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Residual demand models for strategic bidding in European power exchanges: Revisiting the methodology in the presence of a large penetration of renewables

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ABSTRACT

In the deregulated framework in place in most power systems, a significant part of the energy is traded through auctions on day-ahead markets where agents submit bids to either buy or sell energy. When defining a bidding strategy, generators usually resort to models that anticipate and simulate agent interactions. The residual demand curve (*RDC*), a well-known approach to representing competitor behaviour, enables generators to formulate effective oligopolistic strategies.

One way to estimate and build an *RDC* is to use information available about other agents' bids on previous and comparable days as a reference. This basic approach to market modelling has proven useful in the past in European power exchanges. In the current context, however, characterised by substantial market penetration on the part of non-dispatchable renewable resources, the suitability of this method of *RDC* building may need to be tested.

This paper first analyses how the results of day-ahead auctions on European power exchanges have been affected by the growing penetration of renewable energy. It then questions both the use of *RDC* as an approach in this changing context and the aforementioned simplified estimation method to compute these curves. The discussion is illustrated with empirical evidence from the Iberian market.

1. Introduction

In the competitive framework that governs electricity production in many electric power systems, generating company (GenCo) revenues depend largely on generators' ability to devise a suitable bidding strategy for short-term markets. This is particularly true in European markets, which operate around power exchanges (PX) [16], for two main reasons. On the one hand, auction design based on so-called semi-complex bidding protocols and the linear pricing rule requires GenCos to design a bidding strategy (which is not always obvious) that correctly internalises all operating costs. And on the other, large GenCos can optimise their entire generation portfolio to capitalise on (not necessarily acknowledged) oligopolistic strategies.

The bids that are ultimately sent to the market operator condition the overall market outcome, including dispatch efficiency and consequently consumers' power bills. Hence, it is not surprising that this issue has attracted a good deal of attention from both the industry (stakeholders and regulators) and academia.

Strategic bidding has been analysed from two main perspectives. The most common approach assesses the possible impact of imperfect competition and market power on the aforementioned market outcome: the ability of market agents to behave strategically and thus the potential need to design measures to mitigate market power; see for instance [1,2].

The second perspective is to broach the problem from the point of view of an individual GenCo seeking to optimise its energy sales on the spot market based on its portfolio, cost structure and operating constraints. The present discussion lies in this latter realm.

In particular, it focuses on single-agent profit maximisation models based on the residual demand curve (*RDC*) [3]. In this modelling framework, only the bids submitted by the target firm are optimised, while its competitors' strategies are fixed and introduced exogenously via the *RDC*. The *RDC* is a function that links a GenCo's sales to the market clearing price. In other words, it expresses how the amount of energy sold in a given hour by an

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individual GenCo affects the market clearing price in that hour. The *RDC* has been widely used in strategic bidding models; see for instance [4–6].

One basic but common method for plotting the *RDC* takes market data from previous and comparable[2] days to gather information about competitors' price-quantity bidding strategies. This information is used as a starting point to plot a series of *RDC*s in the belief that it constitutes the best proxy for competitors' short-term bidding strategies. The models developed in references [7,8] are examples of the use of this approach.

The objective of this paper is two-fold. It first focuses on how the results of day-ahead auctions on European power exchanges have been affected by the growing penetration of renewable energy. Secondly, it discusses how the applicability of the aforementioned simplified method for estimating *RDC* is affected by these changes.

The paper is structured as follows:

- Theoretical background is provided on the characteristics of the *RDC* approach and its capability to represent the different auction designs implemented worldwide. The reasons why *RDC*s are particularly well suited to markets with a simple auction mechanism are explained (Section 2).
- *RDC* suitability in the more complex auction designs implemented in Europe is qualitatively evaluated. The analysis focuses on the effect of significant market penetration by non-dispatchable and highly variable renewable energy sources (vRES). The behaviour of semi-complex auctions in this context is illustrated by the auction result patterns observed for the Iberian day-ahead market, MIBEL in recent years (Section 3). This market features the two characteristics dealt with in the present discussion: a day-ahead market based on semi-complex auctions and a power system with a vRES share that is among the world's highest.
- Section 4 introduces an ad hoc computation method for testing *RDC* applicability, which is then evaluated in the context of the MIBEL market.
- The main conclusions drawn from the foregoing are set out in Section 5.

2. Background: the problem of modelling day-ahead electricity auctions

The strategic bidding problem in short-term electricity markets is addressed in the literature with a variety of techniques; see for instance the reviews in [9,10]. As pointed out in the latter, many widely varying approaches are in place, fathered by the diversity of the spot market designs implemented worldwide.

A market model intended to accurately reproduce real market interactions and results must contain a detailed description of all the relevant features of the real market in question. These features include the clearing algorithm, network model and bidding protocol. A fully detailed description of all market rules and agents' interactions is seldom a realistic aspiration, however, for two major reasons: (a) the lack of reliable data to feed the model, which mainly depends on the amount of market information disclosed by the market operator; and (b) the size of the resulting problem. In practice, coping with these difficulties calls for a trade-off between the loss of accuracy stemming from representational simplification and the size of the resulting problem.

This section aims to describe how this trade-off is handled in practice. The complexities arising in electricity auction design are addressed in Section 2.1 and exemplified by a particular type of auction design, the semi-complex model in place in the MIBEL (Section 2.2). The standard *RDC* approach is discussed in Section 2.3 and its suitability in the semi-complex market context in Section 2.4.

2.1. Auction design in day-ahead electricity markets

The special features of electricity as a tradable product such as limited storability, the existence of inter-temporal technical constraints and non-linear cost function components have led to a variety of auction designs and pricing rules (see [11] for a review of electricity auction design criteria). One of the major differences that distinguishes one auction design from another is the extent to which agents and particularly GenCos are allowed to include their technical constraints and cost data in their offers. Based on this criterion, electric power auctions can be classified into three major categories: simple, complex and semi-complex.

At one end of the spectrum, GenCo bids may consist exclusively of a series of price-quantity pairs per time period as the terms of sale for the underlying product, i.e., the MWh. Auctions implementing such one-item bid formats are simple auctions. In this model, the market can be cleared directly as the intersection between the aggregate supply and demand curves to obtain both the energy committed and the marginal clearing price. Note the absence of inter-temporal links among the hour-by-hour auctions. Simplicity and transparency are the two strong points of simple auctions. The drawback is that this design obliges GenCos to fully internalise all production costs in their price-quantity bids and exposes them to the risk of unfeasible or uneconomic scheduling.[3] These two considerations have prevented the rigorous implementation of simple auctions and restricted this design to a mainly theoretical alternative. Nonetheless, some market designs such as Italy's GME [12] or the former California Power Exchange [13] come very close to this textbook model.

On the other end of the spectrum, so-called complex auctions allow for multiple-part bidding. Multiple-part bidding implies that, in addition to the quantity-price pairs for energy, bids include non-convex cost data such as start-up/shut-downs as well as technical constraints such as load gradient limits or minimum stable loads. Such markets are cleared in much the same way as centralised paradigm, usually involving the use of the so-called security constrained economic dispatch (SCED) [14] (although in a market context SCED determines outputs as well as prices). Unlike simple auctions, optimisation-based formulations always reach technically feasible solutions. Complex auctions have sometimes been claimed to be scantly transparent, however [15]. US markets such as PJM, NYISO, ISO-NE, California ISO or MISO are examples of complex auctions; further details on the design of such auctions can be found in [15].

In an attempt to combine the transparency of simple auctions with the technical-economic constraints of complex auctions, many markets have evolved towards a trade-off approach referred to as hybrid or semi-complex auctions.

2.2. MIBEL, example of semi-complex auctions

The core idea in this design is to allow agents to reflect constraints in their bids to some extent through so-called complex conditions. The number and features of the complex conditions defined in a market's bidding protocol should suffice to mitigate the risks facing GenCos in simple auctions, while keeping auction clearing as transparent and easy to interpret as possible. In practice, this trade-off has entailed either the direct inclusion of some of the

[2] By comparable it is meant a day whose market conditions (bids, demand, etc.) are similar to those applying to the following day.

[3] This can be mitigated through complementary arrangements such as intraday markets.