Introducing Block Orders in the Italian Day-Ahead Electricity Market

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***Abstract*—The European day-ahead market is characterized by different types of orders and rules, such as block orders and the uniform purchase pricing rule. Block orders are present in many central and northern European countries, whereas the uniform purchase price is enforced in the Italian market under the name of *Prezzo Unico Nazionale* (PUN). In this paper, we analyze the effects of introducing block orders into the Italian market. In particular, we assess how block orders could affect the computation time, the PUN level, and the number of paradoxically rejected orders. The analysis is performed by varying five main determinants, represented by the total number of blocks, the demanded/offered quantity, the block timespan, the block location, and the demand/supply ratio. Numerical results are obtained by using real Italian market data.**

***Index Terms*—block orders, electricity market, scenario analysis, uniform purchase price.**

I. Introduction

The European electricity market is characterized by different types of heterogeneous orders and rules. Two relevant examples are block orders and the uniform purchase pricing rule. Block orders are traded in many of the central and northern countries [1], whereas the uniform purchase price is enforced in the Italian market [2] with the name of *Prezzo Unico Nazionale* (PUN). Currently, the Italian market does not allow block orders.

The PUN scheme requires that all consumers pay a common price (i.e., the PUN) in all the zones, whereas producers collect zonal prices, which can differ each other. Formally, the PUN π_t is defined as the average of the zonal prices ζ_{ti}, weighted by the cleared demand quantities d^{π}_{tk}, that is:

$$\pi_t = \frac{\sum_{i\in\mathcal{Z}^\pi}\sum_{k\in\mathcal{K}^\pi_{ti}} \zeta_{ti} d^\pi_{tk}}{\sum_{k\in\mathcal{K}^\pi_t} d^\pi_{tk}}\,, \tag{1}$$

where $\mathcal{Z}^\pi$ is the set of zones enforcing the PUN, $\mathcal{K}^\pi_{ti}$ is the set of consumers paying the PUN in zone i at hour $t \in \mathcal{T} = \{1,\ldots,24\}$, and $\mathcal{K}^\pi_t = \cup_i \mathcal{K}^\pi_{ti}$.

Given the PUN definition (1), the *PUN clearing rule* is defined as follows:

- demand orders with a price strictly greater than the PUN must be executed;
- demand orders with the price equal to the PUN may be partially cleared;
- demand orders with a price lower than the PUN must be rejected.

Notice that both consumers and producers have elastic curves, i.e., they demand and offer different quantities at different prices. Therefore, the PUN, the zonal prices and the cleared quantities must be computed simultaneously.

Block orders pose additional complexity to the clearing problem. A block is a single order that spans over multiple hours. The quantity submitted can be different for each hour, as in the case of a *profile* block. Furthermore, *curtailable* block orders have been introduced in the northern European countries [1]. In the latter case, the block p can be partially cleared as long as the percentage r_p of the quantity actually executed in each hour is equal over the whole timespan, and greater than a parameter r^{min}_p, termed *minimum acceptance ratio* (MAR). For a profile block order submitted in zone i with price p^B_p and hourly maximum quantity $s^{B,max}_{tp}$, the weighted average market price w_p is defined as:

$$w_p = \frac{\sum_{t\in\mathcal{T}} s^{B,max}_{tp}\zeta_{ti}}{\sum_{t\in\mathcal{T}} s^{B,max}_{tp}}\,, \tag{2}$$

where ζ_{ti} are the zonal prices. By using (2) block orders can be classified according to their *degree of moneyness*. In particular, supply blocks are classified as:

- in-the-money (ITM), if $w_p > p^B_p$;
- at-the-money (ATM), if $w_p = p^B_p$;
- out-of-the-money (OTM), if $w_p < p^B_p$,

whereas for demand blocks the inequality signs are reverted. ITM block orders should be fully executed, ATM block orders can be partially cleared, and OTM block orders must be always rejected. Notice that, due to the indivisible nature of the blocks, a feasible solution satisfying all the market constraints may not exist [3]. For this reason, current market rules allow to reject ITM blocks, that are termed paradoxically rejected blocks (PRB).

Different methods are proposed to handle block orders [4]–[9], whereas the literature on the PUN is rather limited. In particular, reference [10] introduces a complementarity approach to deal with a clearing problem with mixed-pricing rules, which is further extended to block orders in [11] by using an iterative approach. In [12] a model has been proposed for solving a PUN problem in the presence of simple stepwise orders by maximizing the consumer surplus. Reference [13] proposes a new approach to deal with the PUN, which is termed marginal pricing income calculation method. However, it is unable to deal with curtailable blocks. The original method for solving the PUN scheme [14] is based on a heuristic approach which sequentially explores the whole aggregate demand market curve. The current method implemented by the European clearing algorithm (EUPHEMIA) [8], is still based on a heuristic approach, which explores the market curve until a feasible solution is found within a given tolerance range. Reference [15] discusses the rationale of block order restrictions on traditional markets, where the block timespan appears to have the largest impact. A novel method for solving the PUN scheme has been recently proposed in [16]. It maximizes the social welfare in the simultaneous presence of both curtailable profile block orders and the PUN, without resorting to any heuristic or iterative method. The model is built starting from a non-linear integer bilevel model, which is then transformed into an exact and tractable mixed integer linear program (MILP), where the MILP formulation allows one to prove optimality of the obtained solution.

The aim of this paper is to carry out an in-depth analysis of the effects of introducing block orders into the Italian day-ahead electricity market, by using the model proposed in [16]. In particular, we focus on three main aspects:

1) the computation time required to reach the optimal solution, i.e., to clear the market;
2) the change in the PUN level induced by the blocks, and
3) the number of PRBs detected in the final solution.

The analysis of the impact of block orders on the Italian market is carried out by varying five parameters:

1) the size of the blocks, i.e., the maximum hourly demanded/offered quantity;
2) the number of blocks introduced into the market;
3) the demand/supply ratio of block orders, i.e., the proportion between the purchasing and selling blocks;
4) the location where the blocks are physically included;
5) the timespan of the blocks, i.e., how many hours are covered by the blocks.

The remaining part of this paper is organized as follows. Section II briefly recall the model proposed in [16]. Section III describes the analysis performed, and reports the numerical results. Finally, Section IV outlines the main findings.

II. The Model Structure

This Section briefly describes the model recently proposed in [16]. The MILP model is obtained starting from a non-linear integer bilevel model. In general terms, a bilevel model

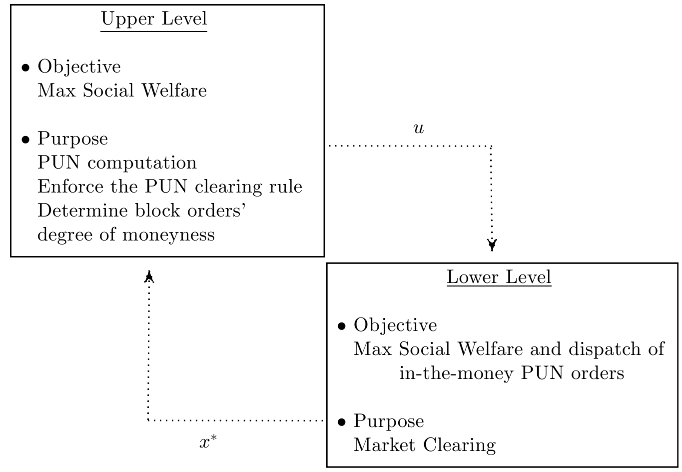

Fig. 1. The bilevel model structure. The upper level problem computes the PUN, enforces the PUN clearing rule, and determines the blocks' degree of moneyness. Given these pieces of information, the lower level problem actually clears the market.

consists of two nested optimization problems, namely the upper and lower level problems [17]. It can be written as:

$$\max_{u \in \mathcal{U}} F(u, x^*) \tag{3}$$

$$\text{s.t.} \quad x^* = \arg\max_{x \in \mathcal{X}} f(x; u), \tag{4}$$

where F is the objective function of the upper level and f is the objective function of the lower level. In the proposed model the upper level maximizes the social welfare, computes the PUN, enforces the PUN clearing rule, and determines the degree of moneyness for block orders. In turn, the lower level actually clears the market, i.e., it determines the executed quantities and the market prices. The overall process is sketched Figure 1.

An important feature of bilevel models is that all the upper level variables enter the lower level as fixed terms. This property makes the lower level problem of the proposed model a *linear* program. By exploiting this characteristic, the lower level can be equivalently represented by using its first order Karush-Kuhn-Tucker conditions. Moreover, by including these conditions into the upper level, a single optimization problem equivalent to the initial bilevel model is obtained. In [16] it was shown that this single level program can be further recast as a MILP.

III. Numerical Results

In this Section, we analyze how different size, timespan, demand/supply ratio, location, and number of block orders can affect the market clearing in terms of computation time, PUN level, and number of PRBs. The numerical results are obtained by using the MILP model outlined in Section II.

A. Experiment setup

The data was obtained from the website of the Italian market operator [2]. It refers to January 1st, 2018, and involves 54,659 market orders over 22 market zones. Six of these areas are the

Italian physical zones, which enforce the PUN rule, whereas the remaining zones are cross-border or special purpose market zones. Additional data was randomly generated to simulate curtailable profile block orders. In the considered day, the average PUN is 45 €/MWh, and the average size of the orders is 32 MWh. For this reason, the block price p_p^B is generated using a normal distribution with mean 45 €/MWh and standard deviation 15 €/MWh, whereas the block hourly maximum quantity s_{tp}^{max} is sampled from a uniform distribution with minimum value 1 MWh, and mean 32 MWh (except in the test of Section III-B). Negative prices are set to zero. The minimum acceptance ratio r_p^{min} is set to 10%. If not otherwise specified, the blocks are evenly distributed among all the six PUN zones, equally divided between demand and supply block orders, and each block spans 4 hours, from the 13th to the 16th hour. The MILP model has been implemented in Python 2.7 by using the code available at [18], and solved with CPLEX 12.5 on a 8-core Intel(R) Xeon(R) CPU E5-2630 v3, with 32 GB of RAM.

B. Test on block size

The aim of this test is to assess the impact of the block maximum offered/demanded quantity, i.e., the block size, on the solution of the clearing problem. Four groups, each composed by ten different data sets are created by using the real Italian market orders, and 300 curtailable profile blocks, randomly generated as specified in Section III-A. For each group, the hourly profile block quantities have been sampled from a uniform distribution with mean 16, 32, 64, and 160 MWh, respectively. Figure 2 shows the computation time required to solve the clearing problem in the different cases. As it can be observed, the range of the computation time required to clear the market increases significantly as the size of the blocks increases. Figure 3 reports the difference between the PUN obtained by adding the block orders, and the original Italian PUN. The median of the price changes is close to zero in all the cases. This can be explained because the block orders are evenly distributed between demand and supply. However, the range of the potential change significantly increases as the quantity increases. Test III-D shows an example where block orders are not equally distributed between demand and supply. Finally, Figure 4 reports for each group the maximum number of PRBs present in the market clearing optimal solution.

C. Test on block number

The aim of this test is to determine the impact of the number of blocks on the clearing problem. In this test, six groups have been created (each composed of ten data sets), generated as specified in Section III-A by using the real Italian market orders, and 30, 60, 90, 120, 150, 300 curtailable profile blocks, respectively. All the blocks are included into the same zone to stress the effect. Figure 5 shows the computation time required to solve the clearing problem for each group, whereas Figure 6 reports the difference between the PUN obtained by adding the block orders, and the original Italian PUN. As in the previous test, the PUN level does not change significantly. By

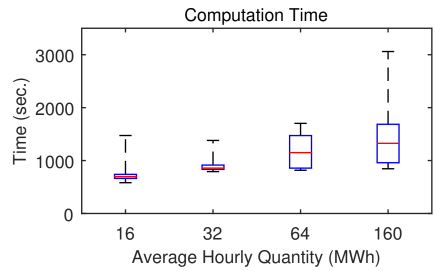

Fig. 2. The box plot shows the effect of the block size on the market clearing problem's computation time. The greater the size of the blocks, the greater the time required to clear the market.

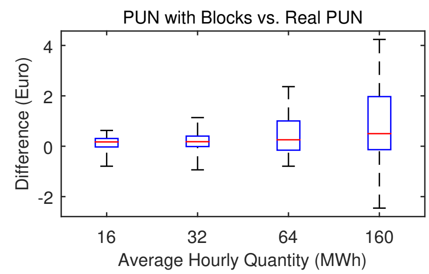

Fig. 3. The box plot shows the difference between the PUN obtained by adding block orders in the PUN zones, and the original Italian PUN. The greater the size of the blocks, the greater the potential change of the PUN.

contrast, the limited impact of the number of block orders on the computation time is unexpected. Each block order requires one binary variable in order to be modeled, and the increase of the binary variables should increase the computation time. However, this is not the case. One possible explanation is that the clearing problem involves 19,246 PUN demand orders, therefore the number of additional binary variables required by the block orders is limited compared to those required to model the PUN scheme. In the test, one PRB was detected only in the case with 300 blocks.

D. Test on block demand/supply ratio

The aim of this test is to assess the impact of the block demand/supply ratio, i.e., the proportion between the purchasing and selling blocks, on the clearing problem. Three groups, each composed by ten different data sets are created by using the real Italian market orders, and 300 curtailable profile

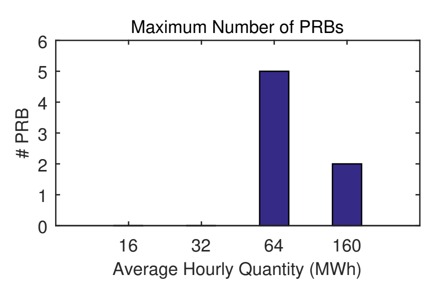

Fig. 4. Maximum number of Paradoxically Rejected Blocks present in the final optimal solution, for each group.

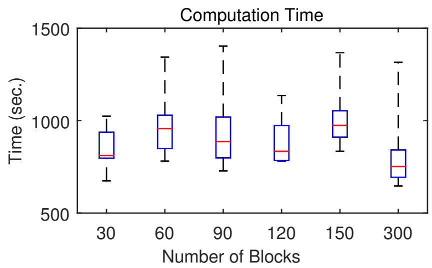

Fig. 5. The box plot shows the effect of the number of block orders on the market clearing problem's computation time. Apparently, there is not a significant relation between the computation time and the total number of blocks involved.

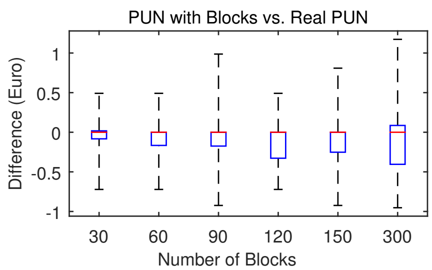

Fig. 6. The box plot shows the difference between the PUN obtained by adding the block orders and the original Italian PUN.

blocks, randomly generated as specified in Section III-A. In the first group, all the blocks are demand blocks. In the second group, the blocks are evenly distributed between demand and supply. In the third group, all the blocks are supply blocks. Figure 7 shows the computation time required to solve the clearing problem in the different cases. As it can be observed, the time required to clear the market appears to be slightly greater if only supply blocks are added. Figure 8 reports the difference between the PUN obtained by adding the block orders, and the original Italian PUN. The change in the PUN is strongly marked. In particular, the change of the median in the group with only demand blocks is 6 Euro, whereas the change in the group with only supply blocks is -8 Euro. This change is due to the additional quantity introduced by the blocks, that shifts to the right the demand and the supply market curves, respectively. In the test, one PRB is detected in both the demand-only and supply-only cases.

E. Test on block location

The aim of this test is to assess the impact of the block location on the clearing problem. Three groups, each composed by ten different data sets are created by using the real Italian market orders, and 300 curtailable profile blocks, randomly generated as specified in Section III-A. In the first group, all the blocks are added only in the North zone. In the second group, the blocks are evenly distributed between the Italian zones termed North, South and Sicily. In the third group, the blocks are evenly distributed over all the six Italian PUN zones. Figure 9 shows the computation time required to solve the clearing problem in the different cases, whereas Figure 10

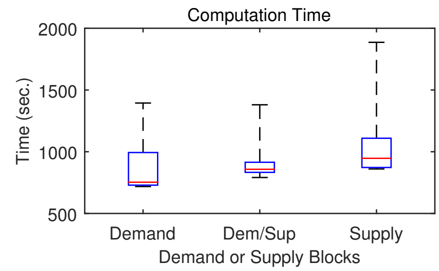

Fig. 7. The box plot shows the effect of adding demand and supply block orders, in different proportion, on the market clearing problem's computation time. The computation time is slightly greater if only supply blocks are added.

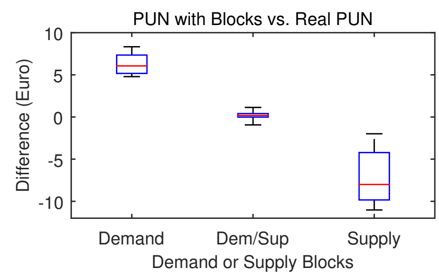

Fig. 8. The box plot shows the difference between the PUN obtained by adding block orders in the PUN zones, and the original Italian PUN. Changing the proportion of the blocks between demand and supply may significantly affect the PUN.

reports the difference between the PUN obtained by adding the block orders and the original Italian PUN. As it can be observed, there is not a significant relation between inserting the blocks in one, three or all the Italian PUN zones, neither in the computation time nor in the PUN. In the test, one PRB has been detected in the first group, i.e., when all the blocks are added into a single zone.

F. Test on block timespan

The aim of this test is to assess the impact of the block timespan on the clearing problem. Two groups, each composed by ten different data sets are created by using the real Italian market orders, and 300 curtailable profile blocks, randomly generated as specified in Section III-A. In the first group, all the blocks have a timespan of 4 hours ranging from the 13th hour to the 16th hour, whereas in the second group all

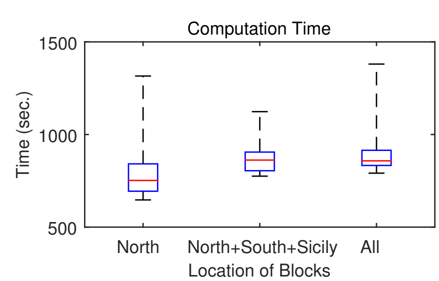

Fig. 9. The box plot shows the effect of the block location on the market clearing problem's computation time.

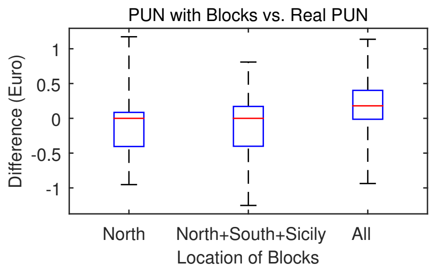

Fig. 10. The box plot shows the difference between the PUN obtained by adding block orders in different PUN zones, and the original Italian PUN.

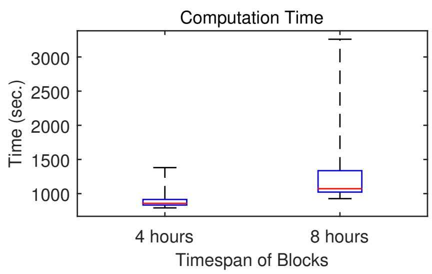

Fig. 11. The box plot shows the effect of the block timespan on the market clearing problem's computation time. The computation time increases significantly in the case where the blocks span 8 hours.

the blocks have a timespan of 8 hours, spanning from the 13th hour to the 20th hour. Figure 11 shows the computation time required to solve the clearing problem in the different cases. As it can be observed, the computation time increases significantly moving from the four-hour case to the eight-hour case. In particular, the maximum time required to clear the market in the first group is 1,380 seconds, whereas in the second group the maximum time is 3,259 seconds. This effect can be explained because block orders impose multi-temporal constraints. Therefore, the increase of the timespan can increase the complexity of the problem. Figure 12 reports the difference between the PUN obtained by adding the block orders, and the original Italian PUN. Apparently, the increase of the timespan leads to a decrease of the PUN. One PRB has been detected in the second group.

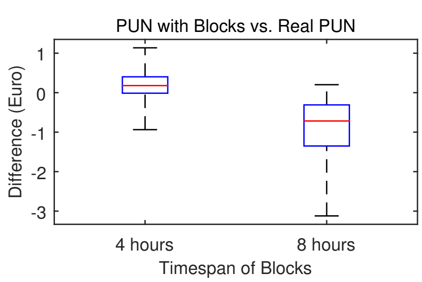

Fig. 12. The box plot shows the difference between the PUN obtained by adding block orders in the PUN zones, and the original Italian PUN. Apparently, the increase of the timespan leads to a decrease of the PUN.

IV. Conclusions

The European market clearing problem is characterized by the presence of different types of heterogeneous orders and rules. In this paper, we discussed the potential effects of introducing block orders in the Italian day-ahead market, which is characterized by the uniform purchase pricing scheme.

The performed analysis showed that the block size and timespan appear to have the largest impact in terms of computation time, whereas the number of blocks, the location, and the demand/supply ratio are less significant.

The number of paradoxically rejected blocks appears to be closely related only to the size of the blocks, i.e., to the maximum hourly quantity. In particular, the increase of the block size increases the number of paradoxically rejected blocks.

Finally, the effect on the PUN level is strictly related to the proportion of purchasing or selling blocks, as expected.

This analysis helps to shed light on the impact of block orders on the Italian market. Ongoing work aims at extending this evaluation to other types of orders, as the Iberian minimum income condition orders.

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