CONGESTION MANAGEMENT IN MESHED GAS NETWORKS:

CAN THE ELECTRICITY MARKET SERVE AS AN EXAMPLE?

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Abstract
As gas networks grow and become increasingly interconnected, a need for more sophisticated congestion management methods is emerging. This paper explores the applicability of congestion management methods that are used for electricity to natural gas transmission networks. We argue that current congestion management is inadequate and leads to suboptimal outcomes. We propose that market-based congestion management methods such as locational marginal pricing (LMP) or auctioning result in Pareto-optimal outcomes. Auctioning is easier to implement than LMP while reaching similar efficiency levels. With respect to the Dutch gas transmission network, auctioning of interconnector capacity with Germany as opposed to the current first come, first served regime results in an increase in Dutch consumer welfare.

1 Introduction

As gas markets are being liberalized, it appears that current capacity allocation methods are becoming inadequate. The energy sector enquiry of the European Commission (EC, 2006) observes that current congestion management methods (such as first-come, first serve: FCFS) are inefficient methods for allocating capacity and managing congestion. In some cases of contractual congestion, it even appears that physical capacity is not yet fully used. In addition, Lise *et al.* (2005) point to the negative effects of existing congestion management methods upon the security of supply in the Netherlands. Thus existing congestion management methods appear to negatively affect both competition and security of supply.

These issues appear to manifest themselves mainly in meshed gas networks such as in North-Western Europe. Complications arise when parallel gas pipelines run through different countries with different regulatory regimes in place. This occurs for instance between the Netherlands and Germany. Due to strict regulation of network tariffs in the Netherlands and unregulated high transmission tariffs in Germany, the Dutch network may be used for transit purposes by German shippers to the extent that there may not be enough capacity to deliver to Dutch customers during demand peak (Lise *et al.* 2005).

Two policy goals apply to gas transmission network regulation: efficient allocation of scarce network capacity and stimulating efficient behavior by the monopolistic Transmission System Operator (TSO). They may appear to be at odds with each other: strict regulation of Dutch network tariffs appears to contribute to congestion. However, different instruments exist with which the two goals can

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be pursued. Network tariff regulation can be applied to stimulate the efficiency of the network manager, while congestion management methods can be applied separately to ensure economically efficient allocation of network capacity.

A number of congestion management methods have been developed for electricity transmission (cf. Knops *et al.*, 2001, De Vries *et al.*, 2002). In general, the EU requires congestion management methods to be market based[1], because they allocate network capacity in the most economically efficient manner. As the liberalization of Europe's electricity sectors started several years earlier than the liberalization of the gas sectors, there may be lessons which can be applied to the gas sector.[2] In addition, little research has been undertaken until now on congestion management in gas markets. This paper explores the scope for more optimal design of gas transmission regulation based on earlier experiences and regulatory regimes applied in electricity transmission.

This paper is structured as follows. In Section 2 we discuss the general types of congestion management methods as applied in electricity transmission: explicit auctions, implicit auctions (of which market splitting is one form) and locational marginal pricing (LMP, also known as nodal pricing). Section 3 describes pricing methodologies and congestion management methods currently applied in gas transmission. In section 4 we assess the theoretical added value of implementing alternative congestion management methods. Section 5 applies alternative congestion management methods to a simple gas transmission network. Section 6 concludes and suggests directions for further research.

2 Congestion management methods in electricity transmission

2.1 Introduction

Network congestion can either refer to contractual congestion or physical congestion. Network congestion implies that a certain line in the network can not (fully) accommodate all contractual or physical flows, because of a lack of physical capacity. Congestion, regardless which type, can hamper market integration and effective competition and creates potential for market power abuse (EC, 2006). On the other hand, given that (electricity) transmission capacity is highly capital intensive, exhibits a high degree of asset specificity and has lumpy investments, capacity expansion may not always be economically efficient. This means that a certain level of congestion may sometimes need to be accepted permanently (Knops *et al.* 2001). For these reasons it is important to have efficient and effective congestion management methods in place. In the EU, congestion is dealt with differently in single control areas (areas managed by a single TSO) than on interconnectors between control areas.

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[1] The (proposed) binding Congestion Management Guidelines under Regulation 1228/2003 explicitly prescribe explicit and implicit auctions as the only congestion management method allowed (EC, 2005).

[2] Literature on congestion management methods in the gas sector is scarce. A notable exception is McDaniel and Neuhoff (2002) who study the British experience with the auctioning of entry terminal capacity.

Within a control area, the TSO is responsible for managing congestion, for instance by using bids for reserve power to change the load flow. Transmission tariffs are typically determined with by a so-called postal tariff: market participants only pay a fixed fee to access the network. Hence, the transmission fee is not distance related and market parties do not need to apply for transmission capacity to carry out their intra-TSO transactions. Due to this lack of cost reflectivity, transmission tariffs do not provide efficient incentives for congestion minimization.

EU regulation provides clear guidelines on inter-TSO congestion management (EC, 2003 and ERGEG, 2005). Congestion management guidelines prescribe that congestion management methods implemented by EU member states must be *market based* and that allocation of capacity shall be made only by *explicit* (capacity) or *implicit* (combined capacity and energy) auctions.[3] Both methods may coexist on the same interconnection. Presently, distributive congestion management methods, such as first-come-first-serve or pro rata allocation, still exist on European interconnections, even though they are at odds with the Regulation (ETSO, 2004).

Currently, four different congestion management methods exist (De Vries *et al.*, 2006): (i) corrective methods, (ii) distributive methods, (iii) pricing methods and, (iv) optimization methods. In the following sections, we briefly describe these five typologies of congestion management methods.

2.2 Corrective methods

A general characteristic of corrective congestion management methods is that market parties are allowed to make transactions without consideration for congestion. As a result a single price emerges, regardless of network constraints. The TSO can avoid network overloading through either redispatching or counter-trading.

Redispatching involves increasing output 'downstream' of the congested connection and decreasing it 'upstream'. The costs related to this system of redispatching are generally socialized in network tariffs. A slightly more market-based approach is called *counter trading*. Within this system, the TSO creates a second market in which it requests bids from generation companies to reduce generation on one side and increase generation on the other side of the congested line. As with redispatching, the costs are socialized in the network tariffs.

Both counter-trading and redispatching have the advantage that they provide TSOs with an efficient incentive for network expansions. A disadvantage of both methods is that they may provide significant opportunities for manipulation to generation companies. In many European countries redispatching (or counter-trading) is the main congestion management method within control areas, although these methods are rarely used for interconnectors (DG TREN, 2002).

2.3 Distributive methods

Distributive methods for congestion management are methods by which the capacity is assigned on other criteria than willingness tot pay. Two common distributive methods are priority and pro-rata assignment. Priority assignment means that parties receive capacity in a priority order until the whole available capacity is allocated, for instance in chronological order (first come first served) or based

[3] The congestion management guidelines are expected to come into force in 2006.

upon past use of capacity. Pro rate allocation means that requests for capacity are partially accepted in such a way that each participant is granted a fixed share of his requested capacity amount.

2.4 Congestion pricing methods

Congestion pricing methods allocate access to a congested network link through some form of a price method. In order to obtain price equilibrium, congestion pricing methods make use of different forms of auctions. Here, we will discuss (implicit and explicit) auctions and LMP.

Standard economic auction theory, using standard assumptions of (i) risk neutral behavior, (ii) independent private bids, (iii) information symmetric bidders and (iv) sufficient bidders, states that auctioning is an allocation method that could lead to welfare optimal outcomes. This means that those bidders showing the highest willingness to pay will indeed obtain the auctioned good and that provides the most revenues for the auctioneer.[4] Initially, auctioning was intended to provide an optimal allocation method for existing capacity, but more recently it is also viewed as an efficient method to determine and allocate future demand (McCabe et al. 1989). In this paper, the primary focus is on the optimal allocation of current network capacity and less so on its function of providing optimal investment signals for expansion of current capacity.[5]

As such, auctioning might provide an excellent allocation method for network capacity, but several specific characteristics of networks might counter the above mentioned assumptions. McDaniel (2003) mentions the following characteristics:

- the auctioned product (energy network capacity) is an 'intermediary good' which is absolutely necessary to compete for the final consumers;
- Bidders for energy network capacity might not be symmetric since different actors of different size compete for the auctioned good;
- Bids are not private nor independent since there is an element of common and private values among the competitive bidders;
- Markets are mixed, which is created by different goals in the sense that a regulated public actor like a network operator auctions to private competitive actors.
- Property rights for future network access capacity are ambiguous.

All in all, auctions might in practice suffer from market power, asymmetric information, non-independent valuations and ambiguous property rights.

In *explicit auctions* the use of transmission capacity is offered to the highest bidders in regularly recurring auctions; often in yearly, monthly and daily auctions. Most commonly in Europe, the price of interconnector capacity is set equal to the marginal bid, which is the lowest bid that is awarded transmission capacity. All bidders that bid equal or higher than the marginal bid obtain capacity rights against the value of the marginal bid. In principle, the willingness to pay is equal to the price difference over the congested link.

[4] For a complete survey on auction theory we refer to Klemperer (1999).

[5] For discussion on the issue of network auctions providing optimal investment signals we refer to McDaniel and Neuhoff (2002a), Yarrow (2003), Newberry (2003) and McDaniel (2003).

In an *implicit auction*, the auction of transmission capacity is integrated with a common spot market. The original design works in one direction and requires the presence of an organized market downstream of the congested link. The transmission capacity is implicitly auctioned: it is allocated to the highest bids in the spot market that make use of the congested link. Thus the energy and capacity bids are combined in a single package De Vries, 2004). Market splitting and market coupling are extensions of implicit auctions in which the case–by–case method for managing structural congestion makes room for a more 'zonal' approach.

2.5 Optimization methods

The main optimization method for congestion management is LMP (also known as nodal pricing). It combines bids for electricity (commodity) with bids for network capacity. As the management of congestion is integrated in the market clearing method, it can be considered an advanced form of implicit auctioning. The system (market) operator (SMO) matches the bids of producers and consumers to clear the market. Congestion is handled by varying the prices among the different nodes in the network: lower prices will lead to less generation and, perhaps, higher consumption at a node, and vice versa (cf. Hogan, 1992; Kirschen and Strbac, 2005).

This method is conceptually elegant, as it is the only congestion management method that fully takes network constraints into account. However, it is also complex and only works in integrated systems. The nodal pricing method can only be applied in an integrated market in which the system operator is also is the market operator. As the SMO fully controls market outcomes it is crucial that the SMO is strictly independent from all the other parties.

Because the constantly varying nodal prices create price risk, hedging instruments have been introduced in the form of financial transmission rights. In the PJM system, point-to-point transmission rights PTPs) are used, also called transmission congestion contracts (Hogan *et al.*, 1996, see also Kirchen and Strbac, 2004). These rights entitle their holders to revenues equal to the quantity of electricity times the price differential between two specified nodes (O'Neill *et al.*, 2003).

2.6 Concluding remarks

While other congestion management methods are still being used, there is a strong preference, both politically and for reasons of economic efficiency, for congestion pricing methods. Compared to implicit auctions, an important advantage of explicit auctioning is that transmission access can be provided in advance. A disadvantage is that the energy trading and capacity allocation process is separated, which increases transaction costs and creates coordination problems. These factors increase the complexity of inter-area trade, which increases quickly when multiple congested borders are involved. Nodal pricing in combination with financial hedging contracts solves these issues, but the institutional requirements for nodal pricing are high. In particular, it can only be implemented in centralized electricity markets, which do not exist in Europe. However, perhaps the financial hedging contracts can also be used in combination with market splitting, thus achieving many of the same advantages.

3 Transmission pricing and congestion management in gas transmission

3.1 Physical characteristics of natural gas

Both electricity and gas are network-bound commodity markets, but the physical characteristics of electricity and gas differ substantially. There are four main differences between gas and electricity.

Firstly, electricity is not storable in an economically viable way, which means that demand and production need to be balanced continuously. Gas, on the other hand, can be stored, and there are many other opportunities for balancing as well. Secondly, gas is a primary energy carrier, which has as a consequence that its production is bound to certain physical locations. In contrast, electricity is a secondary energy carrier that technically can be generated anywhere. Thirdly, due to its physical characteristics, the flow of gas is more controllable than electricity. Where the laws of Kirchhoff and Ohm guide electricity flows, gas flows are guided by differences in network pressure and can be controlled with valves and compressors. Consequently, uncontrollable parallel flows are not a problem in gas transmission like they are in electricity. Fourthly, gas can be transported in both liquid and gaseous states, making it more flexible. The energy losses and costs of gas transport are lower than for electricity.

3.2 Pricing gas networks efficiently

Gas network pricing serves two goals: (1) efficient allocation of available capacity and (2) recovery of network costs. These goals are distinct and cannot be achieved with one instrument. For instance, cost-reflective network charges will not necessarily prevent congestion. Congestion develops when the market value of a network link is higher than its price. Congestion rents, on the other hand, do not necessarily provide sufficient revenues to recover network costs (De Jong and Knops, 2006). Therefore we need to consider two aspects of gas network pricing, namely transmission pricing and congestion management methods.

In general, three types of **pricing methodologies** can be distinguished: 1) distance-based, 2) a 'matrix' approach (including entry-exit and zonal systems) and 3) postal tariffs. A *distance-based tariff system* (also called point-to-point system) is characterized by transmission charges that are proportional to the distance between the point of injection and the point of withdrawal. This pricing methodology provides a clear and transparent framework for shippers but is possibly suffering from a lack of cost-reflectivity. This flaw originates from the fact that distance-based tariffs use contractual paths as a cost base and neglects actual physical paths. This problem more prominently persists in meshed gas networks. The contractual paths imply relatively little flexibility for shippers since they are required to book a fixed combination of entry and exit points.[6] The *matrix approach* shows much more flexibility. It not only recognizes that contractual paths are not always matching physical paths (cost reflectivity) but it also facilitates capacity rights trade on secondary markets. On the downside, it is more complex for TSO to allocate costs to every exit and entry point. Introducing zones where only one entry and exit tariff applies could be a solution, provided that no internal congestion exists. *Postal tariffs* are the simplest approach to transmission pricing since all combinations of entry- and exit points behold the

[6] This inflexibility works through into secondary capacity market liquidity.

same transmission charge. About the same drawbacks apply here as were identified under the distance-based pricing regime: cost reflectivity of the tariffs, flexibility and secondary market trading capacity rights will be limited.

There is only a limited number of **congestion management methods** applied in the transmission of gas. These are (i) first-come first-served (FCFS), (ii) pro-rata allocation and (iii) auctioning. The *FCFS regime* has the benefit that it is simple and transparent. Drawbacks of this method of congestion management are that it does not take into account the different values that shippers attach to capacity rights. In other words: it is a system where the shipper that shows highest willingness to pay is not always expected to obtain firm capacity rights. Theoretically, secondary markets could be the answer, but in practice transaction costs and limited number of market parties might prevent optimal outcomes to emerge. The second congestion management method currently used is a *pro rata based allocation* scheme. When contractual congestion is confirmed by the network operator, capacity applications are again reviewed with each applicant only receiving a pro rata amount of available transmission capacity. This method, although transparent and simple, has the same drawback as the first-come, first-served approach. A congestion management method based on an *auctioning* method is a more market based approach. Auctioning requires shippers to explicitly show their willingness to pay for certain capacity rights and therefore could theoretically realize optimal outcomes. On the other hand, auctioning in general and specific types of auctioning in particular could suffer design problems. A specific complication in design that arises with the use of an auctioning method for specifically gas transmission capacity rights is the time dimension (gas transmission capacity is a so-called 'multi-unit product'. This specific is addressed by McDaniel and Neuhoff (2002).

In the following sub-section we briefly describe the pricing methodologies and congestion management methods in a selected number of countries. We choose to describe the situation in the Netherlands and Germany since the example we use to illustrate alternative congestion management methods in section 4 is based on a Dutch/German setting. In addition we choose to describe the United Kingdom since it has is the most advanced gas market in Europe and the most advanced gas transmission system..

3.3 Transmission pricing and congestion management in practice

The **Dutch** transmission infrastructure consists of 2 separate networks. One network is designed to transport low calorific gas (L-gas) and one gas network is for high calorific gas (H-gas).[7] Figure 1 shows the different gas quality networks in the Netherlands in a stylized way. L-gas originates mostly from the very large Groningen reservoir, whereas H-gas originates from small Dutch fields and from imports from Norway and Russia.

[7] Actually, six different gas qualities exist, but within limits all six can be transported via either the L- or H- gas network. Gas produced by the Groningen field is also labeled G-gas but this falls within the boundaries of the L-gas network.

Since January 2003, the Dutch TSO Gas Transport Services (GTS) has been using an entry-exit system for transmission tariffs. There are around 50 entry points and around 1100 exit points. Apart from the entry and exit charges, there is also a connection charge that is based on the capacity required by the shipper. The tariffs are fixed throughout the year. To our knowledge, there is no transparent methodology through which entry and exit tariffs are set. The overall level of entry and exit tariffs is indirectly determined by revenue regulation, but tariff codes do not give specific pricing calculation methodologies. Final approval of transmission charges lies with the regulator. It is possible to contract capacity on a daily, monthly, annual or multi-annual basis with a maximum of 5 years (60 months).

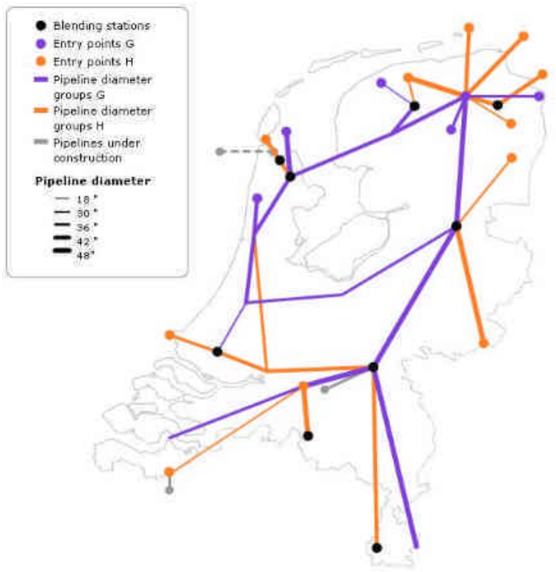


Figure 1: Stylized representation of Dutch gas transmission network
(Source: www.gastransportservices.nl)

The congestion management method applied by the Dutch TSO is FCFS. When all network capacity is booked for a certain link or path, remaining capacity requests are turned down. This implies that scarcity of capacity is not valued: network charges are cost-reflective, not value-reflective, and those who have been able to book network capacity implicitly reap the congestion rents. Current regulatory codes give the TSO the option of auctioning network capacity, but until now, these options remains unused. The secondary market for capacity rights is bilateral. The TSO facilitates trade a 'bulletin board' where shippers can express their willingness to buy or sell certain capacity rights.

The **German** gas transmission network can be separated into five different TSO regions. The five regional networks are owned by Wingas, RWE, VNG, BEB and E.ON Ruhrgas. Since we are especially interested in the meshed gas network in the Netherlands in relation to the neighboring region in Germany, we only describe the practices used by BEB. BEB operates the network in the North-Western part of Germany.

Its network encompasses three different gas quality networks, namely: an H-gas network, an L-gas network and a LL-gas network. BEB has switched to a system of entry and exit charges in the course of 2005. The total network contain 28 entry points and 173 exit points in which each entry and exit point has a different tariff. BEB Shippers are allowed to book counter flow capacity on all non-bi-directional points at a charge of 75% of the applicable entry of exit tariff. BEB's congestion management method is a combination of FCFS and auctioning. In principle, a FCFS regime is applied, but when an entry or exit point is congested an auction is set up to allocate total capacity rights.[8] Gas transmission tariffs have been unregulated until now. This might change in the near future when the new German energy regulator is fully operational.

The **UK** gas transmission system has both a transmission operator (TO) and a system operator (SO), both being part of the UK Gas Transmission Company Transco. The basic transmission pricing approach in the UK is matrix based. Separate charges exist for entry and exit tariffs. In contrast with the Dutch and German practices, clear rules are laid down as how to calculate specific entry and exit tariffs. Both the TO and the SO are regulated by a (separate) revenue cap.

The TO is assumed to derive 50% of its total revenue from entry charges, and 50% from exit charges. Both entry and exit charges are determined using a methodology based on long-run marginal cost, but entry charges are treated differently from exit charges. Capacity for entry points in sold via auctions, in which the reserve price is equal to long-run marginal cost.

Although the obligation to pay for capacity remains with the primary purchaser, all types of entry capacity can be traded between shippers. Primary system entry capacity is allocated to the market via five related auction methods varying from quarterly auctions for capacity rights for two to sixteen years ahead to daily auctions for day-ahead capacity rights. The daily auction only takes place when there is still unsold remaining capacity. Each capacity auction has a different reserve price but each is linked to long-run marginal cost.

3.4 Summary

Although the commodities gas and electricity are both network-bound markets, the physical characteristics differ substantially. The most important differences for our analysis are (1) the higher degree of controllability of gas flows compared to electricity flows, and (2) the relative easiness of balancing gas demand and production compared with electricity due to its storage abilities.

When studying the pricing of gas transmission networks two aspects need to be taken into account. These are the recovery of network costs and the efficient allocation of available capacity. In gas transmission pricing, the matrix approach is most widely used while congestion management schemes are mainly based on distributive approaches such as FCFS and pro-rata allocation. We describe three different gas transmission systems (The Netherlands, the BEB region in Germany and the UK) and observe that all three apply a matrix approach in tariffication. Distributive congestion management method (FCFS) is applied in the Netherlands and a pricing method (auctioning) is applied in the UK. The BEB in Germany uses a mix.

In the next section we turn to the selection of alternative congestion management methods for gas transmission capacity.

[8] As noted earlier we abstract from issues related to the long-term efficiency in providing optimal investment signals.

4 Selecting a promising congestion management method for gas transmission capacity

4.1 Selection criteria

Knops, de Vries and Hakvoort (2001) define several criteria for congestions management methods. In this paper we focus on a selection. We define the following criteria. A congestion management method should be economically efficient in the short-term[9] (capacity allocation), relatively easy to implement, and not have too high transaction costs. We will assess the performance of LMP (optimization method) and auctioning (pricing method). Corrective and distributive methods are not dealt with here, since we have shown the inefficiency of these methods (see Sections 3.2 and 3.3). In general, these methods do not ensure that actors with the highest willingness to pay for transmission obtain capacity rights.

4.2 LMP

Theoretically, LMP is the most appealing congestion pricing method for both gas and electricity. In electricity transmission congestion management, the drawback is that calculations could become very complex due to the large number of nodes and the existence of parallel flows. However, computing locational marginal prices for gas transmission should be less complex due to higher flow controllability. The limited number of entry points in the network (border points, points at gas producing facilities and points at gas storage facilities) should make it still less complex. There is a significant institutional barrier, however. In order to mitigate congestion in the European gas transport network, LMP would need to be implemented jointly by multiple TSOs whose networks are connected. Considering the slow pace of the integration of European gas networks, this does not appear a realistic prospect.

4.3 Auctions

In contrast, the institutional requirements for auctioning congested network links are much smaller. Whereas in electricity networks, parallel flows pose a challenge to auctions of network capacity (that is overcome by subtracting ample reserve margins from the calculation of available network capacity), gas flows can be controlled. Consequently, in theory it should be possible to achieve optimal allocation of network capacity through a separate, uncoordinated set of auctions of congested network links. In practice, the number of congested network links in meshed gas networks is often limited. The networks are not as finely meshed as electricity networks and the flows are not as variable due to the fixed nature of gas sources. Therefore auctions are a promising congestion management method.

There still is a choice between implicit and explicit auctioning for the allocation of gas transmission capacity. An important aspect is the time-frame in which capacity is auctioned and liquidity of the trade in the commodity gas. Implicit auctions can reduce transaction costs by streamlining the arbitrage between the market for network capacity and the commodity market. For example, a shipper with gas in his portfolio who does not succeed in obtaining transmission capacity rights in a day-ahead network

[9] In this paper the focus is not on the longer term implications of congestion management methods (as investment signals) but on its short-term implications

auction will want to re-sell his gas on the day-ahead market. If the day-ahead market is not liquid enough, with day-ahead prices insufficiently representing the real market value of gas, the shipper may incur financial losses. To prevent this, implicit auctions should be used for short-term capacity auctions. In other words, short-term capacity rights should be allocated to shippers with the 'best' gas commodity contracts in their portfolio (who would have the highest willingness to pay in an explicit auction).

4.4 Summary

The efficiency of a congestion management method based on LMP is very high, but its operational complexity will still be substantial since it requires a lot of real-time coordination between gas exchanges and transmission operators. Furthermore, there are institutional barriers preventing short-term implementation: the spirit for a common European TSO are low and gas exchanges, when existing, are generally less developed.

Auctioning could in theory provide the same efficiency as LMP, but it's far easier to implement. In addition, it can be implemented on a very selective base, for example on a gas interconnector. The feasibility of implementation is increased by the fact that auctioning is already considered to be a viable option for congestion management in a number of European countries. Implicit auctioning would be more difficult to implement due to the relatively underdeveloped gas exchanges in continental Europe.

In the next section, both the methods of LMP and auctioning are applied to a simplified network based on the Dutch gas transmission network.

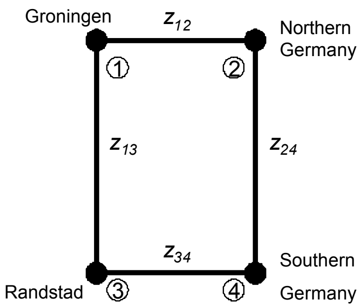
5 Application to the Dutch case

5.1 Introduction

In this section, we illustrate the impact of applying alternative congestion management methods to the Dutch gas network. Since we already described the Dutch (and German) transmission network in section 3.3, we immediately start with the construction of a simplified network model for the Netherlands. Next, we look at the impact of implementing the alternative congestion methods of LMP and auctioning (implicit and explicit, with special cases of market coupling and market splitting).

For the purpose of analysis we further stylize the network presented in Figure 1 and extend it with a parallel transmission line in Germany. This modification allows us make some observations with

Simple network model



Production capacity (mln m^3 per day)

Node 1	299
Node 2	350

Marginal costs of production (€ per 1000 m^3)

Node 1	20
Node 2	40

Flow capacity (mln m^3 per day)

z_{12}	68
z_{13}	274
z_{24}	233
z_{34}	123
z_{21}	110
z_{31}	0
z_{42}	96
z43	0

Transmission tariff (€ per 1000 m^3)

$T_{12}= T_{21}$	2
$T_{13}= T_{31}$	5
$T_{24}= T_{42}$	10
$T_{34}= T_{43}$	2

Peak demand (mln m^3 per day)

Node 1	68
Node 2	131
Node 3	151
Node 4	235

Figure 2: Four-node network of the Netherlands and Germany, including data inputs (source: Lise *et al.* (2005) and own calculations).

respect to alternative congestion management methods for dealing with the problem of German gas flows that are re-routed, which was described in the Introduction. In our computations we use realistic data on flow capacities, production and consumption figures and transmission tariffs, based on Lise *et al.* (2005). Figure 2 shows the simple four-node network that we use and summarizes the data. We look at daily flows during peak demand since congestion is most likely to occur in peak hours. This implies that we abstract from medium and long-term capacity contracts and assume that at least part of the network capacity is sold day-ahead.

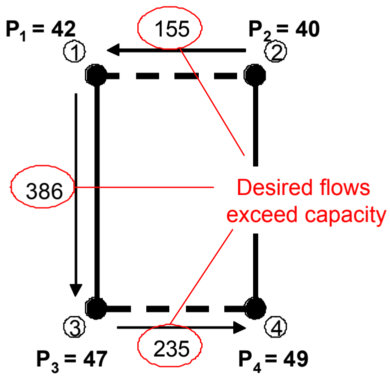


Figure 3: Equilibrium results with unconstrained transmission flows

The starting point for the analysis is the outcome that would result in the current FCFS (first come, first serve) regime. Figure 2 shows the desired flows and nodal prices. Since the transmission costs between nodes 2 and 4 are higher than transmission costs between nodes 2 and 4 via nodes 1 and 3, capacity on the link between nodes 2 and 4 remains unused. The marginal gas producer in this situation is the producer at node 2, which implies a price of €40 at this node. Other nodal prices are obtained by adding transmission tariffs to the marginal price of €40. However, total gas flows between nodes 1 and 2, nodes 1 and 3, and nodes 3 and 4 exceed total flow capacity, with the link between nodes 1 and 3 being the most congested (the bottleneck). In other words, not all desired transactions can take place. However, we cannot observe which consumers at which node would be curtailed in the FCFS regime. We will now discuss the impacts of implementing LMP and auctioning.

5.2 LMP

The most congested link in the network is the link between node 1 and 3 (the dashed line in Figure 4). When LMP is used, congestion on this link is relieved by raising the exit tariff at node 3 with €1. This additional tariff component ensures that gas produced at node 2 can be shipped at the same costs along the route node 1 – node 2 – node 4, as the direct route between node 2 and 4. This results in a gas flow of 112 million m^3 per day between nodes 2 and 4, while full capacity is utilized between the nodes 1 and 3, and 3 and 4. The congestion rent also implies that end-consumers in node 3 pay higher gas prices in comparison with the outcome under the FCFS regime. But now the risk of capacity shortages is mitigated. When the risk of curtailment is high, the higher gas prices in the few periods that congestion occurs will be compensated for by the mitigated costs of curtailment.

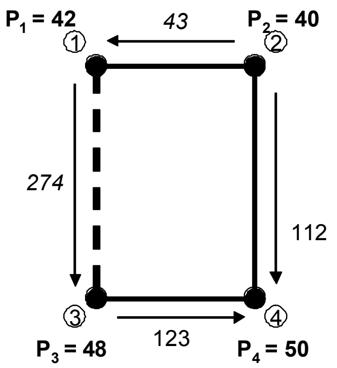


Figure 4: Equilibrium results with LMP with congestion on line 1-3

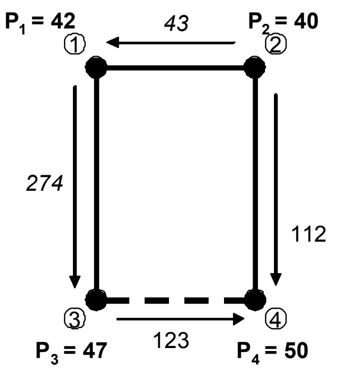


Figure 5: Equilibrium results with LMP with congestion on line 3-4

From the perspective of one common integrated market and system operator covering the whole network, LMP could be considered an optimal solution. However, in reality this network is controlled by two different network operators. What is the optimal solution for the Dutch market? For the Dutch operator it would be optimal to treat the interconnector link between nodes 3 and 4 as the congested link (dashed line in Figure 5). By raising the entry tariff at node 3 by €1, congestion on the line between node 1 and 2 is relieved. The resulting flows are identical to those in Figure 4, but now the nodal prices differ. The additional €1 congestion rent is not collected at the node 1 and 3 linkage, but at the interconnector between nodes 3 and 4. This leads to a decrease in the prices on nodes 1 and 3 with €1. By treating the interconnector as the most congested linkage in the network, nodal prices in the Netherlands return to the levels that prevailed in the regime of FCFS (€42 in node 1 and €47 in node 3), but now without the risk of being disconnected during peak periods. Hence, implementing LMP raises consumer welfare in the Netherlands.

5.3 Auctioning of transmission capacity

Theoretically, auctioning of transmission capacity produces the same results as LMP in a gas network. On transmission lines where capacity is not fully utilized, auctioning will have no impact. Only when a certain transmission line is known (or expected) to be congested, explicit auctioning of total capacity will result in a congestion value (rent). In our example, the auction price would not exceed the value 1 €, because a higher value would lead shippers buying gas in node 2 and delivering at node 4 to prefer the direct route over the route including the congested link between node 1 and 3. Hence, results in Figure 4 apply to the case of auctioning capacity on the line between nodes 1 and 3.

Implicit auctioning could be implemented by integrating gas transmission with the Dutch gas exchange APX gas. The system operator would receive all shippers' bids for the transmission of gas from node 1 to node 3 and reward the highest bids with capacity rights. The value of the highest (marginal) bid will again not exceed the value of €1 in our example. The advantage is that arbitrage between the day-ahead markets for gas and for transmission capacity is automatic.

What is the optimal solution if we only assess the impact on the Dutch system? Analogously to LMP, it would be optimal to consider the interconnector link between nodes 3 and 4 as the congested link. Auctioning this interconnector capacity will lead to a congestion value of again 1€. This relieves congestion on the internal link between nodes 1 and 2, and produces nodal prices of €42 and €47 for respectively node 1 and node 3. Hence, the results in Figure 5 also hold when capacity on the line between nodes 3 and 4 is explicitly auctioned. Subjecting this line to market coupling will produce identical results but requires coordination between the Dutch and German TSO.

5.4 Discussion of results

From an economic point of view, implementation of LMP and auctioning produces identical results when applied to a simple network representing the Dutch transmission network. But when recognizing the fact that two different separate Dutch and German network systems exist and assuming welfare maximization for the Netherlands, it turns out that it matters which specific transmission line is treated as the congested bottleneck. German transmission pricing inefficiencies, due to insufficient regulation, causes a re-routing of gas flows and congestion on the Dutch transmission network. This congestion can be effectively corrected by implementing market-based congestion management methods on the Dutch gas transmission network. However, from the point of view of Dutch society, it would be Pareto optimal to consider specifically the German-Dutch interconnector as the congested link instead of the Dutch internal transmission link. This result holds whether LMP or auctions are applied.

6 Conclusions and suggestions for further research

Different forms of auctioning are common methods for managing congestion in electricity transmission, most often applied to interconnectors. Congestion management methods based on optimization, such as LMP, are theoretically appealing but so far have proven too complex to be introduced in European electricity systems.

In gas transmission, distributive-based congestion management methods such as FCFS and pro-rata are still frequently used, even though they are economically inefficient and not favored by the EC. The Netherlands, for example, has a FCFS regime for capacity allocation. The only European country to adopt a form of auctioning in transmission capacity allocation is the UK. In the Netherlands, the current FCFS-regime is discussed, in response to indications that gas flows that normally run through Germany are re-routed through the Netherlands in response to lower transmission tariffs. The cause for this differential is the strict regulation of transmission tariffs in the Netherlands and high, unregulated tariffs in Germany. This re-routing is considered undesirable because long-term transmission capacity bookings by German shippers could potentially crowd out short-term capacity requests of Dutch gas utilities during periods of peak demand. Hence, security of supply could be threatened. A measure that could increase allocative efficiency in gas transmission in general, and counter this specific re-routing phenomenon in particular, is the implementation of a more market-based congestion management method such as LMP or auctioning.

Implementation of LMP in the short run should be considered infeasible for two reasons. First, it requires a common integral market and system operator for the whole region: institutional barriers for such a development are currently too high. Second, it is quite a complex system due to the large number of entry and exit points and fluctuating injection and off take of gas. Auctioning of gas transmission capacity is far less complex and does not necessarily imply large institutional changes. In contrast to LMP, auctioning could very well be applied to individual congested transmission lines. The potential for implicit auctioning (as contrasted to explicit auctioning) involving simultaneous trading of both commodity and capacity is mixed. Only few European countries have gas exchanges and liquidity is limited. On the other hand, implementing implicit auctions could give a stimulus to further gas hub development. This area remains to be explored.

Using a simple network model representing the Dutch network, including a parallel German transmission line, we have shown that implementation of congestion management methods based on LMP or auctioning would successfully deal with congestion caused by re-routed German gas flows. More specifically, we argue that, from the Dutch point of view, it would be Pareto optimal to consider the German-Dutch interconnector as the congested link instead of the Dutch internal transmission link. This result holds whether LMP or auctions are applied.

In this paper, the focus was on the efficient allocation of access rights to existing transmission capacity and not on the efficient expansion of the current transmission network. The impact of the investment signals provided by the alternative congestion management methods in gas transmission on network expansions should be analyzed in future research.

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