COORDINATING CROSS-BORDER CONGESTION MANAGEMENT THROUGH AUCTIONS: AN EXPERIMENTAL APPROACH OF EUROPEAN SOLUTIONS

Céline JULLIEN
GAEL,
Pierre Mendès France University

Mailing address:
GAEL-INRA
1221 rue des résidences,
38400 Saint Martin d'Hères
France
Phone: +33(0) 4 76 82 54 38.
Fax: +33(0) 4 76 82 54 55.
e-mail:
celine.jullien@ensgi.inpg.fr

Stéphane ROBIN
GATE,
Lyon 2 University

Mailing address:
GATE-CNRS
93 chemin des Mouilles
69130 Ecully
France
Phone: +33 (0)4 72 86 60 83
Fax: +33 (0)4 72 86 60 90
e-mail:
robin@gate.cnrs.fr

Carine STAROPOLI
ATOM,
Paris 1 University

Mailing address:
ATOM - Maison des Sciences Economiques
106-112, Boulevard de l'Hôpital
75647 Paris Cedex 13
France
Phone: +33 (0)1 44 07 83 24
Fax: +33 (0)1 44 07 83 20
e-mail:
carine.staropoli@univ-paris1.fr

Abstract

The creation of an effective "European integrated competitive market" crucially depends on the way cross-border transactions are run. The full potential of the existing European interconnected grid is not realized with administrative allocation rules whereas there is still no consensus on the efficiency of alternative mechanisms based on auctions, which are the cornerstones of the newly created electricity markets. Our contribution aims at assessing two particular auction rules: the so-called implicit auction already applied in some markets and the coordinated explicit auction which is still a project and has never been dealt with analytically up to now. These allocation mechanisms call for further empirical investigations with more realistic assumptions than what has been done up to now. We use experimental methodology to identify and compare the effects of these two market institutions on the economic performances of the electric power market considering a structure configuration akin to the structure present in the western European electricity sector. Our results emphasize the superiority in terms of efficiency of the implicit auction and highlight some of the problems encountered by the two rules in the lab.

Keywords: congestion management, electricity markets, auctions, experimental economics (JEL codes: C92, D43, C72)

1. 1. INTRODUCTION

Since Europe is based on the subsidiary principle, what should be a unique electricity market is in fact fragmented into a number of “regions”, each being featured with their own transactional arrangements. Indeed, the perspective to have a “single market” is still a mirage with many political, institutional and technical obstacles. Notably, the creation of an integrated European market for electric power is highly dependent on the existence of an efficient coordination of the national transactional arrangements at the cross-border level.

Cross-border transmission lines have been developed, but mostly on security purposes and linked with long term supply contracts negotiated by the monopolies themselves. In a restructured context, this relative under development of the cross-border lines puts a major constraint on the benefits that might be expected from competition. It means that the European generators that are often dominant on their historical national market, may be physically isolated from competitors and benefit from local market power. It is nevertheless time consuming and very difficult to invest in the grid since these investments projects raise in general the criticisms of local opponents.
However, the creation of a European electricity market necessitates a non discriminatory access to what are for the moment and no doubt for still some years, relatively scarce cross-border transmission capacities. The European Commission was prompted to ask for market-based mechanisms to allocate in an efficient and not discriminatory way the transmission capacities located on cross-border congested paths.

Current administrative mechanisms (pro rata, first arrived-first served) are to be replaced with more efficient ones in July 2004 to conform to the European regulation 1228/2003 (European Commission [2003]).

Two mechanisms based on auctions are the cornerstones of the newly created electricity markets.

First the so-called implicit auctions are currently used to allocate transmission capacity between the Nordic countries. These auctions are called “implicit” in the sense that the available transmission capacities are directly taken into account in the selection process of energy bids and offers by the market operator. In other terms, it consists in dealing simultaneously with transmission capacities and energy. The resulting price of the congestion can be inferred from the energy prices and corresponds to the difference in the energy prices on either side of the congested path.

In the so-called explicit auctions, transmission bids and energy bids are sequentially separated. From an organizational point of view, this mechanism does not require a centralized organized market for wholesale electric power. Explicit auctions are currently used between France and UK, Germany and Denmark and Belgium and the Netherlands. Here, generators have two ways to trade energy: through an organized energy market or through bilateral contracts. The organization of a separate auction for transmission capacities requires the definition of explicit physical property rights that are then sold to the generators who wish to use these transmission capacities. With explicit auctions the problem is that, given the governing rules of electric power flows in a highly meshed network like the European one, the available transmission capacity that is sold through the auction depends in fact on the results of the other explicit auctions. Except for "linear" (or radial) networks, these rules imply indeed strong interactions between the flows on each transmission line and wide-ranging externalities between the individual energy transactions (the so-called "loop flows"). As a consequence, the available transmission capacity of a cross-border line might finally be over or under utilized depending on the other bidders' choices. In meshed electric power grids, a more coordinated approach to congestion management is needed for an efficient use of existing transmission capacities. That is in this context that the association of European Transmission System Operators "ETSO" suggests to adopt a new allocation mechanism that they call "coordinated explicit auctions".

The main principles of coordinated explicit auctions are the following. First, the separated allocation of energy and transmission capacity is maintained. But instead of having an auction for transmission capacity at each congested cross-border line, the basic idea is to allocate in the same process the transmission capacities located in zones characterized by strong interactions. In a sense, the auctioning of the available transmission capacities on a meshed grid would be gathered, limiting the risk of productive inefficiencies due to uncertainties. This coordination would also enable to better estimate the available transmission capacities that could be auctioned on a secured and reliable way. The ambition of this proposal is thus to achieve the full potential of the existing European interconnected grid through an adequate cross-border congestion management scheme, while respecting the organizational choices made at the national level. On the one hand, coordinated explicit auctions should theoretically help to optimize the use of transmission capacities and lead to a more efficient European electricity market with performances at least comparable to the implicit auctions. And on the other hand, it does not require to set a unique organized market place for electric power at the European level (Pérez-Arriaga *et al.* [2004]).

From a theoretical perspective with benevolent generators that truthfully reveal their generation marginal cost, both mechanisms, coordinated explicit auctions and implicit auctions, should therefore achieve an efficient allocation of the available transmission capacities and the least-cost generation units should be called to produce, knowing the capacity constraints of the grid. However, these allocation mechanisms call for further empirical investigations given that the proposal of the ETSO itself is far from joining together a consensus. As pointed out in Pérez-Arriaga *et al.* [2004], one of the possible issues may be in the anticipations of the market participants.

This article uses the experimental methodology to identify and compare the effects of these two market institutions on the economic performances of the electric power market considering a structure configuration akin to the structure present in the European electricity sector. The main goal is to assess whether the two institutions succeed in allocating efficiently scarce transmission capacity while mitigating the ability of generators to exercise market power and behave strategically. We examine the effects of the two auctions mechanisms on the pattern of both energy prices and transmission prices, on the market efficiency and the surplus. For each institution, we assume a benevolent market operator that maximises the social surplus given the bids of the market participants.

Laboratory experiments can be seen as a complementary tool to analytical models to deal with electricity system complexity. Indeed in multi nodes networks, countervailing effects make an analytic analysis difficult. While analytical models can't model more than a simple two nodes network, it is possible (especially with the use of smart computer assisted markets) to run an experiment with multi node meshed networks (up to 8 nodes in Olson et al. [2001]) and even 30 nodes in Zimmerman et al. [1999] and the consequential constraints (loop flows, congestion …). The specific constraints associated with the operation of an electric grid, including the stochastic nature of load on the lines, the associated need to respect the physical constraints in the network, and the locational variability of transmission losses, can be incorporated in the experiment environment. Therefore, taking into account transmission constrained networks is a first step in dealing with the complexity of an electricity system that can easily be passed in the laboratory.

Our experimental design derives from the current debate on the European electricity market, concerning the appropriate cross-border congestion management scheme. We use a three nodes network taking into account the externalities between individual transactions, that is to say a more realistic representation of the electricity networks as compared to what can be done analytically. Altogether, our contribution to the debate is complementary to the analytical contribution and it allows bypassing some analytical limits.

In section 2, we present the basic outlines of our experimental market and we describe how we model the implicit and the explicit coordinated auctions. Section 3, finally presents the main results and comments.

2. THE EXPERIMENTAL DESIGN

2.1. The network

The network is modelled in the experiments as a three-node network (zones A, B, and C) with loop flows. There is no internal congestion.

The transmission network is characterized by the maximum capacity of each line and by the Power Transfer Distribution Factors (PTDF) matrix[1] (table 1)

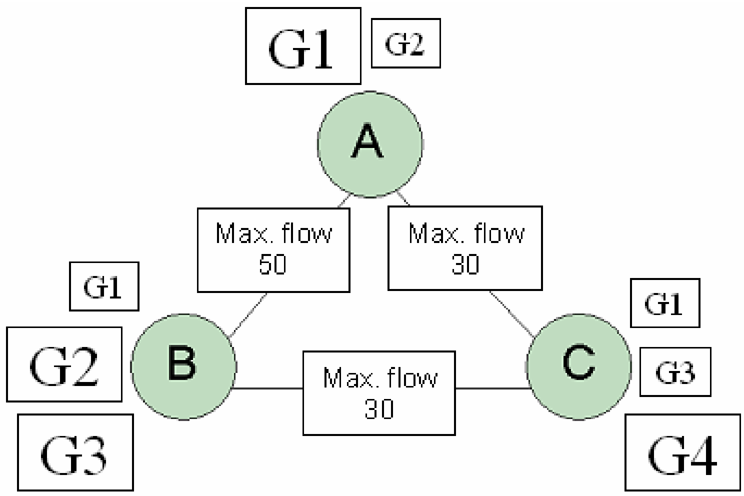

Figure 1: Three nodes network model

Table 1: PTDF matrix

	Interconnection		
Node of injection	**A→B**	**A→C**	**B→C**
A	+1/3	+2/3	+1/3
B	-1/3	+1/3	+2/3
Max. capacity	50	30	30

[1] This matrix quantifies the impact that a per unit transaction between two nodes, the injection one and the withdrawal one, has on every line of the network.

In the experiments, we consider 4 generators (G1 through G4 on the figure 1), located inequitably in the network.

On each zone, generator is endowed with an individual supply function and an individual demand function. These demand and supply functions are designed in order to model individual interest to buy or to sell energy on the market. The inverse demand function gives the price limit under which generator is willing to buy energy. Symmetrically, the inverse supply function gives the limit price above which generator is willing to sell energy. Limit prices are based on opportunity cost for using producing facilities or the commitment for a must serve demand.

Individual demand and offer function are reproduced in the experiment according to the redemption-value theory principles (Smith [1976]). In this way, a generator in the lab is informed about the value (*redemption value*) he could receive for each unit he buys and the value (*unit cost*) he would have to pay for each unit he sells. Supply and demand curves are cyclical with two levels figuring “peakload demand” and “baseload demand”.

Regarding cost and demand function, generators are asymmetrically endowed. G1 is an important supplier in terms of market shares with the lowest costs at node A, G2 and G3 are two important players at node B in terms of market shares with the lowest costs and G4 is an important buyer at node C in terms of market shares with the highest redemption value. Given the way supply and demand functions are designed, one should expect net energy exportations from nodes A and B to node C with a permanent congestion on line AC, i.e. both for baseload and peakload periods.

At the beginning of each session, every participant is given information concerning his location in the network, his cost function per zone and his redemption values per zone. From period to period, each generator can look at his own historical information concerning his production level, and the capacities he traded in the market at each node.

The common information in the market concerns the basic characteristics of the network, that is the PTDF and the maximum capacity of each line (both held constant across sessions). From period to period, the market prices at each zone, as well as the flows on each line are given to all the participants, as an historical information background.

2.2. The institutions

The next two sub-sections present respectively the two mechanisms as we have modelled them in the lab.

The implicit auction

The bidding process in the implicit auction allows each participant to submit bids to either sell or buy units of electricity. Each bid is made for a dedicated zone, and is composed of a pair unit price and quantity.

The allocation of energy results from the maximisation of the total surplus based on the bids on the market under the system constraints. We use an optimisation algorithm to determine the set of bids that maximizes total surplus and is compatible with two constraints[2]: offer must equal demand on the whole system, and the transmission constraints due to the line voltage and stability limits have to be respected.

If no congestion occurs (i.e. the transmission constraints are not binding), then the selection process simply follows the merit order: bids are selected according to the increasing order of prices in order to equalize demand to offer. If congestion occurs, then the merit order is corrected according to the constraint and of the bids locations. In practice, it implies that some bids that would had been retained without any congestion are finally not accepted, while others which were more expensive at first glance will finally be accepted.

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[2] The bidding processes and the optimisations programs used in this research are available from the authors upon request.

Then each generator privately receives information concerning the acceptation rate of each of his bids and public information is given about the price at each zone. Prices are the shadow prices computed from the Lagrangian of the maximization program.

The generator' profits for a period with the implicit auction equal the sum of the profits at each zone. They consist in the sum of redemption values and the units sold in each zones at the market price minus the production costs and the expense on the market.

The coordinated explicit auction

The coordinated explicit auction is basically a two stage mechanism. The first stage consist in allocating the existing transmission capacity units, while taking in account the countervailing effects specific to electricity networks through the *PTDF*. The participants bid to buy solely transmission capacity units sold by a factitious central auction house on the basis of the information given by the transmission system operators.

The bidding process at this stage allows each participant to submit offers to buy a right to use transmission capacity from one zone to another zone in one period. The proposal is defined by the injection zone, the withdrawal zone, the amount of energy transmitted and the transmission capacity unit price. The bidders have to identify the line as well as the sense of the flow.

The bidding process for transmission capacity ends before the beginning of the bidding process for energy. Consequently, the bids for transmission capacity depends on the anticipations of the market participants concerning the equilibrium price for electric power.

A uniform price sealed bid auction is used to allocate capacity. The selection of the bids and the determination of the equilibrium price result from the maximisation of the profits from the auction under the transmission constraints.

We use an optimisation algorithm to determine the set of bids that is retained. In case there is no congestion, all bids are accepted. If one or more congestions do occur, some bids have to be partly accepted and even rejected.

To accept or reject part of a bid, the software calculates the price that each generator agrees to pay for using the congested line. He then gives priority to those bids that value the most the congested line. He orders bids by increasing prices, the latter being normalized by *the PTDF* of the concerned injection zone and for the requested transmission line. He accepts bids until all the transmission capacity has been exhausted (after having checked that it does not create any additional constraint).

The price that each generator has to pay equals the last bid retained by the auctioneer, weighted by the PTDF of each of his bids on the constrained line.

Then each generator receives the information concerning the acceptation rate of each of his bid and public information is given about the price and the flows for each directional transmission line, as well as about the congestion. Here again, the prices for each line are computed from the Lagrangian of the maximization program and the *PTDF*. The Lagrangian multipliers associated to the transmission constraints correspond indeed to the prices charged to transmit one additional unit of electricity from one node to another. They are then normalized by the *PTDF*. We notice that for each line linking nodes *i* and *j*, the price charged from *i* to *j* is the exact opposite to the price charge from *j* to *i*. It implies that some bidders will be paid by the auction office for the transmission capacity units that they booked through the auction. Moreover, if the allocation implies no congestion, generators are not charged for the capacity allocated.

After the capacity auction, each generator is privately informed about the capacity allocated to him. Global flows and transmission prices for every lines are publicly announced.

The second stage consists in three independent markets - one for each zone. Generators are allowed to bid on an auction place either because they have received the corresponding transmission rights at the preceding stage, or because they are already located in the zone of the considered auction place. Otherwise, they expose themselves to important costs. The logic of this institution wants that the problem of the coordination of the flows on the potentially congested line has already been solved by the transmission capacity auction.

The three energy auctions follow the same process: they consist in uniform price sealed bid auctions, where the bids – *offer to sell* and *offer to buy* – are composed of a pair price/ quantity of energy. The allocation of energy through each auction results from the maximization of the total surplus based on the bids. It therefore follows a simple merit order, that is to say that the bids are selected according to the increasing order of prices in order to meet the must-serve demand of the zone considered.

As already pointed out, every transmission right obtained at the first stage has to be used so that all the transmission capacity units may be allocated and every transmission capacity unit that has been allocated but that is finally not used will be penalized. Then each generator receives the information concerning the acceptation rate of each of his bid and public information is given concerning the market price for each energy auction.

The profits of a generator for a period consist in the sum of the gains that result from the sum of the redemption values minus the cost on each zone the sum of the profits and losses that result from the energy exchanges on the three market places. A generator who failed to use the transmission capacity rights allocated to him for the period is penalized through high cost of production at the node he should have to inject energy and a zero redemption value at the node he should have to withdraw energy.

3. RESULTS

The experiments have been run in the experimental laboratory of the GATE (Lyon) and in the experimental laboratory of the ENSGI (Grenoble), using a dedicated market-software developed with the experimental software Regate (Zeiliger [2000]). Undergraduate students were recruited from business school, engineering school and economics department at the University.

Given the complexity of the experimental design, we decided to organize the session over two days. The first day, students were taught the rules and trained during two hours and a half and the second days they played the game during two hours and a half. Six independent observations for each treatment have been collected.

Results are presented in two subsections. The first one concerns global efficiency of the system. The second subsection, we analyze the allocation of transmission capacities.

3.1. Efficiency and generators surplus

At first sight, results show an amazingly high proportion of significant losses for generators with the explicit treatment. These losses are so high than the sum of surplus - which is the indicator for efficiency - is negative. Indeed, over 92 periods, we observe 24 periods with negative global surplus[3]. In itself, it can be considered as a first result since it suggests that the institution is intrinsically inefficient. Nevertheless, for the coherence of the analysis, we focus on screened data by considering only the periods with positive global surplus.

Global surplus

Global efficiency is calculated by dividing the global surplus obtained for each session with the theoretical surplus we have computed[4].

Result 1. From a welfare economics point of view, implicit auction leads to an efficient allocation

Support: We observe a rapid increase in the global surplus realized by producers. The efficiency rate lies between 76 and 100% for the last five periods of each session with an average rage of 85%. Efficiency increases with the number of periods. Efficiency is always higher in peakload period compared to baseload periods. This difference among periods can be explained by the fact that some producers exercise market power.

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[3] We also observe negative global surplus with the implicit treatment but for only 5 periods out of the 166 observed and in each case, losses can be explained by manipulation errors such as price/ quantity inversion.

[4] Theoretical surplus is computed by running the optimization programs assuming price taker benevolent behaviours from generators (they bid at their marginal costs and redemption values).

Result 2. From a welfare economics coordinated explicit auction leads to an inefficient allocation

Support: Efficiency remains low (below 70%) even after repetitions. Moreover there are strong variations among periods. It is not possible to detect any regularity according to the level of demand. Notably there is no evidence efficiency increase over time.

Table 1. Mean efficiency

	Implicit treatement		Explicit treatment	
	obs.	Mean eff.	obs.	Mean eff.
All periods	65	77%	56	45%
Baseload period	36	75%	30	39%
Peakload period	29	79%	26	52%

Result 3. From the welfare economics point of view, implicit auction is more efficient than coordinated explicit auction.

Support: Comparing the efficiency in the two treatments on the same basis (we have excluded the first 6 periods considered as a "learning phase" and stopped the comparison at the 17th period (which corresponds to the maximum number of periods run for the coordinated explicit auction) emphasizes the superiority of the implicit auction over the coordinated explicit auction[5]. This result is significant even with the withdrawal of all period with negative global efficiency.

[5] A two-sample Wilcoxon rank-sum test shows that it is possible to reject the hypothesis at a significant level of 0,01% that these two samples are derived from the same population.

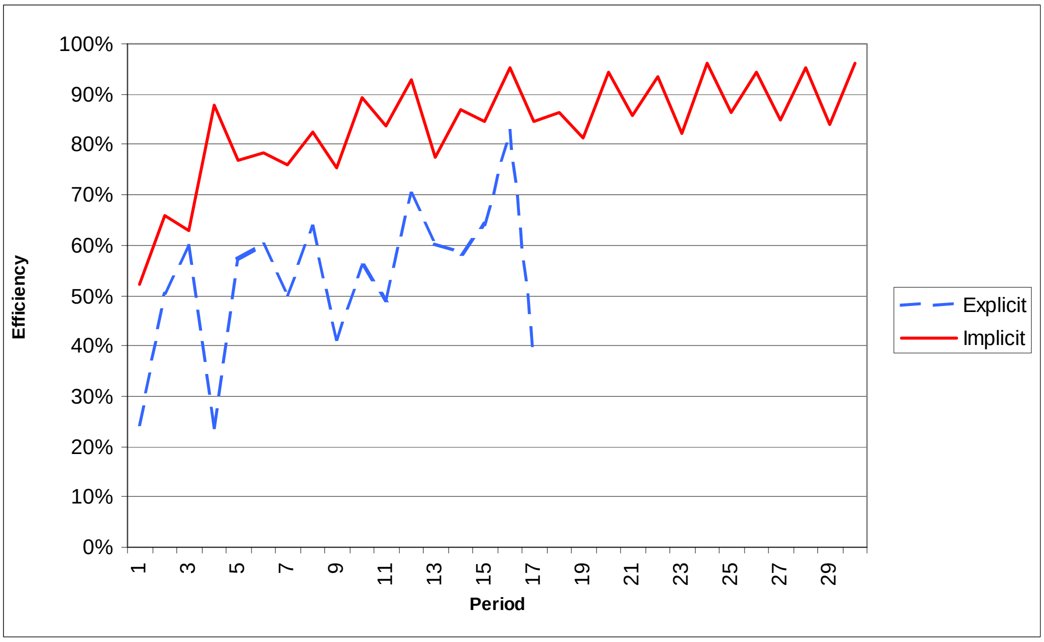

Figure2.: session average efficiency

Generators surplus

Concerning generators surplus which is an indicator of allocative efficiency, we observe two distinctive features (i) significant losses especially for the explicit treatment and (ii) great dispersion of surplus among generators.

Even if the first feature is it itself an indication of the coordinated explicit auction's intrinsic inefficiency, the fact that these losses are so high forced us to correct the data. We have adopted the following rule: for each generator and for the two level of demand we have neglected all period for which at least one profit among the four is superior or inferior to four times the standard deviation. This rule leads us to dismiss 18 observations out of 166 in the implicit treatment and 7 out of 92 in the explicit treatment. However, even after correction, there remain significant losses. Notably for generator 4 who has negative profit 70% of the time in the explicit auction.

Based on corrected data, we observe a significant dispersion among generators surplus especially in explicit auction in favour of producer 1. Producer 1 who is a net seller is indeed in a position to exercise market power notably in peakload demand.

3.2. Flows and congestion

The objective of the mechanism studied in this paper is the efficient allocation of a scare resource: limited transportation capacities at the cross-border level. Taking into account the market structure at each node and limited transmission capacity, we said, in the presentation of the design, that line AC is the critical resource in the research of the optimal energy allocation through the three nodes network. Then, one should expect a permanent congestion on this line with an efficient allocation of transportation capacities. Rates of congestion reported in table 5 and table 6 show a significant difference of the allocation of transportation capacities between implicit auction and coordinated explicit auction.

Table 2. Congestion with implicit treatment

	Baseload demand			Peakload demand		
	AB	AC	BC	AB	AC	BC
Obs.	83	83	83	83	83	83
Mean flow	22	30	8	11	29	19
Congestion observed	17	81	24	0	81	30
Rate of congestion	21 %	98 %	29 %	0%	98 %	36 %

Table 3. Congestion with explicit treatment

	Baseload demand			Peakload demand		
	AB	AC	BC	AB	AC	BC
Obs.	48	48	48	44	44	44
Mean flow	9	25	17	29	24	5
Congestion observed	3	28	19	40	24	0
Rate of congestion	6%	58 %	40 %	91 %	55 %	0%

Result 4. Compared to explicit auction, allocation through implicit auction lead to a better use of transportation capacities of the network.

Support: For the critical line AC, congestion is observed for almost all periods for implicit treatment. With explicit treatment, congestion rate of line AC is above 60%. Line AC capacity is not fully allocated for more than 40% of the periods. For baseload periods, we observe 10 periods without any congestion on the network with coordinated explicit treatment.

4. CONCLUSION

Our aim was to test the relative efficiency of two cross border transmission auction design: the implicit auction and the explicit coordinated auction. Our results provide evidence of the fact that the coordinated explicit auction is not efficient. The implicit auction which is more efficient with respect to the coordinated explicit auction.

Our results contribute to the current discussions as they show that even in a simple environment such as the one we have created in the lab to model the coordinated explicit auction, subjects are not able to anticipate what will happen in the energy market and as a consequence they do not take proper decision in the transmission capacity market. The fact that we have seen no evidence of any regularity suggest that increasing the number of periods might change the main results. The obligation to use the capacity bought in the transmission capacity market put a strong constraints on behavior. Changing this parameter could relax some of the constraints but we don't think it would change the results dramatically. Another explanation could be on the structure configuration. However our aim was to reproduce the west European reality and with this respect it confirms that this auction will not help to mitigate the existing market power.

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