrow \infty$ . The equilibrium capacities of the dominant firm and the competitive fringe then satisfy  $x_f \rightarrow 1$  and  $x_m \rightarrow 0$ .*

### 3.3 Equivalent equilibrium outcomes under uniformly distributed demand

Interestingly, for the special case of uniformly distributed demand and fixed total capacity  $x_T$  and price cap  $\bar{P}$ , we find that the dominant firm's equilibrium capacity and expected profits are the same under all three capacity mechanisms.

$$x_m^* = \frac{k_f - k_m}{\bar{P} - c} \text{ and } \Pi^m = \frac{(k_f - k_m)^2}{\bar{P} - c}$$

Furthermore, fringe capacity and the distribution of spot market prices will be the same for capacity auctions and subsidies. Under strategic reserves, fringe capacity will be generally lower, however, and replaced by reserve capacity. Consequently, under strategic reserves there is a larger fraction of periods in which the spot price peaks.

## 4 Conclusion

It has been the purpose of this study to understand the effects of different capacity mechanisms on the market structure. For our analysis, we have chosen a model consisting of a dominant firm and a competitive fringe. We then have investigated the impact of price caps and capacity payments on the investment incentives and market concentration.

As discussed in Section 2, we find that in our dynamic model with capacity procurement auctions higher price caps reduce the profits and the market share of the dominant firm as well as the frequency of capacity withholding in equilibrium. This means that even though lower price caps reduce the

potential for market power exertion in the short term and the total capacity in the market can be fixed, there is a robust counter-veiling force that a reduction of price caps increases market concentration. This result is very robust and holds true for other capacity mechanisms as it has been shown in section 3.

To extend this preliminary version of our paper, our next step will be to analyse the question whether these results hold true for electricity markets with different market structures, e.g. for markets with many dominant firms or markets with cost of entry. A second question could address the distribution of different technologies for the different market designs.

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## 5 Appendix

The appendix contains all proofs of the paper. Note that by the assumptions on  $G$  and  $g$ ,  $\Pi^m(x_m, \bar{P})$  is twice continuously differentiable in  $x_m$  and  $\bar{P}$ , if  $x_m + x_f \leq 1$ . The case that  $x_m + x_f > 1$  is excluded.

### Proof of proposition 2.

The proof is separated into two steps: First, we prove that the dominant firm's profits are a decreasing function of the price cap. Second, we show that the dominant firm's equilibrium capacities are a decreasing function of the price cap.

(i) The zero profit condition of the competitive fringe, which has to be satisfied is given by

$$z^* = -\pi_f^s + k_f. \quad (10)$$

The dominant firm's profits are therefore given by

$$\begin{aligned} \Pi^m &= (\pi_m^s + z^* - k_m) x_m \\ &= (\pi_m^s - \pi_f^s + k_f - k_m) x_m. \end{aligned} \quad (11)$$

We plug the difference of the expected variable spot market profits into (11) and get the following formula:

$$\Pi^m(\bar{P}, x_m) = (- (\bar{P} - c) (1 - G(x_T - x_m)) (1 - \phi_m) + k_f - k_m) x_m. \quad (12)$$

This equation leads directly to the following lemma:

**Lemma 1.** *If the dominant firm's capacity  $x_m$  is fixed,  $\Pi^m$  is strictly decreasing in  $\bar{P}$ .*

Lemma 1 does not state that the dominant firm's total profits are decreasing in the price cap since generally  $x_m$  depends on  $\bar{P}$ . We consider two different price caps  $\bar{P}_L$  and  $\bar{P}_H$ ,  $\bar{P}_L < \bar{P}_H$ . Let

$$x_m^L \in \operatorname{argmax}_{x_m} \Pi^m(\bar{P}_L, x_m) \quad (13)$$

$$x_m^H \in \operatorname{argmax}_{x_m} \Pi^m(\bar{P}_H, x_m) \quad (14)$$

denote optimal capacity selections of the dominant firm given  $\bar{P}_L$  and  $\bar{P}_H$ , respectively. By optimality of  $x_m$  and Lemma 1 the following inequalities hold:

$$\Pi^m(\bar{P}_L, x_m^L) \geq \Pi^m(\bar{P}_L, x_m^H) > \Pi^m(\bar{P}_H, x_m^H). \quad (15)$$

We have therefore shown that the dominant firm's total profits  $\Pi^m$  are strictly decreasing in the price cap  $\bar{P}$ .

(ii) We show that  $x_m^*$  is a decreasing function of  $\bar{P}$ . The dominant firm's profit function is given by

$$\begin{aligned}\Pi^m &= (\pi_m^s + z^* - k_m) x_m \\ &= (\bar{P} - c) \left( x_m (1 - G(x_T)) + \int_{x_T - x_m}^{x_T} (D - x_T + x_m) g(D) dD \right) \quad (16)\end{aligned}$$

$$+ z^* x_m - k_m x_m \quad (17)$$

The auction price is determined by the fringe's zero profit condition. Plugging

$z^* = k_f - (\bar{P} - c) (1 - G(x_T - x_m))$  into the formula leads to

$$\begin{aligned}\Pi^m &= (\bar{P} - c) \left( x_m (1 - G(x_T)) + \int_{x_T - x_m}^{x_T} (D - x_T + x_m) g(D) dD \right) \\ &\quad + (k_f - (1 - G(x_T - x_m)) (\bar{P} - c)) x_m - k_m x_m\end{aligned}$$

The dominant firm's first-order condition is therefore given by

$$\frac{\partial \Pi^m}{\partial x_m} = k_f - k_m - g(x_T - x_m) (\bar{P} - c) x_m = 0. \quad (18)$$

By taking the derivative with respect to  $\bar{P}$  we get

$$\frac{\partial \partial \Pi^m}{\partial x_m \partial \bar{P}} = -g(x_T - x_m) x_m < 0 \quad (19)$$

since  $g > 0$ . We can apply an analogue of the "Monotone Selection Theorem" to show that  $x_m^*$  is a strictly decreasing function of the price cap  $\bar{P}$ .

**Theorem 1.** (*Analogue of the Monotone Selection Theorem*) Assume that the function  $\Pi^m$  has SDD (strictly decreasing differences). Then every optimal selection  $x_m^*(\bar{P}) \in \operatorname{argmax}_{x_m} \Pi^m(x_m, \bar{P})$  is strictly decreasing in  $\bar{P} \in [0, \infty)$ .<sup>13</sup>

**Proof** Let us fix arbitrary  $\bar{P}_L, \bar{P}_H \in [0, \infty)$  satisfying  $\bar{P}_L < \bar{P}_H$ . Let us again denote optimal selections by

$$x_m^L \in \operatorname{argmax}_{x_m} \Pi^m(\bar{P}_L, x_m) \quad (20)$$

$$x_m^H \in \operatorname{argmax}_{x_m} \Pi^m(\bar{P}_H, x_m) \quad (21)$$

<sup>13</sup>For the monotone selection theorem see Milgrom (2004), p.102. Since  $\Pi^m(\cdot, \cdot)$  is sufficiently smooth, SSD is equivalent to  $\frac{\partial \partial \Pi^m}{\partial x_m \partial \bar{P}} < 0$  for all  $(x_m, \bar{P}) \in [0, 1] \times [0, \infty)$ .

Let us assume that  $x_m^L \leq x_m^H$ . We will bring this assumption to a contradiction. By definition of  $x_m^H$  and  $x_m^L$  we have

$$\Pi^m(x_m^L, \bar{P}_L) \geq \Pi^m(x_m^H, \bar{P}_L) \text{ and } \Pi^m(x_m^H, \bar{P}_H) \geq \Pi^m(x_m^L, \bar{P}_H).$$

This implies that

$$\Pi^m(x_m^L, \bar{P}_L) + \Pi^m(x_m^H, \bar{P}_H) \geq \Pi^m(x_m^H, \bar{P}_L) + \Pi^m(x_m^L, \bar{P}_H)$$

which is equivalent to

$$\Pi^m(x_m^L, \bar{P}_L) - \Pi^m(x_m^L, \bar{P}_H) \geq \Pi^m(x_m^H, \bar{P}_L) - \Pi^m(x_m^H, \bar{P}_H). \quad (22)$$

However by assumption  $x_m^L \leq x_m^H$  and thus the SDD property of  $\Pi^m$  yields a contradiction to (22). Hence  $x_m^L > x_m^H$ , i.e.  $x_m^*$  is strictly decreasing in  $\bar{P}$ .

#### Proof of proposition 4.

The proof is separated into two steps: First, we prove that the dominant firm's profits are a decreasing function of the price cap. Second, we show that the dominant firm's equilibrium capacities are a decreasing function of the price cap.

(i) The proof is similar to proof (i) of the proof of proposition 2. Due to the competitive fringe's zero profit condition, subsidies have to satisfy the following condition:

$$s^* = k_f - \pi_f^s. \quad (23)$$

The dominant firm's profits are therefore given by

$$\begin{aligned} \Pi^m &= (\pi_m^s + s^* - k_m) x_m \\ &= (\pi_m^s - \pi_f^s + k_f - k_m) x_m. \end{aligned} \quad (24)$$

For the rest of the proof we refer to proof (i) of the proof of proposition 2.

(ii) We show that  $x_m$  is strictly decreasing  $\bar{P}$ . Due to the dominant firm's first-order condition, subsidies have to satisfy the following condition

$$s^* = k_m - (\bar{P} - c) (1 - G(x_T)). \quad (25)$$

Plugging  $s^*$  into the fringe's zero profit condition, leads to

$$(\bar{P} - c) (1 - G(x_f)) = k_f - k_m + (\bar{P} - c) (1 - G(x_T)) \quad (26)$$

$$\iff x_f = G^{-1} \left( G(x_T) - \frac{k_f - k_m}{\bar{P} - c} \right). \quad (27)$$

Therefore, by adjusting  $s$  such that the reliability level  $\rho$  and the total capacity  $x_T$  are kept constant, we find that  $x_f$  is an increasing function of  $\bar{P}$ . Since  $x_T$  is kept constant,  $x_m$  is a decreasing function of  $\bar{P}$ .

**Proof of Proposition 5.**

The equilibrium capacities in a market with strategic reserve are given by the solution of the zero profit condition (8) and first order condition (9) for the case of a zero subsidy  $s = 0$ . For  $\bar{P} \rightarrow \infty$  it follows from the fringe's zero profit condition that  $x_f \rightarrow 1$ . Since  $x_f + x_m \leq 1$  and  $x_m \geq 0$  it follows that  $x_m \rightarrow 0$ .