A more efficient procurement mechanism for reserve capacity in the German market for balancing power

Kai Flinkerbusch*

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Abstract

From auction theory we know that multi-unit, pay-as-bid auctions in general lead to bid shading and thus to an inefficient allocation. This result is supported by historical data from the German market for balancing power, which show that bidders bid well above their actual costs. In contrast to the pay-as-bid auction, the Vickrey auction has the dominant strategy property and bidders reveal their true opportunity cost. Consequently, the Vickrey auction allocates efficiently. In this article we show how this auction format can facilitate an efficient capacity procurement process in the German reserve market.

JEL: D44, N74, L11

Keywords: Electricity market, balancing power, uniform-price auction, pay-as-bid auction

1 Introduction

When it comes to efficiency issues in electricity markets it is often argued that market power is a problem. This might also be a challenge in the market for balancing power, as [14] suggest. However, recent data from the procurement auctions indicate that market concentration somewhat diminished lately, primarily due to some changes in the market design. One of these changes is the so called "Netzregelverbund", equivalent to a complete harmonisation of all four German control areas. This harmonisation combined the four control areas into one market place, thereby pooling all supply and demand and netting the individual control area imbalances. Potential cost reductions due to this harmonisation where computed to be around €160 million, see [8] and [2].

In spite of this, overall costs of the German balancing system increased strongly in 2010, albeit declining to some degree in the last months of 2010 and in 2011. This development need not be connected to

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*Westfälische Wilhelms-Universität Münster, Department of Economic Theory, email: kai.flinkerbusch@wiwi.uni-muenster.de

the problem of market power, but can be explained by means of the procurement mechanism, i.e. the auction design in the balancing market itself (cf. [7]). Even though supporters state that the current discriminatory "pay-as-bid" design is favourable with respect to revenue and distributional aspects, it actually leads to strategizing, that is, suppliers submit bids above their actual costs.[1] What is more, the design does not adhere to a proper equilibrium, which is supported by historical data as well. Thus, the pay-as-bid design cannot guarantee that the most efficient suppliers are the winners of the procurement auctions. Additionally, resources are wasted because suppliers have to develop bidding strategies for their submitted bids.

It is often discussed in electricity markets whether to adopt a pay-as-bid or a uniform-price auction (cf. [19] or [6]). As an example, in the early 1990s Britain's energy regulator Ofgem proposed that a pay-as-bid auction would be more competitive than a uniform-price auction. Friedman and Miller on the other hand stated that a uniform-price auction yields a more competitive outcome than a pay-as-bid auction (cf. [11]). This criticism is in line with [12], who also argue that the pay-as-bid auction performs worse than a uniform-price auction.

However, as we will see below, either auction format fails to allocate efficiently. This article aims at deriving a mechanism to procure reserve capacity without these inefficiencies. In the next chapter we first give some important details of the German market design and then show analytically how the current design fails to allocate correctly. The findings are supported by auction results from the recent past. In the third chapter we propose that the Vickrey auction, which in theory facilitates an efficient capacity procurement, can be implemented in the German market for balancing power. The design promises major gains in the market's performance, and as a matter of fact, there appear to be no serious disadvantages. The last chapter concludes.

2 The current procurement mechanism

2.1 The German market design

Due to the grid infrastracture and the lack of storage facilities, electricity demand must always be equal to supply. However, intraday trade closes 45 minutes before delivery, which is called "gate closure". When unanticipated events happen after gate closure, scheduled supply and demand may diverge. This is when the market for balancing power comes into play. There are three kinds of balancing power: Primary, secondary and tertiary reserve (cf. [17]). Primary reserve is fastest, tertiary is slowest. In case of a major imbalance, the slower reserves replace the faster ones subsequently in order to restore availability.

The market for balancing power is two-staged. In a first step, reserve capacity is procured. In a second

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[1] There are virtually no supporters of the pay-as-bid-auction among economists, but the format is popular among politicians nonetheless (cf. [10]). Furthermore, the German Bundesnetzagentur is to be mentioned as a supporter since it adopted the design in the first place.

step, in case of an imbalance balancing energy is delivered, based on the reserved capacity.[2] Capacity procurement is as follows. Transmission System Operators (TSO) tender a certain amount of reserve capacity for which suppliers are awarded a premium for each Megawatt (MW) of capacity. Since suppliers are paid exactly their bid, we have a discriminatory or "pay-as-bid" auction. The auctions take place repeatedly. Primary and secondary reserve were auctioned monthly up to June, 2011. Since then they are auctioned on a weekly basis. Concerning primary reserve no difference is made between positive and negative energy, so there is just one weekly auction. Secondary reserve is split into four different products with the dimensions positive/negative and peak/offpeak. Tertiary reserve is auctioned daily in four-hour time slices, each for positive and negative energy, so there are 12 different products. In what follows, we focus on secondary and tertiary reserve since the market for primary reserve works rather differently. However, the procurement mechanism derived in this article possibly can also be used in the primary reserve procurement process.

When suppliers of secondary or tertiary reserve are called to deliver positive or negative energy, they are paid a premium for each produced (or saved) Megawatt-hour (MWh). Although this is not subject of this article, it is important to keep in mind that [3] have shown that only a two part tariff, with one price for capacity and one price for energy, may lead to an efficient procurement.[3] However, a two part tariff alone does not guarantee the bidders' revelation of their true costs. As we will see in the following, the revelation of true costs is imperative for overall efficiency.

2.2 Preliminaries

First of all, note that we deal with a procurement instead of a selling auction, so we have a *reverse* auction with the auctioneer as the buyer and the bidders as the sellers.

In the procurement process, the TSO first specifies a demanded amount of capacity, measured in Megawatts (MW). In the auctions for secondary and tertiary reserve, the potential suppliers, i.e. prequalified power stations or large consumers, submit bids for the amount of capacity they wish to supply. Bids have the dimension €$/MW$ and the least increment of a bid is 1 MW. Consequently, when there are, say, 3000 MW to supply, we have 3000 identical objects. This makes the procurement process a multi-unit auction. Given that a bidder wins, he is paid exactly his bid. In short, we face a repeated multi-unit, sealed-bid, pay-as-bid, reverse auction.

Let K be the number of identical objects the TSO wants to obtain (i.e. there are K units of 1 MW of capacity) and N be the number of potential suppliers. We thereby neglect the minimum bid size for simplicity:[4] It allows us to state that in the multi-unit auction each unit is of equal size and this size is just 1 MW. Supplier i's cost for the objects is given by the cost vector $\mathbf{X}^i = (X_1^i, X_2^i, \ldots, X_K^i)$. X_k^i

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[2] Note that the latter part, which is a matter of energy pricing, is not subject of this article.

[3] This can easily be illustrated by a simple example of a bakery. Suppose some customer wants the baker to reserve half of his oven's capacity just for him. Certainly, the baker would want to be compensated for the reservation. Now when the customer actually appears in the shop and wants to buy a bread, the baker would charge him at least his marginal cost for producing the bread. Hence, we have a two part tariff with one price for capacity and one price for production.

[4] Actually, suppliers are obliged to bid at least 15 MW for secondary and 5 MW for tertiary reserve.

denotes the marginal cost of obtaining the k'th object. As usual, we assume that costs are increasing in the number of units obtained, so $X_1^i \leq X_2^i \leq \cdots \leq X_K^i$. In the following we will check whether some additional assumptions are valid in the real world electricity market, since suitable procurement mechanisms crucially depend on these.

Risk neutrality Without risk neutrality, the revenue equivalence principle is no longer valid, which makes comparisons of different mechanisms even more difficult. Luckily, the assumption of risk neutrality appears to be reasonable because the procurement auctions are repeated frequently. In addition, the markets clear sequentially. Both aspects imply that if a bidder loses in one auction, he may rebid in a later one (e.g. the day-ahead or intraday auction) or, in the worst case, loses the expected profits for only a day.

Cost variates *iid*-distributed The assumption that each $\mathbf{X}^i$ is independently and identically distributed features some nice advantages. When this assumption is valid, the valuation of any good does not depend on the valuation of other goods or the valuation of other bidders. This means that goods are substitutes instead of complements and values are private instead of common. The *substitutes assumption* appears to be quite reasonable in our context, since there should be no complementarities in aquiring a certain bundle of MW of capacity; if there are 3000 MW of reserve capacity to supply, a supplier should be indifferent which of those MW he supplies – one MW of capacity is as good as the other. The *private values assumption* should briefly be contemplated: Opposing to private values, a common value affects all auction participants equally, but is unknown by the time of the auction. Concerning the market for balancing power, the market participants face the spot market as an opportunity. The day-ahead price, which certainly contributes to the opportunity cost for reserve capacity reservation, is unknown to all suppliers by the time of the reserve procurement auction. This means that here we have a certain common value component. However, market participants should be able to predict the spot price quite precisely and we will abstract away from this common value component for analytical convenience. To conclude, we state that cost variates are *iid*-distributed in the reserve market.

2.3 The pay-as-bid auction in theory

In the pay-as-bid auction a bidder who wins k^i units receives the sum of his first k^i bids, $b_1^i + b_2^i + \cdots + b_k^i$. This corresponds to perfect price discrimination according to the submitted bids. Obviously, no bidder would ever bid his true costs, since this would guarantee a zero payoff. Consider a case with $N = 3$ bidders and $K = 5MW$ of reserve capacity to be obtained. Bidders' cost vectors are $\mathbf{x}^1 = \{1, 3.5, 5.5\}$, $\mathbf{x}^2 = \{2, 3, 5\}$ and $\mathbf{x}^3 = \{1, 2, 4.5\}$. Figure 1 illustrates the example. Let us – for now – assume that all suppliers submit bids according to their true cost vectors, i.e. $\mathbf{b}^i = \mathbf{x}^i$. In this case, the five lowest bids are $(b_1^1, b_1^3, b_1^2, b_2^3, b_2^2) = (1, 1, 2, 2, 3)$ so that bidder 1 obtains one unit, bidder 2 obtains two units and bidder 3 also obtains two units.

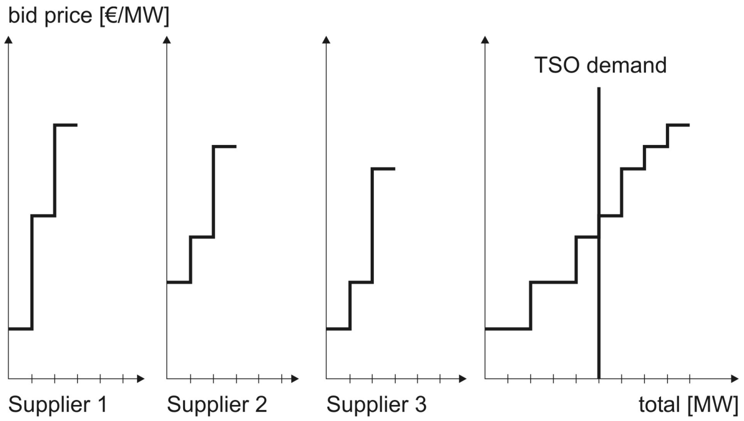

Figure 1: Supply functions and aggregated supply and demand

Let us now establish the concept of the residual demand function facing each bidder. At any price p, the residual demand facing bidder i is equal to the total TSO-demand K less the sum of the supply of the *other* bidders. The residual demand curves show us how many items each bidder wins – just check where they intersect with the individual supply curves. This is illustrated in figure 2. The shaded area shows the suppliers' revenues and, since $\mathbf{x}^i = \mathbf{b}^i$, producers' surplus is zero.

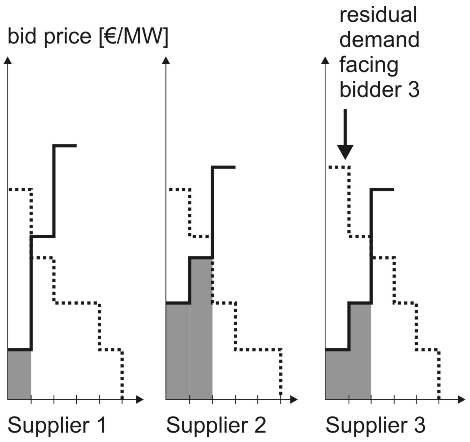

Figure 2: Bid vectors and revenues

Deriving efficient bids when we neglect uncertainty about the other bidders' values is simple: Each bidder will just submit a bid equal to (or marginally lower than) the first declined bid for every unit that can be obtained, given that the cost of supply lies below this value. In the example, the bid vector of supplier 2 would look like $\mathbf{b}^2 = \{3.5, 3.5, 5\}$. The auction result without uncertainty about the suppliers' values is shown in figure 3. Note that it is not exactly clear which bidder should win how many items: there are six identical bids for five objects to obtain. The information about the true costs is inevitably lost. In the figure, bidder 2 obtains only one unit, which may be due to some arbitrary kind of tie braking rule. However, his marginal cost for the second unit would be lower than bidder 1's cost for the second unit. Whenever a bidder is awarded an item for which his cost exceed a losing bidder's cost, we face a loss of welfare.

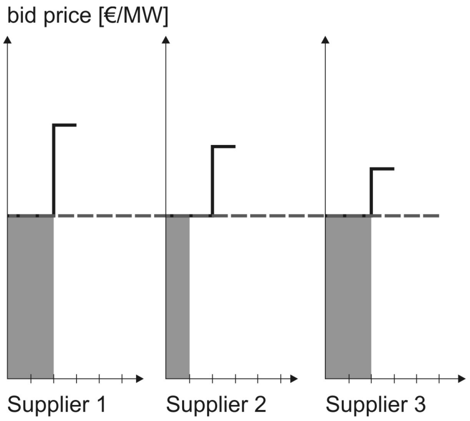

Figure 3: Bid vectors and revenues without uncertainty

Under uncertainty, the bidders' behaviour is as follows: When a bidder's high bid is lower than the lowest competing bid, he wins all items. He wins exactly one item if only his low bid beats one of the other bids, and so on. As assumed, the cost of the first obtained item is lower than that of the second one. Consequently, the submitted bid for the first item should be lower than bids on subsequent items. But here another effect comes into play: Bidders bid more aggressively on subsequent items. Bidder aggression means that submitted bids are relatively close to actual costs, or, in other words, more competitive. First of all note that a bid on, say, bidder i's second item competes with all other bidders' bids on their first item, and the costs for these are stochastically lower than the cost for bidder i's second item. In order to increase the probability of winning additional units – and thereby earning a positive payoff – the bidder's aggression increases with each bid on an additional unit. So the premium on bidder i's bid for the second item will be lower than that on the first item. The premium on the third item will be even lower. When this effect is strong, bidders submit flat supply curves.[5] Even if marginal costs increase sharply (say, because the plant approaches its maximum capacity) and bidders submit increasing supply curves, aggression increases with subsequent items, implying that bid curves are less steep than actual cost curves. This, however, implies a positive probability that an aggressive bid (on an item with high marginal cost and thus a comparably low economic value) crowds a less aggressive bid (on an item with a high value) out of the aggregated supply function.

To continue the example, suppose that the bidders do not report truthfully, but instead bid aggressively. Hence, they bid lower on subsequent items in order to increase their probability of winning. This case is shown in figure 4. Actual costs are already known from figures 1 and 2 and are represented by the solid grey lines. The solid black lines indicate the submitted bid curves. As we can see, bid premiums decrease. The dashed lines show the residual demand functions according to the submitted bids. As we know from the beginning of the example, bidders 2 and 3 should win two items, and bidder 1 only one item. With aggressive bidding, however, we observe a different result. In the example, bidder 3 wins three items, and bidder two wins only one item. This is because bidder 3's bid on his third item is much more aggressive than bidder 2's bid on his second item. This item, which would cause lower cost, is crowded out. The

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[5] A formal derivation can be found in [5].

source of this loss of welfare lies in the mechanics of the discriminatory auction, just as described above: bidders shade their bids and thus the auction cannot guarantee an efficient allocation.

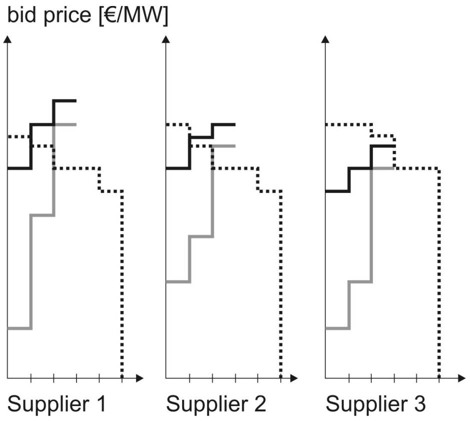

Figure 4: Welfare loss with aggressive bidding

2.4 Some historical observations

We can now have a look at real world data and see how the actual market performed in the past. Figure 5 shows some auction results for positive secondary balancing power in peak time from May, 2010 to April, 2011. The submitted demand rates are arranged in increasing order and weighted with their bid size so that we see the demand rate supply functions for each auction. Rejected bids are represented by the black part of each curve.

Unfortunately, information about the bidders' identities is not made public, so we can only guess at the bidders' strategies. Consequently, aggressive bidding is not clearly observable. Considering the first three depicted auctions, two aspects stand out. First, the supply functions are nearly flat, at least the accepted parts. This indicates that either the bidders anticipate the marginal bid quite well (which we would expect when there is no uncertainty), or they indeed bid very aggressively (which would be rational when bidders are uncertain). Since both effects lead to the same result, i.e. a flat supply curve, both effects imply the same kind of inefficiency. The auction cannot guarantee that the most efficient suppliers win.

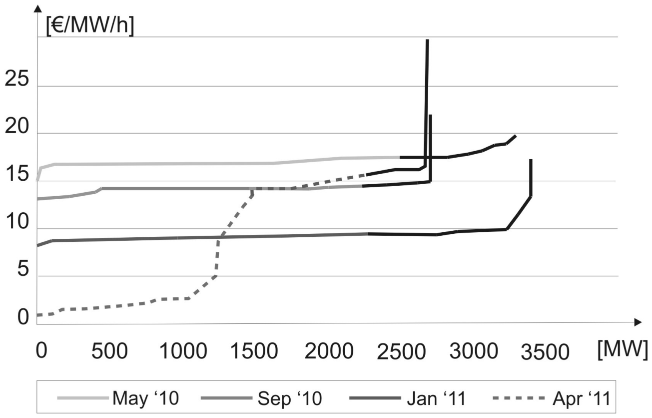

Figure 5: Demand rates for secondary balancing power in [€ /MWh/h]

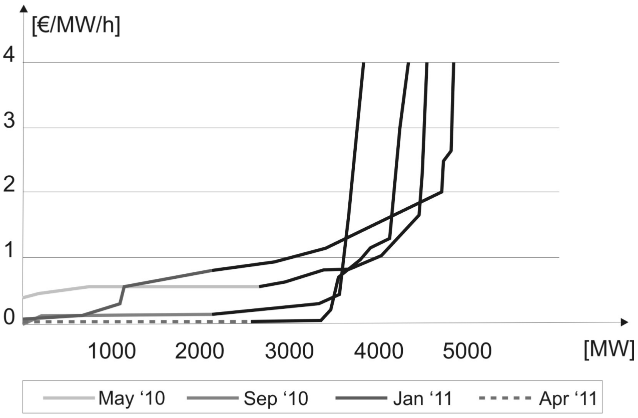

Figure 6: Demand rates for tertiary balancing power in [€ /MWh/h]

Second, one can clearly see that the submitted bids decreased over time. Assuming that the bidders' costs did not change substantially within eight months, we might infer that bids were too high in the early auctions. If it went on this way we could state in line with [16] that with each repetition, the auction approaches an efficient equilibrium.

However, in April 2011 the auction result looks completely different. First, the bid curve is steep. Second, the low bids are lower than those of January's auction and the high bids are higher than January's auction. Before we try to explain this observation, we have a look at some exemplary auctions for tertiary reserve. Actually, as we can see in figure 6, these offer quite a similar result.

What we see here are auction results for negative tertiary balancing power (20-24hrs, first monday in each month). Here, the outlier is January's auction. A possible explanation is new-year holidays. Similar to April's auction in figure 5, the inframarginal suppliers did not manage to submit bids equivalent to the marginal bid.

Why do we observe these outliers? It is unlikely that marginal costs changed considerably within a few months. Moreover, because of the limited number of eligible suppliers and the ambitious prequalification process, it can be ruled out that we face completely different bidders from one auction to the other.[6] Consequently, when we assume that costs and suppliers of secondary and tertiary reserve did not change considerably within the depicted period on the one hand, but on the other hand submitted bids *did* change, it becomes obvious that market participants submit bids not according to their true costs. Additionally, we can point out that the inframarginal bidders lost a lot of money since they did not anticipate the marginal bid correctly. This is unfortunate for the bidders, and here is one major downside of the pay-as-bid auction: Bidders need to get information about other bidders' strategies, asses historical data, and build expectations about future developments for each of their bids in every single auction (cf. [1]). In this way, transaction costs are wasted. It should not be the business of a supplier of balancing power to become a specialist in strategic bidding.

In the introduction we stated that some say the discriminatory auction may be favorable with respect

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[6] As of June, 6, 2011, there were eleven prequalified suppliers of secondary reserve and 28 suppliers of tertiary reserve (cf. [17]).

to distributional aspects since a bidder just receives his own bid. However, bid shading means that bids actually lie *anywhere* above actual costs, so no one can guarantee that successful bidders get less revenue in a pay-as-bid auction than in any other auction format.

In light of this, we conclude that the pay-as-bid design in the German market for balancing power is inefficient. We need to think about a design that facilitates true cost revelation and is more convenient for the market participants.

3 A more efficient mechanism for capacity procurement

In order to establish a suitable procurement mechanism, we have to be aware of the requirements in the specific market environment. First, from [3] we know that only a two-part-tariff is suitable for balancing power procurement, so we need to keep separate rates for capacity availability and energy delivery. Since pricing energy delivery lies not in the scope of this paper, we focus only on capacity procurement. What we want to achieve is a mechanism with the so called *dominant strategy property*: We need a mechanism where it is the dominant strategy to reveal true values. As we will see, the only aspect of the procurement process that needs adjustment is the payment rule, i.e. the determination how much is paid to the winning bidders. The payment rule is the only factor that determines whether bidders bid strategically or if they report truthfully.

An additional aspect is convenience: Because of the daily/weekly frequency of the procurement process, it should be as convenient as possible. This point is easiliy captured by a sealed bid auction. Since this is already featured by the current design, no adjustments are necessary in this point.

3.1 The uniform-price auction

The first auction format that comes to mind is the uniform-price auction, where every winning bidder receives the first declined bid. From single-unit auctions we know that the second-price auction yields an efficient outcome, with each bidder submitting bids corresponding to his actual value (cf. [18]). Yet, it is also common knowledge that this design is not efficient in a multi-unit format (cf. [4] or [13]). Let us briefly sum up why this is indeed so.

Note that bids may never be lower than marginal costs, since this either results in a loss or does not make any difference. However, the bid on the first unit must correspond to its cost, because if $x_1^i < p < b_1^i$ then bidder i does not win any unit, but decreasing his bid to x_1^i would result in winning one unit at a profitable price. In all other cases, shading the bid for the first unit does not make a difference, so by shading (or "demand reduction") there is nothing to win. Yet, there is an incentive for demand reduction on all other units. That is, for all units except the first one, raising one's bid has two effects: First, the probability of winning the, say, second object, decreases. The second effect is that increasing the bid on the second unit raises the expected payment on the *first* unit, even though it does not affect the chance of winning it. This is because the second bid may be the first losing bid and thus determine the price paid for the first unit. So a bidder's own bids may determine the amount he receives. It can be shown that there is an unambiguous incentive for bid shading for all items other than the first one (see [13]). Consequently, the uniform price auction is also inefficient.[7]

3.2 The Vickrey auction

By contrast, an auction format that actually *can* allocate efficiently is the multi-unit Vickrey (1961) auction or, more generally, the Vickrey-Clark-Groves mechanism.[8] Curiously, it is hardly used in practice. This may be due to its complexity or because it requires bidders to be risk neutral and costs to be increasing as well as independently and identically distributed in order to function properly (cf. [1]). In chapter 2.2 we have argued that all critical assumptions are valid in the reserve market. In this section we will briefly explain the mechanism and check whether the format can be put to work in the balancing power market.

First, recall the concept of the residual demand function from section 2.3. This function displays the TSO-demand facing bidder i less the supply of all other bidders at a given price. We denote $\mathbf{c}^{-i}$ the vector of the competing bids facing bidder i. These are the bids on the residual demand function that lie above bidder i's supply function. The competing bids can be considered as those bids that would have had success if bidder i were not present in the auction. Define c_1^{-i} as the highest of the competing bids, c_2^{-i} as the second highest, and so on. The determination of the winning bids in the Vickrey auction is the same as in the pay-as-bid or the uniform-price auction: To win one unit, bidder i's lowest bid must defeat the highest of the competing bids. To win two units, he must defeat the two highest competing bids. The difference concerns the pricing rule: For the first unit, a bidder receives the highest competing bid. For the second unit, he receives the second highest bid, and so on. The amount he gets is $\sum_{k=1}^{k^i} c_k^{-i}$. Bidder i just receives the "area" lying under his residual demand function. In other words, each bidder is paid an amount equal to the externality he exerts on the auction. Thus, a bidder is never paid his own bids and it is a weakly dominant strategy to report truthfully. As an example, suppose bidder i increases his bid on a certain item n to $b_n^i > x_n^i$, and still wins it. In this case, he is still paid the other bidders' competing bid c_n^{-i} and his revenue is $c_n^{-i} - x_n^i$. If, however, he loses the item because of his increased bid, he loses revenues according to $c_n^{-i} - x_n^i$. Note that his revenues are never affected by his own bids. Consequently, we always have $\mathbf{b}^i = \mathbf{x}^i$. This also holds if bidders are not symmetric (cf. [13], p. 181-182).

Since all bidders receive different payments, a crucial aspect to ensure an efficient outcome is that there is no trading in the aftermarket. This means bidders have to maintain unique bidding identities, and all items they win are tied to their identity. If bidders were allowed to trade their items, strategic bidding would be possible. A bidder could submit a huge amount of bids, win a lot of items, and resell them

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[7] In spite of this, there has been a debate in Germany and other countries whether to opt for a pay-as-bid auction or for some sort of uniform-price auction (cf. [12]). With respect to the German reserve market's procurement auction we can point out that neither should be adopted.

[8] The VCG mechanism is a generalisation of the Vickrey auction for the case that goods may be complements. Since we assume goods to be substitutes, both mechanisms are identical.

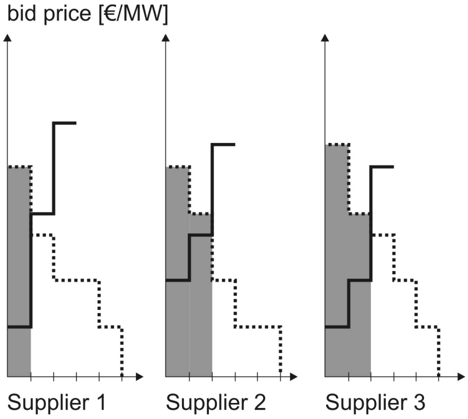

Figure 7: Bids and revenues in the Vickrey auction

to the other suppliers. But since suppliers maintain unique identities in the current design, this is not a problem in our context.

Considering our example, we can now neglect strategic bids and focus on true values. These are depicted in figure 7 together with the resulting revenues. One can see clearly that the five lowest bids win the auction, and no bidder is paid his own bid, so bid shading cannot yield any profits.

Let us briefly summarize the advantages of the Vickrey-auction. First, it inherits the dominant strategy property. This means that, for one, there are no costs for strategizing. More precisely, bidders need not guess at the other bidders' values or strategies and need not contemplate about their own strategy. But most importantly, the auction allocates efficiently. Thus, [9] argue that the Vickrey-Clark-Groves-mechanism is the unique direct mechanism with dominant strategies, efficient outcomes, and zero payments by losing bidders. A second virtue is that the mechanism still works when the auctioneer imposes restrictions, e.g. the TSO might want to procure more capacity than is technically needed or it can limit the amount procured from a certain supplier. For example, in order to work properly the number of rejected bids must be at least as large as the winning bids of the biggest supplier. In a Vickrey auction, the TSO can impose a restriction that there are bids for, say, 130% of the quantity to be procured. Lastly, the revenue equivalence theorem holds. Actually, there is no other mechanism that allocates efficiently and is less costly to the TSOs than the Vickrey auction (cf. [1]).

Critics of the Vickrey auction often argue that the format leads to inequitable or unjust payments. The argument is that those who have the lowest marginal cost receive the largest payments, which raises distributive issues. This accusation is pointless in our context. A supplier just receives those bids that were rejected because of him. That is, he is paid the opportunity cost he induces to the auction. Each unit is awarded the cost that would have materialized if the bidder were not present. To put it differently, the revenues of a bidder reflect the savings caused by his participation. Large suppliers may thus get greater payments because they crowd out a larger amount of bids, and some of these may be quite high. However, if such a large supplier were not present in the auction, those high bids would have won the auction and even higher payments would have been to be made. Consider a case were a supplier is that large that the highest rejected bids are extremely high (like in the rejected parts of the figures in section 2.4). Certainly, such a pivotal supplier would receive an extreme payment. However, a pivotal supplier could submit extremely high bids in the present design, too, and win at least some items at those high prices. Since we do not observe such behaviour, we suggest that there may not be such a pivotal supplier.

Another possible downside may be the vulnerability to collusion, especially because we face a repeated auction. This is not a particular problem of the Vickrey auction. Actually, collusion can be curtailed by means of information disclosure. A repeated auction works the better, the more information is kept secret (cf. [15]). This stands against transparency, but a high level of privacy may improve the auction's performance. When suppliers are incentivized to reveal true costs, they might be reluctant to do so when they are aware that all data is published. If, however, no information is disclosed at all, no supplier has to fear that his bids are used against him. The TSO's certainly should be very careful as to the information they disclose.[9]

4 Conclusion and future prospects

In this article we have shown some major downsides of the current pay-as-bid procurement design. With the famous and, unfortunately, rarely used Vickrey auction, an efficient design is at hand. Implementing the mechansism is easy – in fact, most parts of the procurement process may be kept the way they presently are: Eligible suppliers use their unique identities to submit supply curves, i.e. in the sealed bid auction they specify how much €per MW of capacity they demand. The TSO will then aggregate all supply curves, calculate the market clearing price, and deem all inframarginal bids as winning bids. The property that suppliers maintain unique identities in the reserve market is crucial to the functioning of the Vickrey auction. If there would be OTC trading, like in most electricity markets, the efficiency of the Vickrey mechanism would be underminded. The difference to the present procurement design is the payment rule. Every winning bidder receives the price of the bid that was rejected because of his bid. This point changes the procurement process from an inefficient one with strategizing bidders to an efficient one.

Due to the electricity market's complexity some additional aspects should be kept in mind. For example, strategic opportunities arise from the sequential clearing of the markets. Each market affects the opportunity cost of the suppliers. If some markets work worse than others, the whole sequence of markets is impaired. A task of future research definitely is to design a market such that the whole sequence of markets can work as good as possible. Here is a point to begin with: In this article we just dealt with the question how to procure reserve capacity efficiently. We did not think about how to pay for actual production of balancing energy. In the current regime, this, too, is pay-as-bid. Future research should address the question whether to keep it this way, or to adopt a uniform-price format as in the spot market.

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[9] Other possible drawbacks of the Vickrey auction like non-monotinicity in the number of bidders, the use of multiple bidding identities etc. are only a problem when goods are complements instead of substitutes. As we have ruled out the possibility of interdependent values, these are no issues in this analysis.

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