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# Auction design for a strategic reserve market for generation adequacy: on the incentives under different auction scoring rules

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**Abstract**

How should we select winning bids of generation units for strategic reserves that consist of capacity bids and energy bids? In this paper, we analyze two selecting mechanisms (scoring rules): "simultaneous" and "sequential".

In case of a simultaneous scoring rule, capacity and energy bids are weighted and combined to a single score based on which the cheapest bids are selected. Under sequential scoring rule the selection depends solely on capacity bids. In both cases the energy bids are used to form the merit order for dispatch. We find that the main difference between the simultaneous and sequential scoring mechanism is that under sequential scoring the bids are biased towards lower capacity bids and higher energy bids, since it is only the capacity part that "opens the door" to the reserve market.

We find that a simultaneous scoring is favorable from a welfare perspective, since it avoids the strategic incentives for excessive mark-ups on energy costs and limits the incentives for collusive behavior. This reduces the risk of inefficient selection and dispatch of reserve units compared to a sequential scoring mechanism.

*JEL-classification*: D47; D44; L94

*Keywords*: Electricity; generation adequacy; market design; auction design; reserve market

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## 1. Introduction

The discussion on capacity markets for electricity has recently gained a lot of attention in Europe. The political ambitions of the EU member states to decarbonize the electricity sector have raised concerns whether the traditional market design is able to cope with the necessary large-scale integration of electricity from renewable energy sources (RES-E) into the market. Currently the role of conventional (fossil fuel) generators is shifting from supplying significant amounts of electricity towards the provision of reserve capacity which is only dispatched when it is needed to compensate for the intermittent RES-E supply (see e.g. Bauknecht et al., 2013).

The traditional market design is mainly an “energy-only” market, i.e. revenues for generators only depend on actually produced and sold electricity, and not on availability. In the day-ahead market, for instance, generators have to recover their full costs from energy sales. Since reserve units mainly serve as backup capacities, however, their actual utilization is low. Low utilization implies that revenues from energy-only payments are low. If prices in these periods in which reserve capacity is needed are not sufficiently high, these generators will not be able to recover full costs which in turn endangers investment incentives. This phenomenon, which is associated with energy-only markets, is called the “missing money” problem. There are reasons to believe that peak prices will not be sufficiently high, such that the missing money problem is considered to be a real threat to supply security. For a deeper insight into this discussion, see for example Cramton and Stoft, (2006) or Joskow (2006) who show that one possibility to overcome the problem is to establish a capacity market that provides backup generation with capacity-based revenues.

Among the various design options for a capacity market we focus on a “strategic reserve market”. This is a centrally operated market in addition to the energy-only spot market, where participating units provide reserves for cases of capacity shortage on the spot market (see Brunekreeft et al., 2011). These reserve capacities are centrally acquired by an auction and have to be withheld from the spot market. The remuneration of reserves consists of an energy price and a capacity price and, and are thus by definition no longer “energy only”, but rather a “capacity mechanism”.

This article deals with the auction design issues of implementing a strategic reserve market. In contrast to the spot market auction, a reserve auction involves two kinds of bids, one for energy and one for capacity. Those multi-part auctions (or combinatorial auctions) raise the issue of how the different bids are weighted in order to identify the least-cost bids for the reserve market (see e.g. Cramton et al., 2005).

With different bid components, the obvious question is how to select the winning bids? This paper aims to discuss the auction outcomes and welfare effects for different “scoring rules” that can be used to select the winning bids, by combining the bids into a single scoring value. We analyze two different scoring rules: “sequential” versus “simultaneous”. With sequential we refer to a two-stage approach, where first generators are selected based on the capacity bid after which actual dispatch is determined by the energy bid from the group of preselected generators. With simultaneous we mean that the winning bid is determined by a single value as a weighted combination of capacity and energy bid. We conclude that under a simultaneous scoring rule, bidders will set a mark-up with the capacity bid, whilst reducing the energy bid. In contrast, under a sequential scoring rule, the mark-up is with the energy bid, while the capacity bid is low.

The remainder of the paper is organized as follows. Section 2 describes the basic function and design of a strategic reserve market and shows how it relates to the spot and reserve markets. In section 3 the general auction model for a strategic reserve is developed. The auction outcomes for two basic scoring rules are derived and compared. Section 4 analyzes the welfare effects of the auction outcomes taking into account the impacts of the scoring rules on selection and dispatch efficiency and incentives for collusive behavior. Section 5 concludes.

## 2. Designing a Strategic Reserve Market

The aim of a reserve market is to ensure that a certain amount of reserve capacity is available in the case that capacity on the spot market gets too scarce to ensure supply security. This article analyzes the design of such a reserve market which for instance has been established in Sweden and Finland (see e.g. Brunekreeft et al., 2011). More specifically, the focus is on the issues of auction design to procure these capacity reserves.

In our analysis we refer to the market design in Germany. Herein, a spot and a balancing reserve market are distinguished. In contrast to the spot market – in Germany designed as energy-only – the reserve market consists of a bid encompassing capacity and energy prices. In line with this, we analyze a strategic reserve market that is also designed as a multi-part auction consisting of both capacity and energy bids of generation units. The basic issue of finding an optimal auction design therefore resembles the reserve market, which offers operating reserves for the transmission system management. To avoid confusion, we focus on the two types of markets which are relevant for the purpose of this paper: the term "*reserve market*" denotes the market that entails both an energy and capacity element, while the term "spot market" shall denote the regular energy-only market. Table 1 gives an overview of these two types of markets and its auction designs.

Table 1: Electricity markets and auction design in Germany

| Type of market | Spot market | Reserve market |
|---|---|---|
| Bids | Energy bids | Capacity bid and Energy bid |
| Pricing | Uniform pricing | Pay-as-bid pricing |
| Bidding rule | Simultaneous | Simultaneous |
| Scoring rule | - | Sequential |

As Table 1 shows, we assume the spot market to be organized as a uniform-price auction, i.e. all bidders receive a system price defined by the highest accepted bid. Following the typical auction design for electricity markets, we apply a pay-as-bid pricing for the reserve market. Hence, all winning bids receive their own respective bids both for energy and capacity. The focus of our analysis of auction design options will not lie on the pricing rules, since the pros and cons of pay-as-bid vs. uniform pricing auctions are extensively discussed in the literature.[1] Instead, we focus on different types of scoring rules which are used to evaluate the energy and capacity bids for the selection of the winning bids. As shown in the bottom line of Table 1, two basic forms of scoring rules will be discussed.

A so-called "sequential scoring rule" is for example applied in the German reserve markets. The term sequential means that there is a two-stage approach. At the first stage, the winning bids are selected solely on the basis of the capacity bid. This means that those units with the

[1] We restrict the discussion on pricing to the main impacts on strategic and collusive behavior in section 4.3. For a deeper insight into the effects of uniform and pay-as-bid pricing see for example Krishna (2010). For further details on auction design issues, the interested reader may refer to Ausubel and Cramton (1998, 2002), Staropoli et al. (2000), Rassenti et al. (2000, 2003), or Federico and Rahmann (2003).

lowest capacity bids are selected to participate in the market, independent of their energy bids. At the second stage, the chosen units are ranked according to their energy bids. This ranking determines the merit order in the same way as in the spot market.

The alternative is what we call a "simultaneous scoring rule". Thereby the energy and capacity bids are weighted in order to determine a single scoring value based on which the bidding units are selected. The dispatch is based in the same way on the merit order which is formed by the energy bids. Obviously, the difficulty is to determine the weighing factor(s).

The design of the scoring rule determines the strategic bidding behavior of the generation units and thereby the outcome of the auction. We will analyze bidding strategies and effects in the remainder of this article.

## 3. Description of auction designs and scoring rules

### 3.1 General assumptions and model description

We assume that an auctioneer holds an auction to identify the cheapest bids. In other words, it aims to minimize the costs of the reserve market, taking the auction design, including the scoring rule, as given. As mentioned above, we assume simultaneous bidding and pay-as-bid pricing and focus on the analysis of the two scoring rules. We start with a general description of the model and the behavioral assumptions of the bidders and the auctioneer.

The required amount of strategic reserves is exogenously determined by the regulator. We denote this volume of reserves with $K$ MW. The winners of the auction have to withdraw the accepted amount of capacity from the spot market for the considered period. We assume that capacity is auctioned in equally sized slices of capacity which we normalize to 1; a power plant with capacity x MW can thus be offered with x slices of 1 MW. Therefore, the auctioneer has to select $K$ capacity units. To keep the notation simple, we use K also to denote the highest selected bid, depending on the respective scoring rule applied in the selection process.

All bidders are assumed to be risk neutral profit maximizers. Hence they aim to maximize their expected profits, given their fixed capacity costs $k_i$ and their (constant) marginal production costs $c_i$, respectively. Moreover, due to their risk neutrality, the revenue equivalence theorem holds and the probability of winning the auction can directly be deduced because of the reachable profit. We assume all bidders to have complete information about the auction design rules and know their own costs but (theoretically) only have imperfect information about the other bidders' cost structures. Assuming further that bidders are identical except for their costs, bidders with the same costs will hand in the same bids for any given scoring rule. The number of all bidders is denoted by I, while the index i denotes the single bidders.

Our analysis and notation basically follows the model provided in Bushnell and Oren (1994) and, similarly, in Chao and Wilson (2002). The bidders bid two prices, one for capacity, denote by $b_i^K$, and one for energy, denoted by $b_i^C$, when it is actually scheduled. Hence, the revenue ($R_i$) of a winning bidder is given by

$$R_i = b_i^K + \rho(b_i^C)b_i^C. \quad (1)$$

In line with the notation in Bushnell and Oren (1994), $\rho_i = \rho(b_i^C)$ is the actual demand or dispatch duration of unit i that negatively depends on the energy bid and determines the quantity sold by a successful bid.[2] Normalizing the auction period to 1, $\rho_i$ can also be interpreted as the probability of unit i to be dispatched with $0 \leq \rho_i \leq 1$. According to the classical merit-order, a lower energy bid $b_i^C$ c.p. increases the priority of unit i for dispatch. Hence, a lower bid increases the probability $\rho_i$ of dispatch for this unit.

The auctioneer's optimization problem can be characterized as minimizing total costs of the required amount of strategic reserves, K, denoted by

$$TC = \sum_{i=1}^{K}\left[b_i^K + \rho_i(b_i^C)b_i^C\right]. \quad (2)$$

The auction design issue is to find a scoring rule $S_i(b_i^K, b_i^C)$ according to which the cheapest bids are selected and then ranked to form a merit order for cost efficient dispatch of the reserve units.

We define a general scoring rule in line with the total cost definition given by

$$S_i = b_i^K + \Omega_i b_i^C \ , \quad (3)$$

which determines the selection of winning bids, where $\Omega_i$ is the relative weight given to the energy bid in the selection process. As will be discussed further below, this energy weight can be different for different types of bidders.

[2] Strictly speaking, $\rho_i$depends on *all* successful bids and not only unit i's own bid, but we omit this for the reason of simplicity. Instead we follow the assumption in Bushnell and Oren (1994) that $\rho_i$ is not significantly affected by the outcome of the auction, i.e. it is robust with respect to the strategic interaction of bids.

Cost minimization implies that the bidders with the lowest combination of capacity and energy bids according to the applied scoring rule, i.e. the lowest values of $S_i$, will be selected. The scoring rule and the specific energy weights $\Omega_i$ are assumed to be known to all bidders. As will be analyzed in the following sections, the specification of $\Omega_i$ defines the two basic forms of auction rules as described above.

We define the simultaneous scoring rule such that a positive weighting factor $\Omega_i > 0$ is applied to consider both the energy and capacity bids – "simultaneously" – already in the selection process.

Similarly we define sequential scoring such that the energy weight $\Omega_i$ is zero for the preselection of reserve units. In this case, the energy bid only comes into play at the second stage, when the dispatch of selected units is determined.

Note that in both cases the scoring rule only determines the first-stage selection process, while the actual dispatch is determined at the second stage based on the energy bids only. Note further that the bids themselves are always handed in simultaneously; the terms simultaneous vs. sequential for the scoring rules only refer to question whether both bids are considered at the time the winning bids are selected.

We now specify the optimality conditions for the units' bidding strategies. Bidders maximize their profits, given their costs and facing a predetermined, known scoring rule. Their strategic bidding variables, $b_i^K$ and $b_i^C$, influence the profits in two possible ways:

- First, depending on the scoring rule, both bids may affect the *probability of being selected* for the reserve market. The lower their respective value $S_i$, the higher the probability of entering the market.
- Second, if a unit is selected, its energy bid $b_i^C$ determines its position in the merit order and, hence, the dispatch duration, as a result of $\rho(b_i^C)$.

Let the bidders' probability of belonging to the winning bids be denoted as $P_i\left(S_i\left(b_i^K, b_i^C\right)\right)$. This probability depends on the scoring rule and the bids submitted for capacity and energy, respectively. Hence, the bidders maximize their expected profits as follows:

$$\text{Max } E(\pi_i) = P_i\left(S_i\left(b_i^K, b_i^C\right)\right) \cdot \left[b_i^K - k_i + \rho(b_i^C) \cdot (b_i^C - c_i)\right] \quad (4)$$

The first order conditions with respect to the energy bid and capacity bid respectively, state

$$\frac{\partial E(\pi_i)}{\partial b_i^C} = \frac{\partial P_i\left(S_i\left(b_i^K, b_i^C\right)\right)}{\partial S_i\left(b_i^K, b_i^C\right)} \frac{\partial S_i\left(b_i^K, b_i^C\right)}{\partial b_i^C} \cdot \left[\mathrm{b_i^K} - \mathrm{k_i} + \rho(\mathrm{b_i^C}) \cdot (\mathrm{b_i^C} - \mathrm{c_i})\right]$$

$$+P_i\left(\mathrm{S}_i\left(b_i^K, b_i^C\right)\right) \cdot \left[\frac{\partial \rho}{\partial b_i^C}\left(b_i^C - c_i\right) + \rho\left(b_i^C\right)\right] = 0, \qquad (5)$$

and

$$\frac{\partial E(\pi_i)}{\partial b_i^K} = \frac{\partial P_i\left(S_i\left(b_i^K, b_i^C\right)\right)}{\partial S_i\left(b_i^K, b_i^C\right)} \frac{\partial S_i\left(b_i^K, b_i^C\right)}{\partial b_i^K} \cdot \left[\mathrm{b_i^K} - \mathrm{k_i} + \rho(\mathrm{b_i^C}) \cdot (\mathrm{b_i^C} - \mathrm{c_i})\right]$$

$$+P_i\left(\mathrm{S}_i\left(b_i^K, b_i^C\right)\right) = 0, \qquad (6)$$

Dividing these two equations directly yields the following optimality condition:

$$\frac{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^C}}}{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^K}}} = \rho\left(\mathrm{b_i^C}\right) + (\mathrm{b_i^c} - \mathrm{c_i}) \frac{\partial \rho\left(\mathrm{b_i^C}\right)}{\partial \mathrm{b_i^C}}. \qquad (7)$$

The ratio on the left-hand side of equation (7) corresponds to the weights of energy to capacity bids according to the scoring rule. In the optimum, this ratio equals the marginal rate of substitution between the bids plus a mark-up on the marginal cost, given by the right-hand side of equation (7). The intuition behind equation (7) is that a bidder balances its capacity and energy bid by taking into account the weights of these bids in the scoring rule.

Substituting the elasticity of energy dispatch with regard to the energy bid, $\varepsilon = \frac{\partial \rho(\mathrm{b_i^C})}{\partial \mathrm{b_i^C}} \cdot \frac{\mathrm{b_i^C}}{\rho_\mathrm{i}}$, for the right-hand term in equation (7) yields:

$$\frac{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^C}}}{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^K}}} = \rho\left(\mathrm{b_i^C}\right)\left(1 + \varepsilon - \varepsilon \frac{\mathrm{c_i}}{\mathrm{b_i^C}}\right) \qquad (8)$$

The term ε measures the relative change in the duration of dispatch (i.e. electricity demand) as a result of a relative change in the energy bid.

***Proposition 1:*** *According to the unit's optimal bidding strategy the rate of substitution between energy and capacity bid is mainly determined by the weights of the respective bids in the applied scoring rule. The relationship is described by the following equation:*

$$\frac{\frac{\partial S_i(\mathrm{b}_\mathrm{i}^\mathrm{C}, \mathrm{b}_\mathrm{i}^\mathrm{K})}{\partial \mathrm{b}_\mathrm{i}^\mathrm{C}}}{\frac{\partial S_i(\mathrm{b}_\mathrm{i}^\mathrm{C}, \mathrm{b}_\mathrm{i}^\mathrm{K})}{\partial \mathrm{b}_\mathrm{i}^\mathrm{K}}} = \rho\left(\mathrm{b}_\mathrm{i}^\mathrm{C}\right)\left(1 + \varepsilon - \varepsilon \frac{\mathrm{c}_\mathrm{i}}{\mathrm{b}_\mathrm{i}^\mathrm{C}}\right)$$

Proposition 1 shows that according to the unit's optimal bidding strategy the rate of substitution between energy and capacity bid is mainly determined by the weights of the respective bids in the applied scoring rule. For this optimality condition to hold we assume that the dispatch function $\rho(b_i^C)$ is not influenced by the auction outcome itself (see Bushnell and Oren, 1994).

The following sections analyze two forms of scoring rules:

1) A simultaneous scoring rule, where the energy and the capacity bids are used to simultaneously determine the optimal selection of winning units, while the merit order is based on the energy bids of the selected units.
2) A sequential scoring rule, where, at the first stage, only the capacity bids alone determine the selection of reserve units, while the energy bids are only considered at the second stage where the merit order is determined by the respective energy bids.

Note again that in both cases the two bids are handed in simultaneously by all bidders, i.e. bidding as such is simultaneous. According to the pay-as-bid rule, all winning units receive their capacity bid for withholding their capacity from the spot market. Furthermore, they receive their energy bid for the amount of electricity they produce when their reserves are dispatched. The dispatch schedule under both scoring rules results from the *merit order* which is formed on basis of the energy bids.

The crucial difference between the scoring rules is the selection process due to the different evaluation of bids, depending on the specific energy weight applied. As a consequence, the scoring rules will also lead to different bidding behaviors of the units, and hence, outcomes of the auction.

### 3.2 Simultaneous scoring rule

We define a simultaneous scoring rule as a rule that combines the weighted energy and capacity bids to a single score based on which the winning bids for the reserve market are chosen.

The result of the scoring rule can be seen in equation (7) when applying the scoring rule derived in equation (3).

$$\frac{\frac{\partial S_i(\mathrm{b_i^C},\mathrm{b_i^K})}{\partial \mathrm{b_i^C}}}{\frac{\partial S_i(\mathrm{b_i^C},\mathrm{b_i^K})}{\partial \mathrm{b_i^K}}} = \frac{\Omega_i}{1} = \rho\left(\mathrm{b_i^C}\right) + (\mathrm{b_i^c} - \mathrm{c_i})\frac{\partial \rho\left(\mathrm{b_i^C}\right)}{\partial \mathrm{b_i^C}}. \tag{9}$$

Assume we find scoring weights $\Omega_i$ that correspond to the actual dispatch duration $\rho_i$ for each unit i. In this case the ratio of weights between the energy and capacity bid in the scoring rule $(\Omega_i/1)$ equals the expected ratio of energy and capacity costs in the reserve $(\rho_i(b_i^C)/1)$. We see from equation (9) that both terms cancel out, and what remains is

$$0 = (\mathrm{b_i^c} - \mathrm{c_i})\frac{\partial \rho\left(\mathrm{b_i^C}\right)}{\partial \mathrm{b_i^C}} \text{ , or}$$

$$b_i^C = c_i \tag{10}$$

In other words, the application of a cost reflective weight of the energy bid results in truthful marginal cost bids.

The capacity bid results from the second first-order condition given by equation (4) as

$$b_K = k - \rho(b_c - c_i) - \frac{P_i}{\partial P_i/\partial S} = k - \frac{P_i}{\partial P_i/\partial S} \tag{11}$$

***Proposition 2****: Assuming that a simultaneous scoring rule of the form $S_i = b_i^K + \Omega_i b_i^C$ , and assuming where $\Omega_i = \rho_i\ \forall i$ , bidders will bid their true marginal cost ($b_i^C = c_i$) on the energy market and maximize their expected profits with the capacity price. In other words, the strategic variable is the capacity bid.*

The intuition is straightforward. Bidding a higher energy price increases the price on the energy market when being dispatched, but at the same time it reduces the probability of dispatch. This is the usual trade-off known from the spot market. In addition, however, the higher energy bid reduces the probability of being scheduled for the reserve at all. Therefore, the negative effect of bidding a high energy price is relatively high. In contrast, a high capacity price increases the capacity price but reduces the probability of being scheduled. However, a higher capacity bid does not reduce the probability of being dispatched once being scheduled. Therefore, the negative effect of a higher capacity bid is relatively low. In sum, it is thus better for a bidder to use the capacity bid as strategic variable, whereas the energy bid is not used strategically.

The implication is important. The idea behind the comparison of the simultaneous and sequential scoring rules is the compatibility with the reserve markets to address the "missing-money". The effect of the simultaneous scoring rule, as formulated above is that bidders move away from energy pricing towards capacity pricing which is exactly what is required to address the missing-money problem. The intention is not to design a mechanism which creates optimal bidding (where energy prices are equal to marginal cost); the idea is to address the missing money problem of an energy-only market.

Note that the result $b_i^C = c_i$, is similar to the typical outcome of a Vickrey auction (see Vickrey, 1961). However, the approach of the simultaneous scoring rule addressed here does not depend on a Vickrey auction. We only analyze a first-price auction, while a Vickrey-approach was used in Bushnell and Oren (1994), by making the payments to bidders independent of their own bids. Such a Vickrey auction is known to induce truthful bidding. However, Vickrey auctions are criticized on several grounds for not being suitable for applications in energy markets; among other negative characteristics they do not appear to be resistant against collusion (e.g. Rothkopf et al., 1990). For this reason we will not follow the Vickrey approach. Note further that we do not assume conditions on competition on the energy market. The outcome of $b_i^C = c_i$ is not the result of "perfect competition", but is the result of the design of the scoring rule.

The result that $b_i^C = c_i$ is very powerful but critically depends on the assumption $\Omega_i = \rho_i \; \forall i$. This assumption says that the (ex ante) weight $\Omega_i$ should be equal to (ex post actual or ex ante expected) output quantities (or load factors). This is clearly a problem and deserves more attention.

A first problem is the interdependence between the *selection* of units for the reserve market in the first place, and the *dispatch* of the chosen units in line with the resulting merit order. The minimization of reserve market costs requires considering both capacity and energy costs in a cost reflective way, but the relative weights of these costs depend on the actual duration of dispatch for each of the units. This in turn depends on the selection process in the first place. In other words, when designing the scoring rule, the actual dispatch of units is not yet known, since it results from the auction itself. This is an infinite recursion.

Second, as mentioned above, the assumption is that the reserve demand $\rho\left(b_i^C\right)$ is known a priori when designing the scoring rule and it is perfectly forecasted by the bidders. Otherwise it is not possible to determine the optimal energy weight $\Omega_i$ in the scoring rule.

Third, the scoring rule has to be differentiated for all cost types of bidders. This is due to the fact that the $\Omega_i$ in the scoring rule are parameters which have to equate the individual values $\rho\left(b_i^C\right)$ of each bidder i. In the ideal case this requires full cost information of all units in order to provide differentiated scoring rules. Due to publication requirements on prices and demanded quantities, the bidders are expected to have an educated guess on the true values, such that deviations may be reasonably small.

A practical solution is to use a (limited) number of weighting parameters for different classes (cost types) of generators, assuming that their marginal costs can be estimated. In practice the marginal costs of different generation units are fairly well known. Given that the reserve market auctions are repeated regularly, it seems plausible to assume a more or less accurate cost estimation of the generation units involved.

An alternative approach to set $\Omega_i$ is to use ex post values of $\rho\left(b_i^C\right)$ in the future round. If designed well, a convergence process might eventually approximate $b_i^C = c_i$. Such a mechanism is similar to the mechanism developed in Vogelsang & Finsinger (1979).

### 3.3 Sequential scoring rule

The term sequential scoring rule means that the auctioneer only considers the capacity bids (and ignores the energy bids) when selecting the winning bids at the first stage. Given the selection of reserve generators, the auctioneer then forms a merit order on basis of the energy bids only in order to minimize expenditures on energy at the second stage.

Accordingly, in the first step the cheapest capacity bids are chosen, such that the required amount of capacity is acquired, i.e. $\sum_i K_i = K$. All the winning bidders enter the second stage, competing for their position in the merit order on basis of their energy bids.

The profit maximization corresponds to equation (4) derived above, except that the scoring rule only depends on the capacity bids:

$$\text{Max } E(\pi_i) = \mathrm{P_i}\left(S(b_i^K)\right) \cdot \left[\mathrm{b_i^K} - \mathrm{k_i} + \rho(\mathrm{b_i^C}) \cdot (\mathrm{b_i^C} - \mathrm{c_i})\right]$$

In contrast to the simultaneous scoring rule, however, the profit maximization now becomes a two-stage optimization problem. The first-stage problem is to find the optimal capacity bid for the selection process (scoring rule), while the second-stage problem is to choose the optimal energy bid that determines the dispatch duration (merit-order). Due to the separation of these two selection procedures under sequential scoring, the bidder's optimization problem can be solved by *backward induction,* since the second stage can be interpreted as a separate single-stage game.

Hence, we start with analyzing the second stage. The bidders know a priori that they will face reduced *Cournot competition* at the second stage, since only the selected units compete for their position in the merit order. Note that due to the reduced number of bidders, we need to take into account the strategic interaction between the bidders. They solve the following optimization problem:

$$\text{Max } E(\pi_i|b_K) = \mathrm{b_i^K} - \mathrm{k_i} + \rho(\mathrm{b_i^C}, \mathrm{b_{-i}^C}) \cdot (\mathrm{b_i^C} - \mathrm{c_i}).$$

We generalize the dispatch function $\rho(\mathrm{b_i^C}, \mathrm{b_{-i}^C})$ such that it depends on all energy bids instead of bidder i' bid only. This leads to the following optimization:

$$\frac{\partial(\pi_i|b_K)}{\partial b_i^C} = \left[\frac{\partial\rho}{\partial b_i^C} + \sum_{j\neq i}\frac{\partial\rho}{\partial b_j^C}\frac{\partial b_j^C}{\partial b_i^C}\right] \cdot \left(b_i^C - c_i\right) + \rho(\mathrm{b_i^C}, \mathrm{b_{-i}^C})$$

We state the outcome of the Cournot Nash equilibrium in the general form as

$$b_i^{C*} = b_i^C(c_i, c_{-i}).$$

Furthermore, we define the resulting energy margins, i.e. profits *excluding* the capacity margins $(\mathrm{b_i^K} - \mathrm{k_i})$, as

$\pi_i^{C*} \equiv \pi_i^C(c_i, c_{-i})$.

Now we can solve the first stage of the optimization by

$$\text{Max } E(\pi_i) = \mathrm{P_i}\left(S(b_i^K)\right) \cdot \left[\mathrm{b_i^K} - \mathrm{k_i} + \pi_i^{C*})\right]$$

The first-order condition is given by

$$\frac{\partial E(\pi)}{\partial b_K} = \frac{\partial P_i}{\partial S} \cdot \frac{\partial S}{b_K} \cdot \left[b_K - k + \pi_i^{C*}\right] + P_i = 0.$$

The optimal capacity bid results as

$$b_K = k - \pi_i^{C*} - \frac{P_i}{\partial P_i / \partial S} \tag{12}$$

Equation (12) shows that energy bid and capacity bid are negatively related such that an increase in the energy bid directly has to transform into a decrease in the capacity bid and vice versa.

Note that the sequential scoring rule can be seen by interpreting the sequential scoring rule $\mathrm{S}\left(\mathrm{b_i^K}\right)$ as a special case of the simultaneous scoring rule $\mathrm{S}\left(\mathrm{b_i^K}, \mathrm{b_i^C}\right)$ where the energy weight is zero ($\Omega_i = 0$).

Hence, we find

$$\frac{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^C}}}{\frac{\partial S_i(\mathrm{b_i^C}, \mathrm{b_i^K})}{\partial \mathrm{b_i^K}}} = 0,$$

and equation (5) yields

$$0 = \rho\left(\mathrm{b_i^C}\right) + (\mathrm{b_i^c} - \mathrm{c_i})\frac{\partial \rho(\mathrm{b_i^C})}{\partial \mathrm{b_i^C}}.$$

This implies that instead of truthful marginal bids (as under $\Omega_i = \rho_i$) the following positive mark-up on energy bids applies

$$(b_i^c - c_i) = \frac{-\rho\left(b_i^C\right)}{\frac{\partial \rho\left(b_i^C\right)}{\partial b_i^C}} > 0. \tag{10}$$

***Proposition 3****: in case of a sequential scoring rule, where units are chosen on basis of their capacity bids only, bidders will choose a mark-up on their energy costs according to*

$$(b_i^c - c_i) = \frac{-\rho\left(b_i^C\right)}{\frac{\partial \rho\left(b_i^C\right)}{\partial b_i^C}} > 0.$$

The intuition behind proposition 3 is that under sequential scoring the main profits are gained at the second stage. Increasing the energy bid does only affect the profits in stage 2 and does not affect the probability of winning in stage 1. Hence, for the bidder in stage 2, bidding on the energy market is unrelated to bidding in stage 1 and is in fact a normal market. The capacity bid in contrast has two effects. Firstly, the capacity bid in itself determines the direct expected profit of the capacity price. Secondly, a higher capacity bid reduces the probability of being scheduled and thereby reduces the probability of receiving any positive profits on the energy market. Summing these incentives, the bidder will use the energy bid as the strategic variable to make profit whilst biding a low capacity bid to get into the market.

The implication for the purpose of this paper is that a sequential scoring rule is not compatible with the idea to address the missing-money problem. If the purpose is to have stronger component of capacity pricing then we must conclude that this goal is not achieved with a sequential scoring rule.

These effects are strengthened, as after the selection at the first stage, there is reduced (Cournot) competition due to the smaller number of bidders. Note in particular that if profits on the energy markets are high, the optimal capacity bid can actually be negative. A bidder would be willing to pay to be on the energy market.

If we assume a competitive bidding process and, hence, a sufficient amount of excess capacity available for bidding into the reserve market, the overall profits from participating in the reserve market are limited as well. Let us denote the profits from participating in the day-ahead market as $\pi_i^{opp}$. These define the opportunity costs for all bidders for participating in the reserve market. Under this competitive assumption and given there are no arbitrage opportunities, the expected overall profits both for simultaneous and sequential scoring should both be equal to $\pi_i^{opp}$. Hence, we end up with a so called “iso-profit” condition with $E(\pi_i) =$

$\pi_i^{opp}$ for all bidders i, and only the distribution of profits between energy and capacity bids differs between the scoring rules.

The main difference between the simultaneous and sequential scoring mechanism described above is that under sequential scoring the bids are biased towards lower capacity bids and higher energy bids, since it is only the capacity part that “opens the door” to the reserve market. An empirical indication for this result is provided by the German balancing reserve market, where sequential scoring is applied. In the market for minute reserves, the capacity bids of participating units tend towards zero, while the energy bids strongly exceed regular market prices.[3]

## 4. Welfare effects of different scoring rules

### 4.1 Demand elasticity and pricing efficiency

As the results of the previous sections showed, the main difference between the simultaneous and the sequential scoring rule is the strategic variable with which profits are made. While simultaneous scoring may, in the optimum case, induce undistorted truthful marginal energy bids, a sequential scoring rule results in a mark-up on the energy costs. Table 2 summarizes the main characteristics of the two scoring mechanisms.

Table 2: Summary of scoring mechanisms

| Scoring mechanism | Simultaneous scoring rule | Sequential scoring rule |
|---|---|---|
| Bidding | Simultaneous | Simultaneous |
| Scoring rule (schedule) | $S_i = b_i^K + \Omega_i b_i^C$ | $S = b_i^K$ |
| Dispatch rule | $\rho(b_i^C)$ | $\rho(b_i^C)$ |
| Capacity demand | $K = \sum_i K_i$ | $K = \sum_i K_i$ |
| Energy demand | $\rho(b_i^C)$ | $\rho(b_i^C)$ |
| Strategic variable | Capacity bid ($b_i^K$) | Energy bid ($b_i^C$) |
| Residual variable | Energy bid ($b_i^C$) | Capacity bid ($b_i^K$) |

[3] The auction results are regularly posted on www.regelleistung.net, which is the common internet platform of the four Germany TSOs for tendering control reserves.

Even under the assumption of a competitive bidding process that limits the expected profits in both cases to $\pi_i^{opp}$, the choice of the scoring rule will most likely have an effect on social welfare, since it leads to a different strategic bidding behavior that affects the efficiency of pricing, selection and dispatch of reserve capacities.

The efficiency of pricing is related to the theory of Ramsey-pricing in a combinatorial auction (see e.g. Borrmann and Finsinger, 1999). According to the Ramsey-pricing rule, the mark-up on marginal costs in the optimum has to be inversely proportional to the demand elasticity. The intuition behind this rule is that price distortions cause a relatively lower welfare loss if demand elasticity is small and vice versa. Referring to our setting, the demand for capacity is fixed as part of the auction design and therefore inelastic. The demand for energy, however, is more elastic, depending on the slope of the demand function $\rho(b_i^C)$. Consequently, with respect to this approach, the price for capacity shall receive the larger mark-up, since it does not lead to a distortion of demand. In case of energy, however, a mark-up will have a distortive effect by reducing the optimal level of reserve dispatch. Thus, referring to the results above, a sequential scoring rule is less favorable from a welfare perspective, since it induces a mark-up on the energy bids instead of capacity. This holds especially for the case in which the two different products are demanded independently. For depending demand with existing cross price elasticities, the Ramsey pricing rule suggests that the product of the different mark-ups on the marginal costs and the according price elasticity is the same for all goods (Borrmann and Finsinger, 1999, pp. 177-179), as long as the demand for the product follows a linear function.

### 4.2 Efficiency of selection and dispatch

While the previous subsection deals with the pricing issue, the following paragraphs refer to the optimal selection and dispatch of reserve capacity.

The efficiency of *selection* mainly relates to the technological choice of reserve units, while the term *dispatch* efficiency concerns the optimal order in which the selected units are scheduled, i.e. whether the merit order is distorted.

As shown in the previous sections, only the simultaneous scoring rule may lead to truthful marginal cost bidding, while sequential scoring leads to significant cost mark-ups for the energy bid, while the capacity bid will be low or even negative. The main problem of strategic bidding und imperfect information is the dependence on bids on expectations about other bidder's cost structures and behavioral assumptions.

Both the selection and dispatch of units depend on the observable energy or capacity bids instead of the unobservable underlying costs. Hence, the stronger the incentives for strategic bidding, the higher the risk that differences in cost mark-ups between the bidding units lead to an inefficient dispatch of reserve units. Several problems may arise:

First, in case of sequential scoring, the energy bids are neglected in the selection process. As a consequence, bidders strategically lower their capacity bids. This favors generation technologies with lower fixed costs (peaking technologies). The reason is that those units are less dependent on the capacity payment compared to units with higher fixed costs.

Second, high cost mark-ups on the energy bid under sequential scoring increase the risk of inefficient dispatch which occurs whenever the rank of bids in the merit-order deviates from the rank of actual marginal cost. A simultaneous scoring rule significantly reduces this risk by incentivizing lower mark-ups on marginal costs.

Third, as already discussed before, the energy weights $\Omega_i$ in the scoring rule depend on expectations about the actual ex post dispatch duration $\rho_i$, given that the latter is an outcome of the auction and, hence, not known to the bidders and the auctioneer a priori. Hence, expectation errors on the actual dispatch duration may be made both by the auctioneer (by choosing a wrong weight $\Omega_i$ in the scoring rule and by the bidders trying to gain and exhaust any informational advantage to increase their profits by choosing their optimal bidding strategy.

To summarize, the risk of inefficient selection or dispatch occurs under both scoring rules, but appears to be lower in case of simultaneous scoring, since it reduces the incentives for significant strategic mark-ups. Furthermore, both the bidders and the auctioneer will gain experience after several repetitions of the auctions. Hence, the informational asymmetry will alleviate somewhat over time and prediction errors of the actual load factor of the strategic reserve will reduce.

### 4.3 Strategic and collusive behavior

The incentives for collusive behavior are highly correlated with the market structure and the existence of market entry barriers. Collusion is the coordinated behavior in setting prices and influencing other bidders in order to affect their bids and the resulting quantity or prices. With respect to this, all markets with restricted numbers of bidders bear the danger of causing collusive behavior.

In contrast to reserve markets, which require rather strict conditions for prequalification[4] notably in terms of the adjustment speed needed to balance supply and demand, a strategic reserve market is less demanding with regard to technological prerequisites. Hence, assuming a sufficiently competitive day-ahead market, the total number of bidders allows for a fairly competitive bidding process, such that the iso-profit assumption seems justified.

As shown in the previous sections, however, only the simultaneous scoring rule involves the total number of bidders, while in case of sequential bidding this is only true for the selection stage. At the second stage of the sequential bidding, it is only the K selected units which compete for their position in the merit order. This may significantly reduce the level of competition. Hence, strategic and collusive behavior is more likely under sequential scoring than in case of simultaneous scoring.

## 5. Summary and conclusions

This article analyzes bidding behavior of different scoring rules in the auction designs for a strategic reserve in markets for electric power. The background to this issue is the "missing money" problem. The traditional market design is an "energy-only" market; i.e. revenues for generators only depend on actually produced and sold electricity, and not on availability. In the day-ahead market, for instance, generators have to recover their full costs from energy sales. Since reserve units mainly serve as backup capacities, however, their actual utilization is low. Low utilization implies that revenues from energy-only payments are low. If prices in these periods in which reserve capacity is needed are not sufficiently high, these generators will not be able to recover full costs which in turn endangers investment incentives. This phenomenon, which is associated with energy-only markets, is called the "missing money" problem.

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[4] Prequalification implies that not all power plants are allowed to participate in the market, such that the number of potential bidders is reduced.

Strategic reserves are one option to address the missing money problem. In this option, some institution (eg. regulator, power pool, or system operator) tenders a predetermined quantity of reserves; this reserve capacity is taken off the normal day ahead market, and will produce only if asked to do so, if reserves are needed. It is usual that reserve capacity gets rewarded with a two-part pricing system: a capacity payment for availability and an energy price for actual production.

This paper compares two different scoring rules for the selection and dispatch of reserve units. First, we analyze a "simultaneous scoring rule", where capacity and energy bids are combined to a single scoring value which determines the selection of units. The weighing factor of capacity bid and energy bid is crucial. Second, we analyze a "sequential scoring rule", where selection of capacity depends solely on capacity bids in a first stage, while the energy bids are only used to determine the merit order for dispatch in the second stage.

We find that the sequential scoring rule results in a higher mark-up on the energy cost, rendering this a "strategic variable", while the capacity bid becomes a "residual variable" which is reduced as much as necessary in order to be selected for participation in the reserve market. A simultaneous scoring rule leads to truthful energy bids if the weights assigned to the energy bids perfectly correspond to the actual dispatch duration of energy in the reserve market. The intuition is straightforward. Bidding a higher energy price increases the price on the energy market conditional on being scheduled, but reduces the probability of being dispatched. This is the usual trade-off known also from the spot market. In addition, however, the higher energy bid reduces the probability of being selected at all. Therefore, the negative effect of bidding a high energy price is relatively high. In contrast, a high capacity price increases the capacity price but reduces the probability of being scheduled. However, a higher capacity bid does not reduce the probability of being dispatched once being scheduled. Therefore, the negative effect of a higher capacity bid is relatively low. In sum, it is thus better for a bidder to use the capacity bid as strategic variable, whereas the energy bid is not used strategically.

Basically the result is that the simultaneous scoring rule achieves exactly what would be the idea of approaches to address the missing money problem: it strengthens reliance on the capacity payment and reduces reliance on the energy payment. In a more detailed welfare analysis, we find further arguments why a simultaneous scoring rule is favorable. First, it is in line with the Ramsey principle, since it sets the mark-up on the inelastic component (capacity). Second, it avoids the strategic incentives for excessive mark-ups on energy costs and thereby reduces the risk of a distorted merit order in production. Third, it limits the incentives for collusive behavior. This reduces the risk of inefficient selection and dispatch of reserve units compared to a sequential scoring mechanism.

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