EUI Working Papers

RSCAS 2012/43
ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES
Loyola de Palacio Programme on Energy Policy

DESIGN OF AUCTIONS FOR SHORT-TERM ALLOCATION IN GAS MARKETS BASED ON VIRTUAL HUB

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EUI Working Paper **RSCAS** 2012/43

ISSN 1028-3625

Printed in Italy, September 2012
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy
www.eui.eu/RSCAS/Publications/
www.eui.eu
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Abstract

Gas markets based on virtual hubs has been the preferred EU design. Such market designs are based on socializing network flexibility services. Nonetheless, shippers have different preferences about the network flexibility, which are not reflected in current allocation models. We propose the introduction of auction mechanisms to deal with network service allocation in the short term. The auction aims to represent simultaneously the diversity of players' preferences and the trade-offs implied by network constraints. Two sealed-bid auctions are proposed. On the one hand, an auction with one product allocates network services through the minimization of gas price differences. On the other, a multi-product (gas and line-pack storage) auction is designed to facilitate the revelation of preferences on line-pack storage.

Keywords

Auction design, gas markets, gas balancing, entry/exit allocation, iterative and combinatorial auctions.

1. Introduction

The EU gas markets have followed the design of the UK gas industry liberalization, where gas transactions were organized around the definition of a virtual hub[1], Heather (2010). The virtual-hub approach implies that the market is using a commercial network for the commodity trade. In this context, the standard approach to the definition of the commercial network in the EU is the entry/exit regulation, Hunt (2008). In it, market players have the right to inject gas in the system at any entry point, and to withdraw gas from any exit point.

One of the main advantages of the use of a commercial network is that it may increase market liquidity through the simplification of the physical network it represents. But it comes at the cost of a representation gap between commercial and physical networks. It is thus necessary to transform the allocation of the commercial network into gas flows through the physical network. In this view, the market design requires a set of additional elements that bridge the gap between commercial and physical networks, which are usually grouped under the header of balancing mechanisms.

Vazquez & Hallack (2012) show that some of the rules adopted in European markets lead to inefficient allocation of the network capacity in the short term. On the one hand, entry/exit capacity allocation implies that the system operator must estimate the future use of the network. Hence, ensuring that the capacity sold will be actually available necessarily results in selling less capacity than the network physical capacity. On the other hand, line-pack is rarely sold to market participants, but instead it is a tool used by TSOs to run balancing mechanisms. Therefore, there are inefficiencies in the line-pack socialization implicit in the balancing systems. So the EU gas systems typically face a dilemma between socializing the line-pack (e. g. daily balancing mechanisms) or not using the line-pack (e. g. hourly balancing mechanisms), Lapuerta (2003).

We propose the use of auctions to cope with some of the challenges implicit in virtual-hub regulation, and to shed light on the balancing time structure dilemma (daily versus hourly). We will pursue the strategy of separating the services that are currently managed by the balancing mechanisms into two different types: the services required for the short-term adjustment of players' portfolio (and thus allocated through market mechanisms), and the services required for ensuring the system security (and thus part of the balancing mechanism). We will use the results obtained in Vazquez & Hallack (2012) to identify the services required to be included in the market mechanism. Specifically, the two main challenges of virtual-hub regulation have to do with the socialization of network flexibility[2], in terms of spatial and temporal flexibility. Hence, the auction should allocate such network flexibility according to market preferences. The remaining network services (the ones needed to guarantee the system security) will continue to be part of the TSO's balancing actions and it will be mainly socialized among all the systems' users.

To include the shippers' preferences for time and spatial flexibility, the market mechanisms proposed in this paper include locational signals for the allocation of transmission capacity, and inter-temporal signals for the allocation of line-pack storage. In this view, the typical mechanism used to coordinate the information of a TSO and the decision-making process of market players is the auction. Such auction will consist in the TSO defining the offer of network services, and market players deciding on their bids according to their need of such services. We propose two possibilities for the

[1] The virtual hub is not a physical junction of pipelines, but instead a standard set of delivery points with a simplified representation of the physical characteristics of the network.

[2] We follow Hallack (2011) in defining flexibility services as the ability to "wait and see". In this way, time flexibility is defined as the ability to "wait and see", before deciding on when gas will be injected or/and withdrawn. Spatial flexibility also accommodates to the idea of "wait and see": the flexible shipper can wait and see before deciding on where the gas will be injected or/and withdrawn.

design of the auction for short-term gas markets: Our first proposal builds on the idea that market players need only to know their preferences for injections and withdrawals from the system. The implicit allocation of network services with respect to gas prices allows them to avoid calculations of the possible values of network services. The players will bid for injections and withdrawals of gas, specifying the hour of the day and their location in the network. The auction will be based on a clearing algorithm that represent approximately the network operation, and decides the allocation of network services according to players' bids. Such clearing algorithm will be a multi-period optimization, with hourly granularity, taking account of transmission and line-pack representation. Nonetheless, the representation of the optionality associated with line-pack storage by means of gas injections and withdrawals is not straightforward; our second proposal is aimed at considering that by allowing players to bid for the option (but not the obligation) to have different injections and withdrawals at the end of each hour. This is done by reducing the multi-period optimization of the previous design to a single-period one, so that the auctioneer decides on the gas flows in order to maximize the social surplus.

In that view, this paper shows two possibilities to improve the efficiency of transmission network allocation. In a context of highly valuable line-pack storage, how to use the network (whether to use networks for gas transmission or for line-pack storage) becomes a key decision and such choice needs to be driven by players' preferences. The main differences between the two proposals stem from that way in which they consider the optionality associated with line-pack storage. In the first auction, the injection and withdrawals do not need to be the same for each player in each hour. But all injections and withdrawals are established in the clearing of the auction[3]. In the second auction, there is a service that gives the option to withdraw gas at different points in time[4].

The structure of the paper is as follows. Section 2 briefly summarizes the challenges faced by virtual-hub regulation, in order to motivate the auction mechanism. Section 3 describes the general scheme for the short-term gas market after the introduction of network service allocation through the auction mechanism. Section 4 defines the single-product auction, based only on gas commodity bids. Section 5 presents the multi-product auction, which includes the explicit representation of the line-pack storage. Section 6 compares the two proposals and discusses on further issues in the design of short-term gas markets. Finally section 7 collects our conclusions.

2. The role played by balancing mechanisms in EU gas markets

The main consequence of using virtual hubs is the fact that the physical representation of the network is not available to market participants, so they must address two special issues: the way in which the transmission capacity is allocated to market players, and the way in which the actual technical characteristics of the gas network are finally dealt with.

2.1 Entry/exit capacity allocation

Virtual hubs are designed to reduce network assets specificity, and thus transaction costs, by disregarding several physical characteristics of the network. As a part of such design, the network capacity and the gas are sold separately. But as virtual hubs disregard the physical representation of the network, the allocation of the network does not correspond to the real physical flows.

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3 The shipper can withdraw gas in a certain hour or withdraw it afterwards. But she cannot withdraw it at any time, it is a firm contract for withdrawing gas.

4 If the player withdrew gas in a certain hour, and purchased the associated line-pack service, the shipper can inject it in such hour or later on.

The solution adopted by EU gas markets is to define the capacity to enter and exit the system. Shippers need only to define their needs for entry and exit capacity. They first purchase the right to enter (or exit) the market, and then they are allowed to trade without capacity constraints. Besides, entry and exit capacity are allocated separately, in order to keep asset specificity low (i.e. shippers do not need to purchase entry and exit capacity at the same time).

In markets with entry/exit capacity allocation, the TSO must define in advance the transmission capacity that will be made available for shippers, see for instance Lapuerta & Moselle (2002). Vazquez, Hallack & Glachant (2012) show that this allocation procedure leads in general to constraints on the way in which market players may use transmission networks. As entry and exit capacity is allocated before the trades take place, the capacity calculation is made with estimation of the future gas flows, and thus the network capacity cannot be allocated according to actual market preferences[5].

2.2 The line-pack dilemma

The central idea behind simplifying the network to reduce transaction costs is to socialize some of the transmission services in order to reduce their asset specificity. The underpinning for this regulatory strategy may be thought as benefitting from the fact that some services have approximately the same value for all network users. In this view, removing those services from the market and socializing them implies little inefficiency, while it significantly reduces the specificity of transmission services. However, a central condition to pursue this strategy is the condition that the services have approximately the same value for all users. Whether this condition is fulfilled markedly depends on the particular characteristics of each system.

The choice of a daily gas balancing mechanism was conceived to provide shippers with enough time flexibility in a context of homogeneous flow patterns. However, it may be not approximate enough in a context of increased heterogeneity of flow patterns Keyaerts, Hallack, Glachant & D'haeseleer (2011). These heterogeneous patterns are currently found in most gas markets in Europe, because of the high consumption of gas-fired power plants or of supply from LNG sources, see for instance Honore (2011) or Hallack (2011)[6]. Consequently, with the current characteristics of EU gas flows, the inefficiencies associated with the socialization of line-pack services may likely outweigh the benefits of the asset specificity reduction of such socialization.

Currently, as shown in Vazquez, Hallack & Glachant (2012), balancing mechanisms face the dilemma of choosing between a daily balancing mechanism and an hourly balancing mechanism. Daily balancing mechanisms imply free time flexibility within the day. As the line-pack is allocated for free, all players may use the balancing to adjust freely their portfolios. However, it has an economic value for shippers who need flexibility to balance their portfolios. On the one hand, when the network must be balanced on a daily basis, there are cross-subsidies between flat and flexible patterns. On the other, there are few (or no) incentives to develop other mechanisms to hedge shippers' imbalances within the day. Thus, in addition to cross-subsidization, there is non-market competition between free line-pack storage and other flexibility services, such as hourly storage or regasification facilities.

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5 Consider for example two pipelines connecting a certain entry point A to two different consumption points, B and C; each pipeline has a maximum capacity of 100 MW, so that the physical capacity to carry gas to point A is 200 MW. However, in an entry/exit scheme, injections at point A have the right to sell either to B or to C. That is, injections at A have the right of using both pipelines at the same time. Therefore, the firm capacity at point A is only 100 MW. Spatial flexibility, in this case, is a substitute of gas trading, as the remaining 100 MW will be allocated by means of TSO's actions.

6 Moreover, the increase insertion of wind generation in the electricity portfolio drove the growth of amount of flexibility provided by gas to the electricity system and as consequence it increased the costs of the flexible use of the gas network Keyaerts, Rombaults, Delarue & D'haeseleer (2011).

In the hourly balancing mechanism shippers are required to be balanced at the end of each hour. Hence, line-pack flexibility is allocated only within the hour, so players cannot use line-pack storage to adjust demand and supply in different hours within a day. Put it differently, the system will be allocating less network services than the physical ones, as shippers are prevented to use line-pack storage for adjustment. This option becomes more problematic with the increased needs for within-day flexibility demanded by gas-fired power plants (particularly in the context of increasing participation of intermittent generation). In order to provide shippers with the complete flexibility of the system, the EU choice is to rely on daily balancing mechanisms, ACER (2011).

3. Auctions as tools to improve network services allocation

In the current EU regulation, the TSO becomes the main provider of flexibility within the day. On the one hand, within-day flexibility is valuable service. However, if this service is provided without the adapted economic signals, it can interfere with the incentives for network capacity allocation. The strategy that we pursue to improve the short-term allocation of network resources is to identify two kinds of imbalances in the short-term operation of gas system.

The first kind of imbalance may arise when shippers may deviate from their positions resulting from previous long-term contracts. These deviations may often be anticipated by shippers. Shippers may also anticipate that along the day they will have some variation following a known profile (for instance, they will consume more in the morning). Shippers may also anticipate some volatility in their consumption, i.e., demand may deviate but they cannot anticipate the amplitude and pattern of such deviations Graves & Levine (2010). A typical example is a shipper purchasing gas for the consumption of a CCGT. Such shipper may know day-ahead when it will be dispatched and its production profile over the day. Furthermore, if the power plant produces in the within-day market (or in the electricity balancing market), it is not possible to anticipate its gas consumption. But it is possible to anticipate the volatility of such consumption. In that view, line-pack storage, as any other storage tool, can be used to deal with profiles variation or to hedge shippers' consumption.

The second kind of imbalance comes from close-to-real-time events, such as the sudden disruption of some injection source (like wind or solar production patterns), which are difficult to anticipate and hence to coordinate around market arrangements. Such very-short-term events (within the hour) would be left under the responsibility of the system operator. Since the network is a public good, sharing the cost among consumers is an efficient allocation mechanism.

From that standpoint, many of the arrangements that take place in current balancing mechanisms, and thus under the responsibility of the TSO, have to do with the adjustment of shippers' portfolio. And the shippers' adjustments are suitable for market mechanisms. Thus, auctions seem to be a useful tool to allow shippers to reveal their preferences. The requirement for a market-based, short-term mechanism is that it is capable of allocating both transmission capacity and line-pack storage.

3.1 Inter-dependency of line-pack storage and transmission capacity

In order to design an auction, the first step is to define the services that will be auctioned. Ideally, the short-term market would allocate separately line-pack services, transmission capacity and gas commodity, possibly by means of three independent auctions. However, these three products are inter-dependent, and hence it is relevant to allow players to express their preferences on the relationship among them. The direct way to do this is to allocate the three products in a single auction.

3.1.1 Dealing with spatial flexibility

The main challenges of entry/exit capacity allocation may be identified with the fact that it separates entry and exit allocation. This implies the cross-subsidization of shippers with needs for spatial flexibility, and leaves the TSO with significant uncertainty about the real paths that the gas will follow internally. Put it differently, as shippers cannot reveal their spatial preferences, the TSO does not have the required information to allocate network capacity. To cope with the problem, we propose to rely on the joint allocation of entry and exit capacity in the short term. Shippers' bids will contain, explicitly or implicitly, the paths that they intend to follow for their gas trades. In this view, instead of allocating entry capacity, the market will manage bids for enter the system to sell gas in a specific exit point. In other words, market players do not buy the right to enter the system, but the right to enter the system and to sell gas in a specific location.

3.1.2 Dealing with time flexibility

The TSO must bridge the gap between commercial and physical networks without enough information about shippers' preferences on the timing of injections and withdrawals. In the current approach, when there are differences between the time of injections and withdrawals, the TSO must use line-pack storage to adjust them. Moreover, the TSOs must decide on the trade-off between line-pack storage and transmission capacity without market signals, as there is not a place for market players to reveal their preferences on line-pack storage. We propose two different solutions for the line-pack allocation. In the auction design 1, it is possible to determine the market preferences from the bids made by market players in the short-term auction. To do so, the auctioneer will use an algorithm to minimize the differential of gas prices through the day's hours and the network points. Hence, the TSO decides on network services, both transmission capacity and line-pack storage, in order to obtain the maximum surplus. In this view, the line-pack could be used to match, for example, a cheap injection bid at a certain hour and an expensive withdrawal bid several hours later. Under this scheme, shippers need only to decide on their gas injections and withdrawals, and the network services (transmission and line-pack) are allocated through the auction clearing.

In the auction design 2, two products are auctioned: the gas in each hour and the line-pack in each hour. There are two main differences between this auction and the previous one. First, in the auction design 2, the amount of line-pack allocated is explicitly defined by shippers (and not as a result of the algorithm). Second, players in auction 2 will be revealing preferences on the optionality to inject or withdraw gas. The line-pack services can be accumulated, and thus the shipper can inject or withdraw gas at any hour, as long as she is hedged by line-packs services.

3.2 Auctions and the sequence of allocation mechanisms

The general criterion that we use is that some of the physical characteristics of the transmission network will be ultimately deal with by the TSO. The logic for that can be traced to the idea that some of the original asset specificity is inescapable, and must be managed by the operator(s) of the network[7]. As the asset is highly specific, the set of contracts will never be complete ex ante. We will group the set of services managed by the system operator(s) under the header of ancillary services. This can be alternatively thought of as the activity of bridging the gap between commercial and physical networks.

To design an efficient mechanism for the short-term allocation of network services, one needs to take account of the three inter-dependent products that are actually traded in the short run. First, gas supply and demand may be used to manage imbalances in the short term. Second, line-pack, analogously to other storage facilities, is an effective tool to manage imbalances, especially when the demand pattern is strongly time varying. Third, buying and selling gas at different points of the entry/exit system represents an additional option available for shippers in the balancing mechanism.

[7] Note that this is the case even in systems where network activities are liberalized, as the US sector.

The allocation of the three products implies a complex interaction between market decisions and TSOs. In order to facilitate such coordination, this paper proposes the use of short-term auctions. Nonetheless, after the auction, players should be allowed to renegotiate their contracts. Hence, the auction designs take into account the shippers' capacity to trade gas in the within-day markets. Furthermore, there is an essential role to be played by Transmission System Operators (TSO), and some tools must be left under their responsibility, so that they may ensure the security of the system. In any case, the contracts resulting from the auction will be firm, to ensure incentive compatibility in the auction. This in turn implies the design of a gate closure for within-day trading in a format well known in the electricity market.

4. Single-product, combinatorial auctions to allocate network services (Auction design 1)

A first alternative is to choose the gas commodity as the driver for the allocation of all network services. The main idea behind this option is that shippers just bid on the price of gas that will be injected and withdrawn from all entry and exit points over a certain time period. Once those decisions are taken, the clearing of the auction determines the flows through the network and the line-pack storage, in order to minimize price differences among entry and exit points.

Consider first that the gas system has no possibility to store gas inside the pipelines. In that case, the temporal dimension of the allocation process disappears, and the only service to be allocated by the auction is the transmission capacity. The option chosen means that transmission capacity will be allocated implicitly in the gas prices at each entry/exit point, in order to minimize the differences of gas prices among the entry/exit points at a certain point in time. This problem, which does not take into account the line-pack flexibility, is close to the spirit of zonal pricing in electricity auctions Schweppe, Caramanis, Tabors & Bohn (1988). However, compared to electricity auctions, zonal pricing in gas networks face the additional difficulty, from the design point of view, that there is an additional degree of freedom: the line pack storage ability of the transmission network under use for transmitting gas.

But in any case, it would be possible to use the model for the optimization of gas flows as the clearing algorithm of such auction. Under this frame, shippers would submit bids consisting in the quantity of gas that they are willing to sell or buy at each entry/exit point, and the corresponding prices. The Transmission System Operator (or in general the auctioneer in charge of the short-term auction) would receive the bids, and would decide on the flows and line-pack in order to minimize price differences. This first alternative is intended to mimic the bidding process of zonal pricing in electricity markets. In gas systems, however, one needs to allocate, in addition to transmission capacity, line-pack services.

4.1 A proposal for the clearing model in an implicit auction

The algorithm for an implicit gas auction that takes into account the line-pack is close to the reasoning of combinatorial auctions for electricity markets, which are based on using unit-commitment models to clear the market, Hobbs, Rothkopf, O'Neill & Chao (2001). The logic for the application to short-term gas markets is to represent, by means of a simplified model of the operation of the gas network, the optimal allocation of gas flows and line-pack storage implicit in the players' bids for the gas commodity.

In that view, the objective function of the optimization of the network services will be to maximize the social benefit. In this case, it will be represented by the maximum of values of bids for injection minus values of the bids for withdrawal over the auction horizon.

Consider a certain system made up of $i = 1, \dots, N$ entry/exit points and $j = 1, \dots, M$ pipelines. Let us denote:

- $I_t = \begin{bmatrix} I_t^1 \\ \vdots \\ I_t^N \end{bmatrix}$ is the vector of injections at each entry/exit point at time t

- $B_t\ (I_t) = \begin{bmatrix} B_t^1(I_t^1) \\ \vdots \\ B_t^N(I_t^N) \end{bmatrix}$ is the vector of bids for injections at each entry/exit point at time t

- $W_t = \begin{bmatrix} W_t^1 \\ \vdots \\ W_t^N \end{bmatrix}$ is the vector of withdrawals at each entry/exit point at time t

- $C_t\ (W_t) = \begin{bmatrix} C_t^1(W_t^1) \\ \vdots \\ C_t^N(W_t^N) \end{bmatrix}$ is the vector of bids for withdrawals at each entry/exit point at time t

- $f_t = \begin{bmatrix} f_t^1 \\ \vdots \\ f_t^M \end{bmatrix}$ is the vector of flows through each pipeline of the system at time t

- $l_t = \begin{bmatrix} l_t^1 \\ \vdots \\ l_t^M \end{bmatrix}$ is the vector of line-pack storage in each pipeline at time t

- $\mathcal{M}$ is the incidence matrix: its element $\mathcal{M}_{ij}$ is 1 if the line j is leaving the entry/exit point i, -1 if the pipeline is arriving at the point, and zero otherwise.

- $\mathcal{F}_f$ is the matrix relating flows through the pipeline and pressure differential

- $\mathcal{F}_l$ is the matrix relating line-pack storage inside the pipeline and pressure differential

- $p_t = \begin{bmatrix} p_t^1 \\ \vdots \\ p_t^N \end{bmatrix}$ is the vector of pressures at each entry/exit point at time t

The system constraints that we will be considering are:

- The energy balance at each entry/exit point

$$l_t = I_t - W_t + \mathcal{M} f_t + l_{t-1}$$

- The flow and line-pack definition in terms of nodes' pressure

$$f_t = \mathcal{F}_f\ p_t$$
$$l_t = \mathcal{F}_l\ p_t$$

- The pressure limits of the pipelines

$$p_t^{min} \le p_t \le p_t^{max}$$

With the previous notation, the total social surplus can be written as $\sum_t \left(B_t\ (I_t\ ) - C_t\ (W_t\ )\right)$. Therefore, the clearing algorithm can be represented by

$$\begin{array}{lll} max_{I_t\ ,W_t\ ,f_t\ ,l_t\ ,p_t} & \sum_t \left(B_t\ (I_t\ ) - C_t\ (W_t\ )\right) & \\ s.t. & l_t\ = I_t\ - W_t\ + \mathcal{M} f_t\ + l_{t-1} & : \mu_t^{price} \\ & f_t\ = \mathcal{F}_f\ p_t & : \mu_t^F \\ & l_t\ = \mathcal{F}_l\ p_t & : \mu_t^L \\ & p_t^{min} \leq p_t\ \leq p_t^{max} & : \mu_t^{min}, \mu_t^{max} \end{array} \quad (1)$$

This formulation purposely simplifies significantly the laws governing the flows through a gas network (see for instance Mokhatab, Poe & Speight (2006) for detailed representations). The idea is that the auction mechanism is not intended to represent in detail physical flows, but to separate the network services required to adjust shippers' portfolios from the complex technical characteristics that will be managed by the TSO. This should not be surprising, as it is the same strategy pursued by unit-commitment models for electricity markets. Again, the institutional choices in the EU gas systems have reduced markedly the economic differences between power and gas networks.

The optimality conditions for the previous program yields

$$Optimality\ I_t\ : \qquad \frac{\partial B_t\ (I_t\ )}{\partial I_t} = \mu_t^{price}$$

$$Optimality\ W_t\ : \qquad \frac{\partial C_t\ (W_t\ )}{\partial W_t} = \mu_t^{price}$$

These two equations just assert that the price is the one that makes the marginal utility of injections equal to the marginal utility of withdrawals.

$$Optimality\ l_t\ : \qquad \mu_{t+1}^{price} - \mu_t^{price} + \mu_t^L = 0$$

$$Optimality\ f_t\ : \qquad \mathcal{M}^T \mu_t^{price} - \mu_t^F = 0$$

These two equations give the value of the transmission and the line-pack storage along the whole network. The former is expressed by means of the price differences among the nodes of the network at a certain point in time, and the latter is expressed by the price difference between two consecutive periods of each node of the network.

Finally, pressures optimality gives the relationship between line-pack and transmission.

$$Optimality\ p_t\ : \qquad \mathcal{F}_f^T \mu_t^F + \mathcal{F}_l^T \mu_t^L + \left(\mu_t^{max} - \mu_t^{min}\right) = 0$$

The last optimality condition gives the relationship between transmission and line-pack storage. Both services are related by means of the pressure differential of the pipeline.

4.1.1 Line-pack pricing

Consider that we do not have congestion, so

$$\mathcal{F}_f^T \mu_t^F = -\mathcal{F}_l^T \mu_t^L$$

Therefore, in terms of node prices, we have that

$$\mathcal{F}_f^T \mathcal{M}^T \mu_t^{price} = \mathcal{F}_l^T \left(\mu_{t+1}^{price} - \mu_t^{price}\right)$$

The left-hand side of the equation represents the value of transmission along the network. It is representing the comparison among the price differences in the pipelines (and hence the value of transmission) at each node of the network. The right-hand side of the equation gives the value of the line-pack. It compares, at each node of the network, the price differences between the present period and the next period (the value of line-pack). In this view, the right-hand side of the equation is the analogue of the right-hand side, but instead of looking at the price differences among the nodes, it looks at the differences among prices in the next period.

Therefore, the algorithm clears the auction in order to make the marginal utility of transmission equal to the marginal utility of line-pack. Such marginal utilities are represented by offers of gas injections and withdrawals.

4.1.2 Bidding for line-pack storage

From the viewpoint of players' bids, the choice between line-pack and transmission is done implicitly in their offers for gas commodity injections and withdrawals in the different hours of a day. It is worthy to note that the line-pack is allocated according to the results of the interaction of shippers bids. The line-pack is not allocated to any individual shipper but as result of the pricing differences in the day's hours.

As result, on one hand, the capacity is efficiently allocated according to the preferences of the shippers in the moment that the auctions were completed. On the other hand, in case of changes in the shippers' preferences, the capacity could be re-allocated through a secondary market. Thus, the line-pack is allocated, but the players' flexibility (wait and see) to change their positions regarding the movement of injections and withdrawals is let to the secondary market.

4.2 The combinatorial auction

In principle, the auction would have the same time scope as the previous balancing mechanisms, as it is intended to play the same role as the balancing mechanism. In fact, a sensible time scope for the auction is a day, as network line-pack will be used largely by gas-fired power plants (GFPP), so it is sensible to facilitate the operations by making both time scopes coordinated.

The mechanism proposed in this section consists in a combinatorial auction where shippers decide on their bids for gas injection and withdrawal at each entry/exit point and each hour of the gas day. The auctioneer receives the bids, and uses the algorithm described above to clear the market. In doing so, the auctioneer determines the winning bids and the price for the gas commodity at each entry/exit point at each hour of the gas day. Transmission capacity and line-pack storage are thus allocated implicitly by the market clearing.

5. Sealed-bid auctions with explicit line-pack contracting (Auction design 2)

The previous auction design is based on a multi-period optimization, aimed at deciding on the trade-off between transmission capacity and line-pack storage over the gas day. However, in order to design their bids, market players must calculate what will be the preferences of the rest of shippers in the auction.

To facilitate this process, a useful solution is make line-pack explicit. The main idea is to consider separately the line-pack rights. Under this design, the short-term auction would allocate two products:

- The gas commodity at each entry/exit point

- The right to have an imbalanced portfolio in two consecutive hours

As in the previous option (auction design 1), the transmission rights would be allocated implicitly in the gas commodity prices. With this auction design (2), we transform the multi-period optimization of the previous alternative in a single-period optimization. In addition, shippers are now able to express their preferences on line-pack storage, instead of having to internalize them in the bids of injections and withdrawals. The potential problem would be that shippers must decide on a wider range of contracts, and thus the associated transaction costs would increase. In our opinion, compared to the increase of efficiency in the use of the network, this effect is negligible.

Shippers would be bidding for gas commodity and line-pack. Hence, there is no degree of freedom for the clearing algorithm. Given the gas injections and withdrawals at each hour of the auction horizon, and the line-pack requirements, the only free variable for the Transmission System Operator to decide on is the gas flow at each hour. In doing so, the clearing algorithm is now essentially the same as zonal pricing of power networks.

5.1 Calculating the relationship between line-pack and transmission capacity

The optimization program is the single-period version of the previous alternative:

$$\begin{aligned} & max_{I_t, W_t, f_t, L_t, p_t} && B_t(I_t) - C_t(W_t) + D_t(L_t) && \\ & s.t. && L_t = I_t - W_t + \mathcal{M} f_t + L^*_{t-1} && : \mu_t^{price} \\ & && f_t = \mathcal{F}_f \ p_t && : \mu_t^F \\ & && L_t = \mathcal{F}_l \ p_t && : \mu_t^L \\ & && p_t^{min} \le p_t \le p_t^{max} && : \mu_t^{min}, \mu_t^{max} \end{aligned} \quad (2)$$

This is the clearing algorithm. The auctioneer knows at the beginning of the auction the line-pack cleared in the previous hour, L_{t-1}. She also receives bids for injections and withdrawals, $B_t(I_t)$ and $C_t(W_t)$, and bids for line-pack storage in the hour, $D_t(L_t)$. Bids for gas injection and withdrawal are cleared according to

$$Optimality\ I_t: \qquad \frac{\partial B_t(I_t)}{\partial I_t} = \mu_t^{price}$$

$$Optimality\ W_t: \qquad \frac{\partial C_t(W_t)}{\partial W_t} = \mu_t^{price}$$

This optimality condition states that the last bid cleared for line-pack storage will be the one with the gas price plus the costs of the transmission that is given up to provide the flexibility service.

$$Optimality\ l_t: \qquad \frac{\partial D_t(\mathrm{L_t})}{\partial \mathrm{L_t}} - \mu_t^{price} + \mu_t^L = 0$$

Note that, as L_{t-1} is not a decision variable of the algorithm (it is decided in the previous hour optimization problem, see problem 2), the relationship with the previous hour is decided on by market players through the bids D_t.

The two remaining equations express such relationship.

$$Optimality\ f_t: \qquad \mathcal{M}^T \mu_t^{price} - \mu_t^F = 0$$

Finally, pressures optimality gives the relationship between line-pack and transmission.

$$Optimality\ p_t: \qquad \mathcal{F}_f^T \mu_t^F + \mathcal{F}_l^T \mu_t^L + \left(\mu_t^{max} - \mu_t^{min}\right) = 0$$

With this option, the line-pack is defined by the bids of market players, not by the market clearing process. Consequently, the network resources are allocated regarding shippers preferences on natural gas supply and offer (time and place) and also in line-pack storage services.

6. Revenue properties, risk bearing and the sequence of markets

The allocation of products in both auctions is not exactly the same. In the auction design 1 the line-pack storage is used to adapt efficiently the existent capacity to profiles varying hour by hour. It increases the efficiency of network allocation by revealing the hourly preferences and allocating cost and incentives of network restrictions. It takes into account the capacity of the pipelines to store gas. The decision of line-pack storage is based on the aggregate flows optimization and it guarantees the optimum use of network in the whole day based on day-ahead preferences.

The line-pack storage in the auction design 1 is completely allocated to smooth the demand variations through the day. However, if the shippers have some (unforeseen) flows shift after the auction they need to rely in the within-day market and possible derivative products, Graves & Levine (2010).

The auction design 2, selling explicit line-pack services, provides an additional service which is the shippers hedging against the need for within-day trading in case of volatility. The line-pack services work as option of selling (or buying) gas in each hour. In this scheme, the auction is selling line-pack as hedge service to face daily volatility in demand. The shippers keep an amount of capacity in case they need it. In the auction, shippers will thus bid for gas prices and for a complement service of flexible injection (or withdrawal). This service can have a key value for high volatile demand, especially in the absence of complementary financial services offering hedge, or of a liquid and reliable within-day market. On the other hand, as the shipper will buy the line-pack service for having the individual right to choose when they will use the network as transport or as line-pack, it may happen that the option is not exercised. The line-pack service, being a right and not an obligation, may result in a network capacity that is not completely used in the short term.

If the shippers are able to trade in a liquid within-day market to allocate volatilities and preference changes, the two auctions will be equivalent. Under the hypothesis of efficient within-day markets, total payments (taking into account all markets and auctions) will be the same under both designs. The network will be remunerated equivalently, and the transactions in the secondary market will just reallocate resources among shippers. As the hedge trading is only related to re-distribution of risks, its total payment would be zero.

The line-pack storage is allocated for different purposes in the two auctions and the efficiency of using one or the other mechanism depends on the complementary markets. In the case where the within-day market is well-developed and the shippers may deal with the volatility through trade of hedge products, the first auction design seems to be a better option.

The first option guarantees an efficient use of the resource and there is a low transaction costs as just one product is traded. In the case where there is not a developed market of hedge products, the use of line-pack services to face volatility seems to be a valuable service. The second option allocates storage flexibility according to the economic preferences of shippers and the costs of the system. As consequence the allocation of flexibility reveals the information about the shippers' preferences willingness to pay for flexible services. As consequence, there is not market distortion in the flexibility market and also give incentives for the needs of future investment[8].

7. Conclusion

This paper has shown how a day-ahead auction that takes into account gas prices and network capacity, could improve the efficiency of the short-term allocation of the network resources. We propose two different auctions. The first one allocates the whole network resources according to gas prices. The second one allocates the network resources according to gas prices and their preferences on the right to use line-pack. In that view, we propose two different auctions models to improve the current network allocation mechanism. In the first auction design, we consider the line-pack storage as an instrument to arbitrage gas prices away, and thus we allocate the resource through a daily network optimization. In the second auction design, we consider the line-pack storage as a shippers' tool to hedge volatility. And thus the line-pack storage is explicit allocated by shippers' preferences based on the bid price in the auction.

Of course, the allocation of products in both auctions would be the same, under the hypothesis of perfect within-day markets. In the auction design 1 the line-pack storage is better adapted to deal with profiles varying on an hourly basis. And it is the most efficient solution in the presence of extremely liquid within-day markets, where shippers could hedge against all within-day volatility.

The auction design 2, including a new service in the auction, the line-pack service, actually offers a hedge service. However, whether there is not a within-day market able to reallocate the resources this auction do not guarantee the full use of the network, but the guarantee that the resources is used to offer the services according to players preferences.

As the main difference between the two auctions is the explicit allocation of the optionality associated with line-pack storage, design 1 (without explicit allocation of optionality) will be adequate in markets where within-day trading is expected to be liquid. Otherwise, the hedge provided by the line-pack contract in design 2 will be difficult to replicate, and hence will be preferred.

The paper has not tackled the discussion on the choice between combinatorial and sequential auctions. Regardless the auction design is design 1 or design 2, there are potential benefits in using a sequence of simple auctions to clear the short-term market (along the lines of European power markets), but such choice is not analyzed in the paper.

Lastly, we want to emphasize that the worth of the proposed solution increases in a context where network flexibility becomes a valuable resource in the energy market and thus, the distortion caused by misallocation of resources may generate important economic inefficiencies.

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[8] The impact of the better allocation of the network resources in non-regulated markets as storage and LNG regasification capacity should be further study and it is not discussed on this paper.

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