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Risks and incentives for gaming in electricity redispatch markets

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Abstract:

Market design for electricity often ignores network congestion initially and addresses it in a second, so-called 'redispatch' stage. For market participants, any two-stage design offers an opportunity to strategically optimize between the different market stages. The current debate is how to design a market-based redispatch to integrate new actors, in particular consumers, given increasing levels of congestion. Strategic bidding may occur if market players anticipate congestion in their region and manipulate bidding to exploit this congestion.

In this paper, we pick up the current debate and study the precise incentives for gaming with respect to competitive conditions on the market with a formal model. We propose that depending on competitive conditions, the expected profits of gaming can be negative and link the range of negative expected gaming profits to a so-called reference bidder, reflecting competitive conditions in the market. We also discuss how several potential remedies can increase the risk of the gaming strategy and can thereby reduce the practical potential for gaming. With this paper, we provide the theoretical framework for authorities and empirical works to assess the potential of market-based as opposed to administrative redispatch.

Keywords: Electricity market, Market-based redispatch, Strategic behaviour, Inc-Dec gaming, congestion management

JEL-classification: D21, D22, D43, L13, L94

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1. Introduction

The surge of renewable energies and increasing consumption following electrification causes severe congestion in electricity networks. One way to address network congestion is by redispatch.[1] Market clearing then takes place in two steps. First, generators and consumers bid and are scheduled in a first market stage that ignores network constraints. Second, whenever the allocation from the first market stage violates existing network constraints, the network operator starts to redispatch regionally, i.e., order up and down adjustments of generators and consumers to take account of network constraints until the final dispatch schedule is compatible with the network capacity. Generators and consumers are compensated for the adjustment of their previously scheduled energy in this second step.[2] The network operator aims at a cost-minimizing redispatch. This supply of redispatch by consumers or generators is also called flexibility; in other words, the network operator procures flexibility to resolve network congestion.

For market participants, any two-stage design offers an opportunity to strategically optimize between the different market stages. To avoid issues of strategic behavior and market power, many countries at first opted to settle the second redispatch stage administratively. This means that the network operator orders flexibility and compensates according to predetermined regulated cost estimates. Given the need for precise technology cost estimates within the administrative regime, historically, system operators would enlist only large-scale conventional generators to adjust their output and take consumption as given. Providing a precise cost estimate to redispatch other actors in the system administratively proved to be difficult.

The current debate is how to design redispatch to integrate new actors, in particular consumers, given increasing levels of congestion. In Germany, for instance, the costs for congestion management measures amounted to about € 1.4 billion or 0.04 % of its GDP in 2020 (BNetzA & BKartA, 2022). The European Union ruled that redispatch is to be organized in a market-based manner unless the expected level of competition in

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[1] Nodal markets, as described by Schweppe et al. (1988), take all constraints into account in one single stage with a large number of smaller areas. They are an alternative to this set-up with a first allocation that ignores network constraints and a second stage of redispatch. In the short run, nodal markets are efficient in allocating electricity supply in a constrained transmission grid (Hogan 1992). Operation of nodal markets can be more complex and distributive effects from congestion become more obvious. Therefore, the European electricity market currently operates with a two-stage design.

[2] In the case that the adjustment entails a decrease of production or an increase in consumption, the compensations are negative, i.e. generators and consumers pay for the adjustment. This is because in the case of generators, for instance, they save variable costs by not producing.

such a market were insufficient (Article 13, EU Regulation 2019/943). In such a system, the flexibility suppliers bid on a redispatch market, upon which the network operator will purchase flexibility and compensate following the bids and market clearing prices.

Intuitively, market-based redispatch is the preferred option, simply because it allows the market to align supply and demand efficiently. However, it might also provide flexibility suppliers with an incentive for strategic bidding, which potentially manipulates market outcome and artificially worsens network congestion resulting in welfare losses (e.g. ACER, 2021; ENTSO-E & Frontier Economics, 2021; BMWi, 2020). This strategic behavior is known as “increasing-decreasing” (in short: inc-dec) or gaming strategy. This is why in response to the EU Regulation, network regulators among others have raised concerns about the impact of strategic behavior on the operation cost and on network stability (ACER, 2021; CEER, 2021).

Strategic bidding in this context happens if market players anticipate that congestion will occur in their region and change their bidding behaviour on the redispatch and on the general market to exploit this congestion. An example illustrates. Suppose that a strategic bidder has such high production costs, that her generation would not be scheduled in the first market stage if she bid true marginal costs. With non-strategic bidding, she would be out of the market. With gaming, she strategically bids below production costs in order to be scheduled in the first market stage, only to be redispatched in the second stage. Thus, a profit can be made. We will discuss this bidding behavior in detail further below.

To the best of our knowledge, the literature lacks a formal representation of the effect of competition on the incentives of gaming in redispatch or flexibility markets. Therefore, in this paper, we pick up the current debate and study the precise incentives for inc-dec gaming with respect to competitive conditions on the market. We use a formal model to define the profit of a strategic bidder as a function of probability to be selected in both markets. In both markets, this probability depends endogenously on the gamer’s own bid as well as exogenously on what we call the reference bid, reflecting the strength of the competition in the market. The gamer needs to outbid this reference bid to be scheduled in the market. We focus on the incentives of a single potential gamer and we do not model a game-theoretical equilibrium between several strategic bidders. We propose that depending on competitive conditions, expected profits of gaming can be negative. We show that the range where the expected profit of gaming is negative is critically determined by the reference bid. The stronger the competition in the market, the less likely gaming will occur. Based on the theoretical framework we also discuss how several potential remedies can increase the risk of the gaming strategy and can thereby reduce the practical potential for gaming.

This paper has a theoretical focus to describe the precise incentives of gaming. How strong the incentives are in practice, is a context-dependent empirical question. With this paper we provide the theoretical framework, for authorities to carefully analyze the real market situation empirically and assess the potential of market-based redispatch. The assessment can differ regionally: in some regional markets the incentives for gaming will be strong, whilst in others they are not. Therefore, adequate market design may differ regionally. The framework presented in this paper can also serve to assess and develop potential market designs accordingly.

The structure of the paper is as follows. Section 2 provides a brief overview of the relevant literature on the relation between competitive market conditions and incentives for gaming. Section 3 is the core of the paper and presents the model and the main claims. Section 4 discusses the key concept of the reference bidder and suggests remedies. Section 5 concludes.

2. Literature

The analysis provided in this paper adds to the literature on strategic behaviour in two-stage markets in general and electricity markets in particular.

Ito & Reguant (2016) and Borenstein et al. (2008) analyze strategic bidding in sequential electricity markets of equal geographical scope on the examples of the electricity markets in Spain and California. They study the role of market power in sustaining price differences between sequential markets which should otherwise converge due to arbitrage. Hogan (1997), Borenstein et al. (2000), Joskow and Tirole (2000) among others analyse the incentives for market power abuse in locationally differentiated but not sequential markets. They find that generators have incentives to bid strategically in an otherwise efficient nodal market, depending on different mechanisms for the allocation of transmission capacity such as physical or financial transmission rights. The analysis of market-based redispatch essentially combines these two strands of literature.

Literature that specifically addresses gaming based on arbitrage both in time and space is relatively limited so far. Concern about this type of behavior has been first raised by Stoft (1998) as a criticism of the implementation of the Californian zonal market at the time (c.f. Palovic et al. 2022). Dijk & Willems (2011) as well as Holmberg & Lazarczyk (2015) implicitly study this behaviour in theory, yet they do not consider the effect of competition. Using agent-based modelling, Sarfati et al. (2019, 2020) show the network user behavior motivated by such incentives to result in large production inefficiencies and associated network costs. Reviewing the international experience with market-based redispatch, Palovic et al. (2022) find this type of gaming to be rare in practice and to occur in the presence of market power.

The academic discussion is evolving in view of the topicality. Graf et al. (2020) empirically trace gaming in Italy. Hirth & Schlecht (2020) provide a model-based assessment of gaming in a future market-based framework in Germany, whereas Perino & Schnaars (2021) provide simulation-based indication for gaming within the existing administrative framework. Brunekreeft et al. (2020) qualitatively analyze the incentives for gaming with a focus on consumers. Furthermore, Beckstedde et al. (2022) differentiate in a model-based analysis between three different gaming strategies that can emerge.

Building on this state-of-knowledge we present in the following a decomposition of the strategic considerations of potential gamers in a two-stage market design. Based on this we show how the incentives for gaming are limited to specific circumstances of imperfect competition. Thereby, we provide the theoretical framework to assess concerns of gaming in real-world electricity markets and pave the way to soundly discuss and compare potential remedies.

3. The Analysis

3.1. The model

To analyse the incentives for gaming between two subsequent market stages with different geographical size, we use a stylized model of two regions that are connected by constrained transmission capacity. Each region hosts generators and consumers; together they constitute the bidders i in the market. To simplify, we assume that each generator and consumer is only active in one region. One region is characterized by net generation (i.e. local generation exceeds local consumption), while the other is characterized by net consumption. Thus, one region is typically exporting and the other region importing.

We model two subsequent market stages. The first market stage invites bidding from both regions without regard to physical constraints. The bid by bidder *i* in the first stage to produce or consume the quantity q_i is denoted by b_i^f (with superscript f for first market stage). This market is cleared by accepting generating bids below and consumption bids above the equilibrium price, i.e. a price at which quantities demanded are equal to quantities supplied. In the event that the first stage market results in congestion, the second stage invites bidders in the two regions separately to offer the necessary adjustments to resolve the constraint. This means that bidders deviate from their original schedule from the first market stage. The financial transactions from the first stage are unaffected by redispatch, as common for the European power markets. Yet, if the change in dispatch causes additional cost, i.e. in case of increased generation or forgone consumption, bids reflect the payments bidders are willing to accept to compensate for the opportunity costs.[3]

The network operator aims at minimizing total redispatch costs of the second stage, i.e. the net payments for redispatch in the two regions. In the importing region, the operator selects the lowest bids offered (i.e. covering additional costs of the suppliers); whereas in the exporting region the highest bids offered (i.e. repayment of saved costs) are selected until the congestion is resolved. The bid by bidder *i* to adjust production or consumption by q_i in the second stage is denoted by b_i^s (with superscript s for second market stage).[4] We assume discriminatory pricing (pay-as-bid) in both market stages.[5]

In each there are two representative flexibility providers as potential gaming bidders (one generator, one consumer each). As depicted in Figure 1, we focus in the model on a gaming generator (j) with constant marginal generation costs (C_j) in the export constrained region.[6] The figure relates the physical set-up of the two-region model on

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[3] Vice versa if redispatch saves cost or increases utility.

[4] We assume for simplicity that the quantity of (a change in) consumption and production is q_i in both stages, which means that the bidder will not change the quantity offered between the two stages. The differentiation between quantites offered in the first and the second stage is readily possible, yet does not offer more insights.

[5] This market design is common in practice for redispatch markets (e.g. the Netherlands, the UK). We also chose it for the first market stage to focus on the effect of two market stages and not of differences in pricing between the stages. We expect a pay-as-cleared approach to be similar in expectations. Depending on the specific assumptions and settings, however, the two auction formats differ in detail (c.f., e.g., Kahn et al., 2001; Federico & Rahman, 2003; Fabra et al., 2006; Willems & Yu, 2022). We leave the analysis of pay-as-cleared pricing and of different pricing rules between the stages for future research.

[6] This is the classical case of inc-dec gaming, i.e. the generator increases production in the first stage and decreases it in the second stage, and it is well suited to outline the incentives for gaming. The cases of the

the lefthand side with the two-stage market set-up in the middle and on the righthand side. In the first market stage (in the middle) all generators and consumers trade energy in one uniform market; whereas in the second stage it is separated into two local markets, on which both generators and consumers from the respective region can offer adjustments of the first stage's market result to the system operator.

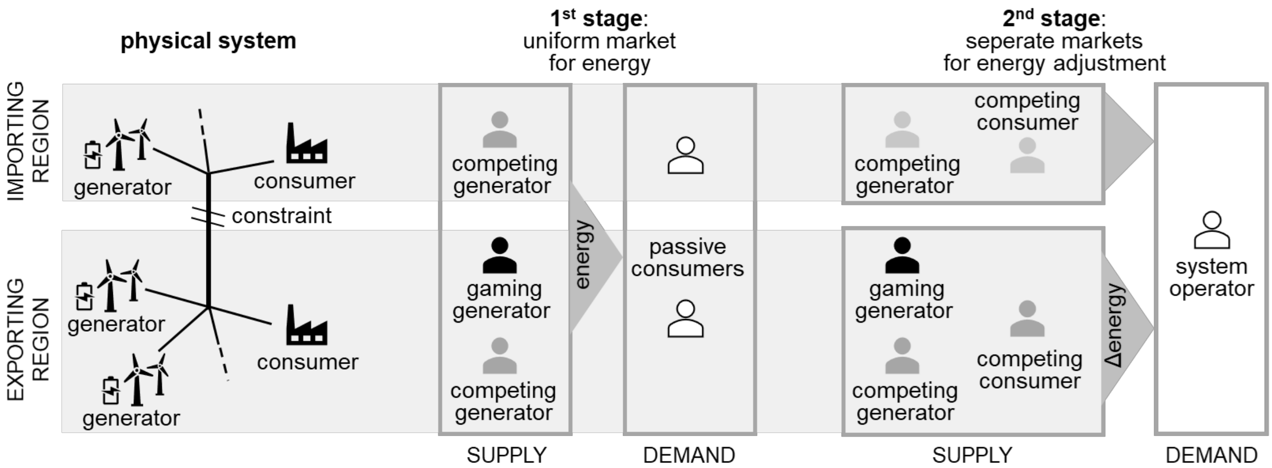

Figure 1: The set-up of the physical system (left) and the two market stages for energy (middle) and energy adjustments (right); the focus lies on a gaming generator in the exporting region (displayed in black)

3.2. Strategic considerations of gaming by generators in the exporting region

The illustrated gaming generator j in the exporting region is assumed to have such high marginal costs that she would not be dispatched in the first market stage at a given consumption level, if she bid her true costs. When gaming, she strategically bids below marginal costs in the first stage in order to be dispatched initially and to subsequently enter a profitable bid in the second stage, speculating that congestion will occur and that her bid will be selected to resolve congestion. The bid in the first stage reflects the payment the generator is willing to accept for producing a certain quantity. The bid in the second stage of the export constrained region reflects the payment the generator is willing to make for not producing (downward adjustment) of the previously sold quantity as generation costs will be saved.

other potential gamers, i.e. generators in the importing region and consumers in both regions, are different in detail (e.g. what constitutes the opportunity costs), but the incentives and risks are very similar. For reasons of space we focus on this case.

Under the pay-as-bid rule, the first stage's bid (b_j^f) is what the generator receives (if selected) for producing a certain quantity, and conversely the second stage's bid (b_j^s) is what the generator pays (if selected) for not producing the previously sold quantity.

Let $\alpha(b_j^s)$ be the probability of the generator's bid being selected in the second stage, $\beta(b_j^f)$ denote the probability of her bid being selected in the first stage, and γ be the probability that congestion will occur.[7] Figure 2 illustrates the overall set-up, abstracting from the market design as depicted in figure 1. It shows the potential outcomes of each stage, corresponding probabilities and potential payoffs connected with the gaming decision: the first potential outcome is that the bid of the gamer is not selected in the first market stage; the second is that congestion does not occur, the third that the gamer's bid is not selected in the second stage and the fourth that the bid is selected. Only in the latter case gaming would be successful; whether or not the expected profit of the successful game is positive depends on the price differences between the stages and the associated probabilities.

[7] The probability of congestion (γ) depends on the result of the first market and, hence, on the bidding of the market participants in this stage. We assume that a single bidder believes that her bid does not affect this probability.

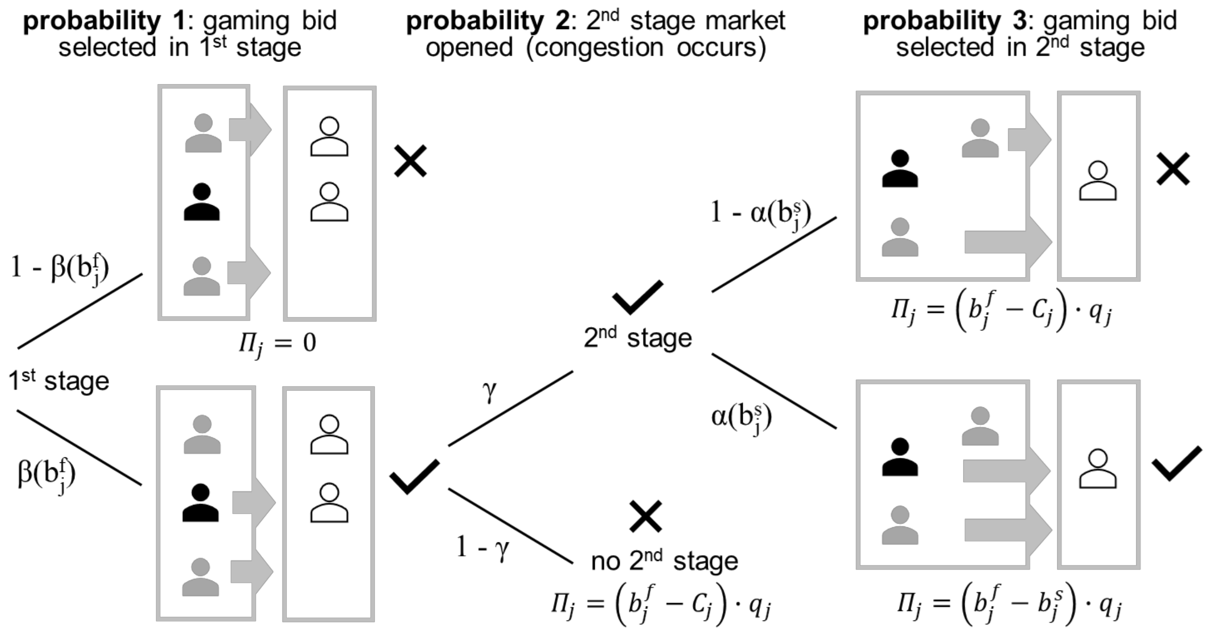

Figure 2: Components of the decision-making of a gaming generator over two market stages: potential outcomes of each stage, corresponding probabilities and potential payoffs

Assume that the gaming generator was selected in the first market stage (lower branch depicted in Figure 2). In the case that congestion occurs (i.e the second market stage becomes necessary) and the generator is selected in the second market stage as well the profit would be (with a probability of $\gamma \cdot \alpha(b_j^s)$)

$$\Pi_j = \left(b_j^f - C_j\right) \cdot q_j + \left(C_j - b_j^s\right) \cdot q_j = \left(b_j^f - b_j^s\right) \cdot q_j \tag{1}$$

In an export-constrained region, in case of redispatch, the generator will be asked to run down production as compared to the schedule in the original dispatch. The notion of the pricing rule is that the generator is paid as if she had produced under the unconstrained schedule (thus acknowledging the original contract), but has to pay back the cost that are saved by not producing. As these costs are not known, they are approximated by the bid on the redispatch market. This rule reflects in the righthand term of eq. (1). It implies that a bidder will try to bid low on the redispatch market in this region. The two market results would sum up to the difference between the two market stages times the quantity sold.

In the cases that either congestion does not occur or that the gamer is not selected in the second stage, the profit would reduce to the result of the first stage and hence be negative, since the gamer has bid strategically below cost on the first market:

$$\Pi_j = \left(b_j^f - C_j\right) \cdot q_j \tag{2}$$

Let us now look at the expected profit function of *j* in more detail. Generator *j*'s expected profit of gaming ($E\Pi_j\left(b_j^f, b_j^s\right)$) is the sum of the expected profits of both market stages, which depend on her bids in the respective stages (b_j^f and b_j^s).

$$E\Pi_j\left(b_j^f, b_j^s\right) = E\Pi_j^f\left(b_j^f\right) + E\Pi_j^s\left(b_j^f, b_j^s\right) \tag{3}$$

The expected profit of her bid in the first stage is given by

$$E\Pi_j^f = \beta\left(b_j^f\right) \cdot \left(b_j^f - C_j\right) \cdot q_j, \tag{4}$$

i.e. the probability that the bidder will be selected based on her bid ($\beta(b_j^f)$) times the difference between the bid and production costs for the quantity supplied.

The expected profit of the bidder in the second stage is given by

$$E\Pi_j^s\left(b_j^f, b_j^s\right) = \beta\left(b_j^f\right) \cdot \gamma \cdot \alpha\left(b_j^s\right) \cdot \left(C_j - b_j^s\right) \cdot q_j \tag{5}$$

i.e. in short, the product of the probability of being selected in the first stage, the probability of network congestion, the probability of being selected in the second market stage and the difference between the price paid for not producing the adjusted quantity and saved generation costs. For the generator in the export constrained region the adjustment in the second stage is the decrease of production quantity sold in the first stage.

In the second market stage of the export constrained region the system operator selects the highest bids, which express the willingness to pay of the bidders for increasing consumption or decreasing generation, to solve the constraint. A successful gaming strategy requires that the bid is accepted by the network operator in the second stage. To be selected the gaming bidder thus needs to outbid what we call the "reference bid" (b_{ref}^s). The reference bid is defined in the export constrained region as the lowest accepted bid in the second market, i.e. the bid that is just needed to resolve congestion.[8] The reference bidder could be a generator in the second stage market, who reduces her first-stage-dispatch. Or it could be a consumer in this market, who increases consumption in the second stage. This bidder does not need to engage in gaming to be active in the second stage. A generator would be dispatched in the first

[8] We refer to section 4 for a more detailed discussion on the reference bidders.

stage, anyway, due to low production costs, and a consumer, respectively, would not have been served in the first stage due to low willingness to pay.

The gaming generator maximizes her expected profit of gaming. Inserting equations (4) and (5) in (3), she maximizes

$$\max_{b_j^f\, b_j^s} E\Pi_j = \beta(b_j^f) \cdot \left[(b_j^f - C_j) \cdot q_j + \gamma \cdot \alpha(b_j^s) \cdot \left(C_j - b_j^s\right) \cdot q_j\right] \tag{6}$$

subject to the constraint that the expected profit from gaming is positive.

The generator's decision-making on gaming in the export-constrained region hence contains the three decisive factors:

1. the probability that the strategy succeeds ($\beta\left(b_j^f\right) \cdot \gamma \cdot \alpha(b_j^s)$),

2. the potential profit of the successful strategy (if generation is first dispatched and then reduced downward in redispatch this results in a profit of $(b_j^f - b_j^s) \cdot q_j$), and

3. the impending losses if the strategy fails, i.e. in this case of having to produce below marginal costs ($(b_j^f - C_j) \cdot q_j$).

3.3. The role of competition in the considerations of strategic bidders

In the following, we argue that the reference bid of the second stage determines whether expected profit of gaming is positive or negative, for all optimal bids. The reference bid reflects competitive pressure in this market stage. The stronger the competitive pressure, the higher the reference bid and the more likely expected profits of gaming will be negative.

To show this, we conduct the following steps: First, focusing on the components of the expected profit of the second stage, we show how the probability of selection of the second stage is affected by the expected reference bid of this stage. Second, we derive the optimal bid of the second stage and how it depends on the expected reference bid. Third, we show that the overall expected profit of gaming based on the optimal second stage bid decreases with the expected reference bid of the second stage. Fourth, we derive the conditions under which gaming leads to expected losses, even if the bids are chosen optimally, and derive from this the threshold value of the expected reference bid of the second stage for which the expected profit of gaming is equal to zero.

3.3.1. The probability of being selected in the second market stage

In the following we discuss in more detail the probability of being selected in the second market stage and show how it is affected by the expected reference bid of this stage. Since the probability of selection (β) plays a minor role in this respect, we do not go into detail on it here.

To be selected in the second stage the gaming generator's bid has to exceed this stage's reference bid, b_{ref}^{s}. While this might seem counterintuitive, it is owed to the fact that in the exporting region generators offers up their cost savings from reducing production.[9] Assuming that the reference bid is a random variable that is normally distributed[10], the probability of being selected in the second market stage can be expressed as follows:

$$\alpha\left(b_j^s\right) = Pr\left(b_{ref}^s \leq b_j^s\right) = \int_{-\infty}^{b_j^s} f(x)\,dx \tag{7}$$

Where Pr denotes the probability of being selected in the respective market, $f(x)$ the probability density function (PDF) of the respective reference bid, μ its mean (the expected reference bid) and σ its standard deviation.

The corresponding cumulative distribution function (CDF) to the probability density function is denoted by $F(\cdot)$, i.e. $\int_{-\infty}^{b_j^s} f(x)\,dx = F(b_j^s)$. For a normally distributed variable x, the CDF can be expressed as

$$F(x) = \Phi\left(\frac{x-\mu}{\sigma}\right) \tag{8}$$

Where Φ is the cumulative distribution function of the standardized normal distribution function, i.e. $\Phi(z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} e^{-\frac{1}{2}t^2}dt$, and φ is the respective probability distribution function ($\varphi(z) = \frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}z^2}$). The probabilitiy of being selected in the second market stage can hence be written as

[9] In the first stage, it is the other way around: to be selected here, the gaming generator's first stage bid has to fall below this stage's reference bid that clears the market, b_{ref}^{s}.

[10] This is a common assumption, also applied e.g. in Swider & Weber (2007) and Ziel & Weron (2018), and serves our purpose of illustrating the general, qualitative effect of changes in the mean and the variance of the expected reference bid on the probability of selection. For other purposes, e.g. price forecasting, economic evaluation of investments, etc., other distributions that account for asymmetry, heavy tails, etc., would have to be considered.

$$\alpha\left(b_j^s\right) = Pr\left(b_{ref}^s \leq b_j^s\right) = F\left(b_j^s\right) = \Phi\left(\frac{b_j^s - \mu_{b_{ref}^s}}{\sigma_{b_{ref}^s}}\right) \tag{9}$$

From eq. (9) follows that the probability of being selected, α, of the exporting region increases with an increase in the bidder's own bid:

$$\frac{\partial\alpha}{\partial b_j^s} = \frac{\partial\Phi\left(\frac{b_j^s - \mu_{b_{ref}^s}}{\sigma_{b_{ref}^s}}\right)}{\partial b_j^s} = \varphi\left(\frac{b_j^s - \mu_{b_{ref}^s}}{\sigma_{b_{ref}^s}}\right) \cdot \frac{1}{\sigma_{b_{ref}^s}} > 0 \tag{10}$$

since $\varphi(\cdot)$ is always greater than zero and the reciprocal of the standard deviation is positive.

Furthermore, the probability of being selected decreases c. p. with an increase in the expected reference bid

$$\frac{\partial\alpha}{\partial\mu_{b_{ref}^s}} = \varphi\left(\frac{b_j^s - \mu_{b_{ref}^s}}{\sigma_{b_{ref}^s}}\right) \cdot \left(-\frac{1}{\sigma_{b_{ref}^s}}\right) < 0 \tag{11}$$

It decreases c. p. with an increase in the expected reference bid's variance, as long as the gaming bid exceeds the reference bid

$$\frac{\partial\alpha}{\partial\sigma_{b_{ref}^s}} = \varphi\left(\frac{b_j^s - \mu_{b_{ref}^s}}{\sigma_{b_{ref}^s}}\right) \cdot \left(-\frac{b_j^s - \mu_{b_{ref}^s}}{\left(\sigma_{b_{ref}^s}\right)^2}\right) < 0, \text{ for } b_j^s > \mu_{b_{ref}^s} \tag{12}$$

The relationship between the probabilities of being selected and the gamer's own bid can also be illustrated graphically. This is done in Figure 3, which shows the probability distribution function and the cumulative distribution function of the respective reference bid. The probability of selection for a certain bid by bidder j is the shaded area below the PDF and the value of the CDF for the particular bid, respectively.

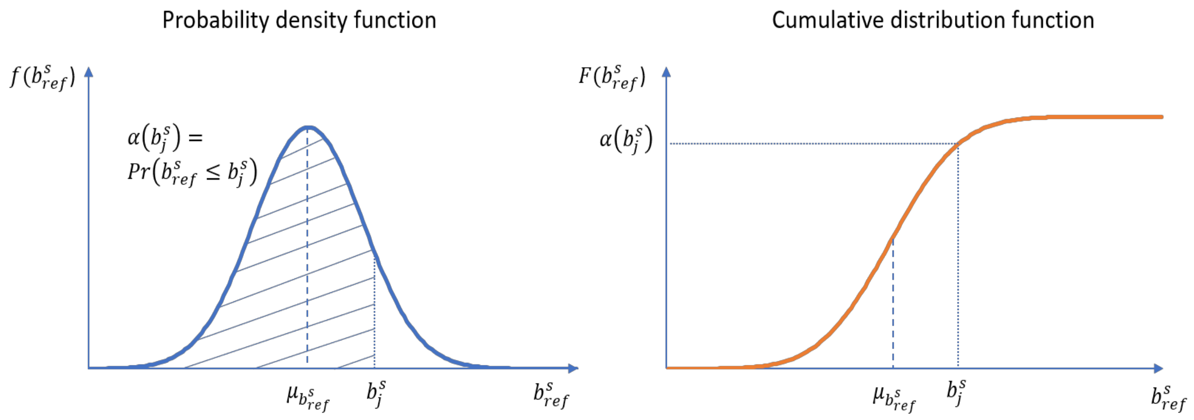

Figure 3: Stylized probability distribution function (left) and cumulative distribution function (right) of the reference bid of the second stage in the export constrained region and depicted probability of selection of a certain second stage bid of gaming generator j, $\alpha(b_j^s)$

The negative effect of an increase in the expected second-stage reference bid and of an increase in the variance of the reference bid on the probability of selection of a certain bid in the second stage can also be shown graphically, see Figure 4.

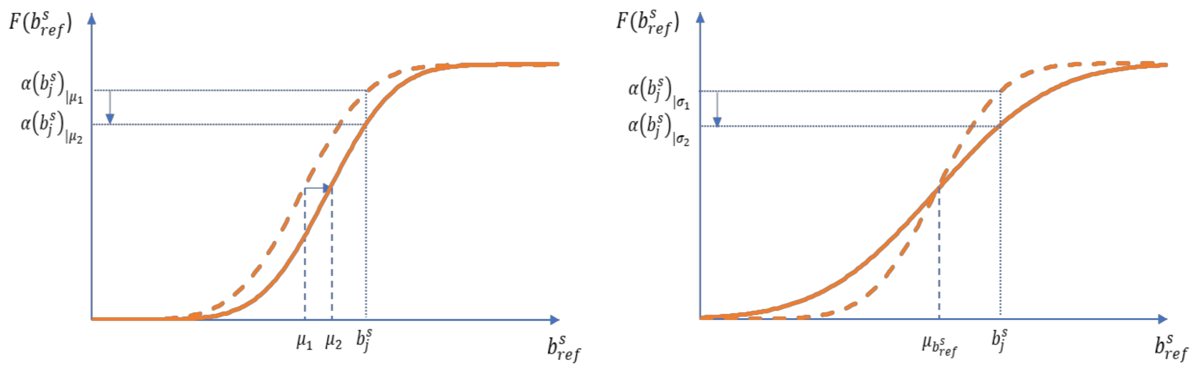

Figure 4: Stylized effect of an increase in the expected reference bid of the second stage (left; from μ_1 to μ_2)and of an increase in its variance (right; from $\sigma_1$to σ_2) on the probability of selection for a certain local bid $\alpha(b_j^s)$;

3.3.2. Optimal bid in the second stage

Based on the insights on the probability of selection, we now derive the optimal bid of the second stage and analyse how it depends on the expected reference bid. The optimal bid in the second stage market is derived by differentiating the expected profit of gaming (eq. (6)) with respect to the second-stage bid

$$\frac{\partial E\Pi_j}{\partial b_j^s} = \beta(b_j^f) \cdot \gamma \cdot q_j \cdot \left[\frac{\partial \alpha(b_j^s)}{\partial b_j^s} \cdot \left(C_j - b_j^s\right) + \alpha(b_j^s) \cdot (-1)\right] \tag{13}$$

The expression in brackets shows that the bidder trades off the probability of being selected (the first term, which increases with the bid as seen in Section 3.1.1) and the profit conditional on being selected (the second term, which decreases with the bid), which results from the discrimantory pricing rule (c.f. e.g. Federico & Rahman, 2003).

The first order condition for the optimal second-stage bid is given by

$$\frac{\partial E\Pi_j}{\partial b_j^s} = 0$$

$$\Leftrightarrow \beta \cdot \gamma \cdot q_j \cdot \left[\frac{\partial \alpha(b_j^s)}{\partial b_j^s} \cdot \left(C_j - b_j^s\right) - \alpha(b_j^s)\right] = 0 \tag{14}$$

$$\Leftrightarrow b_j^{s^*} = C_j - \frac{\alpha(b_j^{s^*})}{\alpha'(b_j^{s^*})}$$

Recall that in the export constraint region the probability of being selected increases with the size of the bid, $\frac{\partial \alpha}{\partial b_j^s} = \alpha'(b_j^s) > 0$, which can also be easily seen in figure 2. The second term on the right-hand side in the expression is hence positive and is the "mark-down" from true costs, which results from the pay-as-bid pricing rule as bidders bid the expected market-clearing price instead of marginal costs (so called bid shading) and which depends on the bidder's belief of what will be the market clearing bid (cf. e.g. Krishna, 2010). The upper limit of the optimal second stage bid are the marginal costs, i.e. the optimal bid ranges between the expected second stage reference bid and the marginal costs.

The optimal bid of the second stage is driven by the expected reference bid and its variance, and by the marginal costs of the bidder. An increase of the reference bid and/or its variance forces the gamer to increase her bid in optimum (until marginal costs are reached) and hence lowers the margin of gaming.[11] Next, we analyse the effect of the reference bid on the expected profit of gaming in total.

3.3.3. Effect of expected reference bid on expected profit for optimal second stage bids

In this section, we can now analyse the relation of the expected reference bid of the second stage and the expected profit for optimal second stage bids by differentiating

[11] Due to particularities of the normal distribution function, this can only be shown numerically.

the expected profit of gaming (eq. (6)) with respect to the reference bid of the second stage

$$\frac{\partial E\Pi_j(b_j^{s*})}{\partial \mu_{b_{ref}^s}} = \beta \cdot \gamma \cdot \left(\frac{\partial \alpha(b_j^{s*})}{\partial \mu_{b_{ref}^s}} \cdot \frac{\partial b_j^{s*}}{\partial \mu_{b_{ref}^s}} \cdot \left(C_j - b_j^{s*}\right) - \alpha(b_j^{s*}) \cdot \frac{\partial b_j^{s*}}{\partial \mu_{b_{ref}^s}}\right) \cdot q_j < 0 \qquad (15)$$

The expected profit of gaming decreases monotonously with an increase of the second-stage reference bid, due to a decrease in selection probability (see eq. (11)) and an increase in the optimal bid (see section 3.1.2) that leads to a decrease in the margin.

3.3.4. Negative expected profit of gaming and the role of the reference bid

In the following, we can now derive the conditions under which gaming leads to expected losses, even if the bids are chosen optimally, and derive from this the threshold value of the expected reference bid of the second stage for which the expected profit of gaming is equal to zero.

Gaming generally becomes risky when expected profit of gaming as described in eq.(6) is negative, that is:

$$E\Pi_j(b_j^f, b_j^s) = \beta(b_j^f) \cdot \left[(b_j^f - C_j) \cdot q_j + \gamma \cdot \alpha(b_j^s) \cdot \left(C_j - b_j^s\right) \cdot q_j\right] < 0 \qquad (16)$$

Transposing the inequality yields

$$\beta(b_j^f) \cdot (b_j^f - C_j) \cdot q_j < -\beta(b_j^f) \cdot \gamma \cdot \alpha(b_j^s) \cdot \left(C_j - b_j^s\right) \cdot q_j$$
$$\Leftrightarrow \frac{(C_j - b_j^f)}{\left(C_j - b_j^s\right)} > \gamma \cdot \alpha\left(b_j^s\right) \qquad (17)$$

The numerator of the expression on the left-hand side expresses by how much the marginal costs exceed the payment of the first stage (i.e. the absolute value of the impending loss), and the denominator is the potential profit in the second stage, conditional on being selected. This means that the expected profit of gaming turns negative, when the relation of marginal cost and payment divide in the first stage to the potential profit in the second stage is greater than the probability of winning. This threshold can also be expressed in terms of the price difference between the two stages:

$$b_j^s > (1 - \frac{1}{\gamma \cdot \alpha(b_j^s)}) \cdot C_j + \frac{1}{\gamma \cdot \alpha(b_j^s)} \cdot b_j^f \quad (18)$$

As shown in Section 3.1.2, the optimal bid is $b_j^{s^*} = C_j - \frac{\alpha(b_j^{s^*})}{\alpha\prime(b_j^{s^*})}$. Inserting this in eq. (18) yields

$$C_j - \frac{\alpha(b_j^{s*})}{\alpha'(b_j^{s^*})} > (1 - \frac{1}{\gamma \cdot \alpha(b_j^{s^*})}) \cdot C_j + \frac{1}{\gamma \cdot \alpha(b_j^s)} \cdot b_j^f$$
$$\Leftrightarrow C_j - b_j^f > \gamma \cdot \alpha(b_j^{s^*}) \cdot \frac{\alpha(b_j^{s^*})}{\alpha'(b_j^{s*})} \quad (19)$$

This means that gaming results in an overall loss, if the impending loss from the first stage (i.e. the difference between marginal costs and the first stage's payment) cannot be compensated by the expected optimized profit of the second stage even, if the bid is chosen optimally in this stage (i.e. the product of the probability of winning and the optimized mark-down from marginal costs). The optimal mark-down of the second stage is determined by the expected reference bid of this stage. As was shown in section 3.1.2, it decreases with an increase in the expected reference bid and/or its variance.

A threshold value of the second-stage reference bid exists, for which expected profit of gaming is precisely zero for optimal bids. At this threshold it holds that

$$T_{b^s_{ref}}: \; C_j - b_j^f = \gamma \cdot \alpha(b_j^{s^*}) \cdot \frac{\alpha(b_j^{s^*})}{\alpha'(b_j^{s*})}$$

Summing up the expositions above:

1. As long as the marginal cost of the gamer is more than marginally higher than the market clearing price, a reference bid very closely below the market price (strong reference bidder), will secure that the expected profit of gaming is negative even for optimal bids.
2. For the expected profit of gaming to be positive, the reference bidder must be weak.
3. The expected profit of gaming is monotonously decreasing with the reference bid (see section 3.1.3).
4. Therefore, there exists a threshold value of the reference bid, for which expected profit of gaming is precisely zero for optimal bids. Therefore, given this reference

bid, there is always a range for which expected profit of gaming is negative for optimal bids, and thus, gaming is always risky.

4. Discussion

Having shown that the range where the expected profit of gaming is negative is critically determined by what we call the reference bidder, we now discuss this result and define weak in contrast to strong reference bidders as a reflection of the competitive conditions in the redispatch market. Second, we outline remedies that restore welfare for the case that gaming can be expected.

4.1. Weak versus strong reference bidders

Section 3.1 has shown the critical importance of the probability of selection in case of gaming (expressed by α). The main contribution of this analysis is to discuss α as an endogenous variable for gamers. If gaming goes wrong, it is costly. In the case analyzed in section 3.1, the cost of unsuccessful gaming is that the gamer has to produce at a price below marginal cost as scheduled in the first stage. In other words, by losing gaming, the gamer incurs a loss in the first stage. In the cases of the other potential gamers, i.e. generators in the importing region and consumers in both regions, such opportunity costs are different in detail, but exist nonetheless. In all cases, gaming can be risky.

The probability α is the subjective endogenous probability of winning, which as such are well known from general auction theory. The probability of winning depends on one's own bid and the expected bids of competitors, which are reflected here mainly in the expected reference bid. As outlined above, we refer to the reference bid as the one just selected at the margin, i.e. the generator or consumer that is just needed to solve congestion in the second stage. Gamers have to outbid this bidder in the second market stage in order to be selected. Therefore, the reference bid is of key importance as it limits the scope for strategic bidding.

The presence of reference bidders reflects the competitive situation. We distinguish three different types: 1. strong reference bidders, 2. weak reference bidders and 3. the special case of players that are critical for congestion relief, which is basically equivalent to a case of no reference bidders. Our notation in weak and strong reference bidders follows the classical distinction in competition policy between weak and strong substitutes to demarcate the relevant market (cf. eg. Motta, 2004, ch. 3). In the following we focus on the reference bidder in the second stage, as this is where the generator in the exporting region incurs a loss in case of unsuccessful gaming.

We now define strong and weak reference bidders as follows.

1) Strong reference bidders

Strong reference bidders make the expected profits of gaming negative, as they limit the expected optimized profit from the second stage to a low level which cannot compensate the first stage's loss.

Suppose that the reference bidder places a bid very close to her first stage's payment. The reference bidder then makes no profit and is indifferent to her participation in the market. It follows from this that this ideal reference supplier has no opportunity costs. Consequently, this reference bidder would require only a low margin in the second market stage in order to be indifferent between the first and second market. A situation with a strong reference bid exceeds the threshold ($T_{b^s_{ref}}$) defined above. Thus, a gamer cannot outbid the ideal reference bidder while still making a profit. Put differently, strong competition prevents gaming.

2) Weak reference bidders

Weak reference bidders render the expected profits of gaming positive, as they allow for an expected optimized profit from the second stage that overcompensates the first stage's loss.

Suppose now that the reference bidder has relatively low costs (or low willingness to pay in case of a consumer) as compared to the first stage's payment, leaving a potential profit margin. Now, the reference bidder has relatively high opportunity costs to offer redispatch and will submit a relatively low bid which renders the situation below the threshold ($T_{b^s_{ref}}$) defined above. The low reference bid leaves a margin between the two markets and thus offers an opportunity for the gamer. Hence, low competitive pressure potentially allows gaming.

In between weak and strong reference bidders, a reference bidder on the threshold renders the expected profits of gaming exactly equal to zero. Whether the reference bidder is weak or strong in a specific market is an empirical issue.

There is one more special case. It is technically possible, that the gamer's facility presents the only option to resolve network congestion.

3) Absence of reference bidders

In this case the facility of the gamer is exclusively required for congestion relief as no other generator or consumer can offer the adjustments needed. If a gamer knows that she is critical for redispatch, the selection probability (α) is equal to one by definition for any bid and the gamer can monopolise the margin. Analytically, this is equivalent to a case of no (or extremely weak) reference bidders.[12] Clearly, this is a case of market power and has been described in the literature in a different context extensively (eg. Stoft, 1998 and Harvey & Hogan, 2000).

The analysis above shows how gaming can only take place with relatively weak or in the absence of competition. International experience and the literature suggest that gaming -if at all- is associated with market power (cf. Palovic et al., 2022). Due to the complex structure of the markets and changing congestion points and respectively redispatch areas in meshed networks, an appropriate definition of market power can be controversial.

4.2. Remedies

Where potential for gaming can be expected, we consider several remedies that can counter this behavior and prevent the welfare losses it entails. It is useful to distinguish between weak reference bidders (case 2) and the complete absence of reference bidders (case 3).

In the absence of competition, markets cannot function well and congestion should be addressed with regulated redispatch; where regulation pre-determines compensations or bid caps.

The case of weak reference bidders is more interesting. It is not an obvious case of market power and classic competition law does not apply seamlessly. Instead, gaming behavior described in the analysis above may be considered as market manipulation (cf. Ledgerwood & Carpenter 2012). Regulation can monitor and penalize such manipulation to prevent it while maintaining a market-based redispatch. In Europe, for example, such monitoring and penalization is implemented by the regulation on wholesale energy market integrity and transparency (REMIT). This regulation equips national regulatory authorities in the EU with investigatory and enforcement powers

[12] This principle also applies to a group of potential gamers together: if the gamers as a group know that they are needed, they have market power as a group and each individual will know that the probability of success is equal to one.

that are necessary to prevent manipulations of energy markets. These consists of various information and data collection powers, cooperation networks among national and European authorities, possibilities of prohibiting undesirable market-related practices and behaviors, as well as penalization powers when necessary.

An alternative option would be empowering an authority or the network operator for counterstrategy. The analysis in section 3 shows that, depending on parameters, the expected profit of gaming can become negative, such that gaming becomes a risky strategy. The relevant parameters can be influenced as a counterstrategy. We see the following options.

Long-term contracting of a flexibility provider

The system operator could contract a flexibility provider on a long-term basis via a tender. The idea is that the long-term contract brings the plant into the second market with a bid close to the reference bid of the first stage. This countermeasure thus artificially reduces the margin between the two market stages and thus reduces the incentives for gaming. There would always be competition between the long-term contracted facility and the gamers.

Use of alternative flexibility options by the network operator

The network operator could employ alternative flexibility options (eg. mobile storage, temperature monitoring, etc.), which are not contracted via the market, specifically in those market areas where incentives for gaming are expected. The idea is that these flexibility options reduce the selection probability (α) for gamers in the second market stage and potentially also the probability of congestion (γ). They may further reduce the demand in the second stage market and move the expected second-stage payment closer to the result of the first stage. As explained in section 3.1, gaming is risky if the probability of selection and/or the probability of congestion is low. If competition from alternative flexibility options is credible, the incentive for gaming reduces.

Occasional random selection in the second market.

If selection in the second market occasionally does not follow the merit order and is instead random (within limits), uncertainty of the expected profit increases and gaming thus becomes riskier. Occasionally random selection in the second market stage is of course inefficient in itself. Yet, if it avoids gaming and improves the functioning of the market, overall system efficiency might well increase.

5. Conclusions

This paper studies the incentives for gaming of market-based redispatch in congested electricity networks. To the best of our knowledge, the literature lacks a formal representation of the effect of competition on the incentives of gaming in redispatch or flexibility markets. As a consequence, it is controversial to what extent competition mitigates the incentives for gaming. Therefore, in this paper, we pick up the current debate and study the precise incentives for inc-dec gaming with respect to competitive conditions on the market.

With a formal approach, we argue that the expected profits of gaming can be negative, depending on competitive conditions. The range where expected profit of gaming is negative is critically determined by what we call the reference bidder; this reflects competitive conditions in the market. The stronger the competition in the market, the less likely gaming will be.

The role of the reference bidder is critical. We refer to the reference bidder as the bidder in the second market stage that is just needed to solve the congestion. The gamer has to outbid this reference bid; and if the reference bid is high, the profit margin for the gamer will be low. The presence of reference bidders reflects the competitive situation. We distinguish three different types: 1. strong reference bidders, 2. weak reference bidders and 3. the absence of reference bidders, i.e. the special case of plants that are exclusively required for congestion relief. The presence of a strong reference bidder makes gaming unlikely and a weak reference bidder facilitates gaming.

We note that even where gaming is possible, remedies may mitigate the problem. Exploiting the insights from the formal model, we discuss three remedies, which affect the incentives for gaming: 1. long-term contracting of a weak reference bidder, 2. use of alternative flexibility options by the network operator and 3. occasional random calls in the local market. The system operators could be authorized to execute these remedies.

As an issue for further research, we note that whether or not reference bidders are weak or strong and whether or not gaming might occur, is a context-dependent empirical issue. The decisive parameters differ in time and per region. It requires careful empirical analysis of the real market situation to assess the potential of market-based redispatch. The assessment can differ regionally: in some regional market the incentives for gaming will be strong, whilst in others they are not. Therefore, adequate market design may differ regionally.

With the presented analysis, we provide the theoretical framework for authorities and ex-post empirical works to assess the potential of market-based as opposed to administrative redispatch and to design markets for other types of local flexibilities.

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