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Abstract

Strategic interaction between gas and electricity sectors is a major issue in the implementation of competitive energy markets. One relevant aspect of the problem is the potential for input foreclosure between gas and power industries. In this paper, we are concerned with situations where input foreclosure opportunities are associated with the choice of market design. In particular, we study input foreclosure in the case that the short-term capacity allocation mechanism of gas networks raises barriers to cross-border trade. In that situation, one may find gas markets that are isolated only in the short term. We explain players' ability to influence the electricity price using their gas decisions in those isolated markets. We also show that this should be a concern of EU capacity allocation mechanisms, which provide spatial flexibility in the short term to promote liquidity, at the cost of creating barriers to cross-border trade. Therefore, input foreclosure opportunities are additional costs to be taken into account when weighing benefits and drawbacks of European gas market designs.

Keywords

Market design; Input foreclosure; Gas-power interaction; Network economics.

1. Introduction*

The integration of gas and electricity companies has attracted significant attention in the last decade. This convergence encompasses a variety of effects and it is difficult to find a unified framework to analyze the problem. The approach of this paper is based on considering that production of electricity using gas as primary fuel has become a relevant part of the demand in the gas industry. In that view, it is possible to look at part of the gas industry as an intermediate product in the supply chain of electricity. Hence, gas-electricity convergence may be viewed as a playing field for the theory of vertical integration.

As shown by Joskow (2005), there is not one unified theory of vertical integration —Barquín et al. (2006) and Padilla et al. (2006) showed the difficulty to define a unified academic position on the topic. Vertical integration encompasses different aspects of the same problem, including a number of efficiency increasing effects. In fact, a large stream of the literature is devoted to show that vertical integration has in many cases beneficial effects, see for instance Williamson (1975). Loosely, when assets are specific and, for instance, contracts are considerably incomplete and/or uncertainty is relevant, large transaction costs may justify vertical integration. From this standpoint, gas and electricity assets are in fact specific, contracts are incomplete and uncertainty is relevant. Thus, one will likely find cases where vertical integration between gas and electricity companies responds to industry needs.

On the other hand, vertical integration may also allow the existence of opportunities to raise prices anti-competitively. In particular, vertical integration may be used to harm competition in the case of input foreclosure, Ordover et al. (1990) or Hart and Tirole (1990). It describes a situation where the vertical firm can increase his rivals' costs by manipulating the prices in the upstream market and therefore can benefit from higher prices in the downstream market. When applied to gas-electricity integration, this would in theory allow a vertically-integrated firm to exercise increased market power in electricity if it controls somehow the gas market. Hunger (2003) analyzed the problem in the context of gas-power mergers in the US. He shows that gas producers may raise rivals' costs in the power market by raising gas contract prices.

In practice, when trade can happen both at the long-term markets and at the short-term markets, the rules of exchange may have an important impact on market results. In particular, we show that analyzing only long-term transactions does not give a complete description of the problem. A first effect of this is studied in Vazquez and Barquín (2007), which describes a situation

*The authors are grateful to Carlos Vazquez and Ana Berzosa for fruitful discussions.

where large players may benefit from avoiding to sell or buy at the short term, thus draining liquidity from the spot market. Under this strategy, any small deviation or imbalance can be managed internally by the large players. But these imbalances are highly penalized for the smaller ones, as they cannot find counter-part for trading in the short-term market.

In this paper, we show that short-term network allocation may be an additional source of opportunities for strategic behavior. The idea behind this is that the design of gas markets implies the definition of a mechanism to allocate network capacity, and such mechanism needs to deal with the trade-off efficiency/liquidity, **?**. This trade-off comes from the fact that market arrangements in gas industries have to deal with the strong specificity of gas networks, which in turn is the source of significant transaction costs, Williamson (1975), Williamson (1983) and Williamson (1985). In that view, market designs have faced the trade-off between maintaining gas network specificity (and hence obtaining efficient network allocation) and reducing specificity by defining simplified common standards for products (at the cost reducing efficiency). These simplified standards would be less specific and hence easier to trade in markets —see Riordan and Williamson (1985) for a general treatment of this problem.

So the implementation of market arrangements in gas industries is faced with a trade-off "efficiency versus transaction costs". In this paper, we do not aim at giving general recommendations to decide on this trade-off, but at identifying additional costs of reducing transaction costs by simplifying network services. These additional costs are associated with increased opportunities for input foreclosure in the short run. We show in this paper that, even if long-term gas markets are relatively competitive, market designers should be concerned with market power opportunities in the short run. Put it differently, even if the market for producers and suppliers (a long-term market) is competitive enough, inefficient network allocation may result in isolated short-term markets where gas suppliers may be highly concentrated, and hence in strong cases for input foreclosure.

However, assessing generally the potential for those isolated markets to appear is significantly complex in gas markets, as there is no unified design for network allocation mechanisms. The US market is based on long-term pipeline contracting, complemented with considerably liquid secondary capacity trading. In the Victoria gas market, trading was implemented through implicit auctions based on gas prices. The EU relies as well on secondary network capacity trading. In that view, the rules governing such secondary trading are central in the analysis of potential opportunities to foreclose the market. Both the US and the Australia mechanisms are based on highly efficient mechanisms to allocate capacity. In the EU, capacity allocation mechanisms create trading zones in order to increase liquidity within those zones.

This in turn creates barriers to cross-zone trading in the short run. National short-term markets may be isolated from the rest of European markets, and thus the potential for input foreclosure may be relevant. In that view, the opportunities to foreclose the market are motivated by the capacity allocation mechanism, and hence will be softened if it were substituted for a more efficient mechanism.

We will adopt a model-based approach to explain the impact of the vertical effects. Our model will be aimed at explaining the effects of vertical integration when there are opportunities to foreclose the short-term market. With that formalization, we will then discuss whether regulation facilitates the existence of such effects. This in turn allows us to identify additional costs of European network regulation[1]. If one sees vertical integration as a compromise between efficiency-increasing effects and increased opportunities to behave strategically, network regulations that allocate network capacity more efficiently would reduce the opportunities for strategic interaction.

We begin in section 2 by describing the interaction between gas and electricity markets that we consider in this paper. In section 2.1, we develop a model to study the vertical effects between the downstream gas market and the power market. Section 4 analyzes the model and obtains general factors to characterize input foreclosure situations. Section 5 provides policy implications of the previous results. Finally, section 6 collects our conclusion. Formalization details are developed in the Appendix.

2. The interaction between European gas and electricity markets

In the setting we will be considering in this paper, there is a long-term gas international market —with time frames of about 10 or 20— where all players in a certain market can attend to buy their gas supplies. There is also a short-term gas market —with horizons from several hours to several months— where market participants buy and sell gas to manage deviations from their expected plans. Both markets require purchasing the associated transmission rights. Such market for transmission rights is critical to analyze the opportunities for input foreclosure.

Actually, one needs to differentiate between long-term markets for transmission and secondary trading of transmission rights. The logic for this is that the liquidity of each market might be quite different, and lack of liquidity in markets for transmission rights may create barriers to trade the gas commodity. If there are barriers to trade transmission rights, it is sensible to

[1]EU network regulation is based on entry/exit zones where shippers need to balance injections and withdrawals only on a daily basis.

expect the existence of regional markets. In those regional markets, the gas market structure would tend to be horizontally concentrated and thus the opportunities for input foreclosure would increase.

The strategy we pursue in this paper is to characterize first a game where those barriers to trade transmission in the short run exist. With the game characterization, we will be able to study formally the opportunities for input-foreclosure strategies. Furthermore, we will identify the key parameters that determine the potential for input foreclosure. By the analysis of that game, thus, we will study whether or not one finds those barriers to trade, which will be the aim of section 4.

We consider thus the market as made up of three consecutive stages. First, all agents go to the long-term gas market to purchase their basic gas contracts. We assume that they are all small compared with the size of the market, so they act as pure price-takers, even if there are other players in that market that are acting strategically —relaxing this assumption adds the effects studied in Hunger (2003). Therefore, from the strategic interaction point of view, this stage will be irrelevant for us; we will just reflect it through an long-term gas price that we will take as constant for the following stages.

Second, the short-term gas market takes place. All gas end-consumers buy their energy in this market, and there is a price-elasticity associated with them. Typically, the price in this market results to be higher than the long-term price. Besides, gas-fired power plants buy their opportunity gas in this market. We will assume that this opportunity gas is sold at the same price that resulted from the national gas market. The price will never be lower than that, since otherwise arbitrageurs could sell all their long-term-contracted gas in the end-user gas market and buy extra gas afterwards with a profit. This would tend to level both prices and will surely erode the ability of the oligopolists to withhold gas quantity. Therefore the extra gas will be sold at least at the short-term gas price. It could be more expensive than that, since the constraint on the opportunity gas purchases to be positive limits the possibility of arbitrage here. In practice, it is likely that it will be approximately the retail gas price plus some mark-up, depending on the willingness to pay of the buyers and other characteristics of this market. Although we have not modeled explicitly this effect, including it would result in additional opportunities to behave strategically. Suppliers in this short-term market have to decide how much they would sell at this stage, considering that they may want to reserve some gas for electricity production at the following stage. The needs of gas contracted in advance for electricity production are uncertain. In addition, we assume that suppliers in the short-term market are concentrated enough to manipulate the price. This assumption is made in order to formalize the idea that regional markets may exist only in the short run. We will model this by assuming that suppliers play Cournot strategies in this market.

Third, the electricity market takes place. Each gas-fired generator may use the remaining part of his contracted gas with no additional cost. However, since gas purchases are made many years in advance from the actual electricity market, uncertainty is high and additional amounts of gas may be required. The short-term gas market is not liquid enough, so electricity producers have to buy this extra gas to the few firms that do trade in the short run.

2.1. Formalization of the game

Most of the models concerned with strategic behavior in gas markets focus on the relationship between the upstream and downstream of gas markets, assuming that some of their players are oligopolists. To our knowledge, the first work modeling market power in gas markets is Mathisien et al. (1987). In Mulder and Zwart (2005) the gas market is represented by means of a small number of strategic gas producers, and price-taking gas traders in the downstream market. Boots et al. (2004) model the gas market as a sequence of oligopolistic markets in gas production (upstream) and trading (downstream). Holtz et al. (2008) model the same structure of the market, but relax some assumptions of Boots et al. (2004), such as the approach of modeling the domestic production as an exogenous variable.

The aim of our study, on the other hand, is to analyze the interaction between the gas and the electricity market in the short run. In that view, a relevant part of that interaction takes place between the downstream gas market and the electricity market. So in our model, we represent a sequence of an oligopolistic gas market (the short-term market) and an oligopolistic power market. We thus implicitly assume a competitive upstream gas market. In doing so, our modeling strategy will be close to Barquín (2006) and Crampes and Hernandez-Alva (2007).

Summing up, we will describe the interaction between electricity and gas markets as a two-stage game, where the electricity market players decide their output in the electricity market once the gas market has cleared. We model the two markets as non-cooperative games in quantities.

To set up the game, we first define the profit-maximization problem of each firm. The problem we will describe in this section builds on a market made up of N firms with positions both in the gas and in the electricity markets. The time-uncertainty setting is defined by two periods (date 0 and date 1), and S states of nature at date 1. It represents a situation where the gas market takes place at date 0 subject to an uncertain power market at date 1. The possible states at date 1 will be denoted by $s = 1, \ldots, S$.

In addition, player $i \in N$ has a preference ordering on the revenues set $R^i = R^i_0, \ldots, R^i_S$, and we will assume that the ordering can be expressed by a utility function:

$$U^i : \Re^{S+1} \to \Re$$

This utility function, thus, defines the producers' preferences for each state of nature, and it is assumed transitive, convex and complete.

Gas market decisions are defined by the maximization of the income in the short-term market, $\pi^g V^i$, where π^g is the price of the gas market and V^i is the firm i's sales in the gas market. In addition, all firms must purchase their gas sales from a certain gas producer. This step is not represented in the model, and we assume all the trades have been made before short-term decisions take place. It is summarized by the variable A^i, which represents the gas purchases of firm $i \in N$. Hence, firm i buys the amount A^i in advance both for selling in the gas market and for producing electricity. The price of the gas supplies bought in advance through long-term contracts is denoted by p^g.

In the power market stage, π^p_s is the price of the electricity market at state s and c^i_s is the firm i's variable cost of her non-gas-fired power plants. $q^{N,i}_s$ is the firm i's output of her non-gas-fired power plants. $q^{G,i}_s$ is the firm i's gas purchases in the gas markets to produce with of her gas-fired power plants. $q^{C,i}_s$ is the firm i's part of her gas purchases dedicated to production with of her gas-fired power plants.

The revenue stream in the power market at state s is thus defined by

$$R^i_s = (\pi^p_s - c^i_s)q^{N,i}_s + (\pi^p_s - \pi^g)q^{G,i}_s + (\pi^p_s - p^g)q^{C,i}_s$$

and the share of the total purchases that will be used in each market is decided on in the optimization of the firm's profits fulfilling

$$V^i \le A^i - q^{C,i}_s$$

The profit-maximization problem of market players can be represented by the following program:

$$\begin{aligned}
\max_{R,V,q^N,q^G,q^C} \; & \left\{(\pi^g - p^g)V^i + U(R^i_s)\right\} \\
\text{s.t.} \quad & R^i_s = (\pi^p_s - c^i_s)q^{N,i}_s + (\pi^p_s - \pi^g)q^{G,i}_s + (\pi^p_s - p^g)q^{C,i}_s && : \mu^i_s \\
& q^{N,i}_s \le q^{N,i}_{max} && : \mu^{N,i}_s \\
& V^i \le A^i - q^{C,i}_s && : \mu^{gas,i}_s \\
& 0 \le q^{G,i}_s && : \mu^{min,i}_s
\end{aligned} \tag{1}$$

In addition, we consider the inverse demand curves both the short-term gas market and the power market:

$$\pi_s^p = \pi_0^p - \alpha_s^p \sum_i (q_s^{N,i} + q_s^{G,i} + q_s^{C,i}) \qquad (2)$$

for the power market and

$$\pi^g = \pi_0^g - \alpha^g \sum_i V^i \qquad (3)$$

for the gas market.

3. Incentives for cross-industry input foreclosure

Gas-fired generators often purchase much of their gas supplies in the long-term gas market. We assume that this market is liquid enough, so no firm in the demand side has the ability to manipulate it. In that view, none of the companies operating in the short-term gas market, selling gas to the end customers, would have any influence on the price that the electricity producers pay for their long-term gas, and both segments of the demand (end users and power producers) would become in practice two completely separated markets. Considering the market for long-term supplies alone, vertical integration provides no additional opportunity to exercise market power, since the electricity price is independent from the price in the short- gas market that gas oligopolists control.

In that situation, we find that:

Result 1 (No cross-industry input foreclosure). *Given that player's behavior is described by problem (1), if no firm is producing with opportunity gas, there are no opportunities of input foreclosure.*

The equilibrium gas price is given by the Cournot pricing condition for the short-term gas market:

$$\pi^g = p^g + \alpha^g V^i \qquad (4)$$

This result is derived in the Appendix.

However, gas-fired power plants usually need to buy some extra gas in the short-term gas market in order to compensate for deviations from their expected plans. And this opportunity gas (short-term gas) needs to be bought in the market that oligopolists control. This is a potential case for input foreclosure. In that view, the simplest situation of input foreclosure would describe a gas monopolist that also owns a power company. A raise in the price of gas automatically implies a raise in the cost of fuel for the combined cycle generators and, depending on the load curve, a raise in the electricity price of some hours. The monopolist benefits from three factors: a higher price for the gas it sells directly to customers —in balance with a loss of income derived from a reduction in consumption; a higher price for the gas it sells for power generation —in balance with a reduction in the production of the gas-fired units as they become more expensive; and a higher price for the rest of the electricity it is producing. The first two terms are the same ones that any equivalent monopolist faces when competing against demand elasticity, but the third one is a direct consequence of vertical integration, and it is providing extra benefits when the gas price is raised. This means that there is an additional incentive for the firm to raise gas prices. In other words, the quantity that is affected by an increase in gas prices is not just the amount of gas sales —as it happens in the problem of the gas monopolist. It is related to his electricity sales, especially those coming from non-gas-fired generators. This represents a worsening effect on the market abuse conditions that arises when the gas monopolist integrates with an electricity firm.

However, short-term gas markets do not correspond to the relatively simple setting above. In our setting, the previous example is a particular case of it, so it reflects the factors that explain the interdependence between the gas price and the electricity price. In particular, we can derive from the model the following result:

Result 2 (Cross-industry input foreclosure)**.** *Given that player's behavior is described by problem (1), if K firms including firm i are buying opportunity gas in the short-term market, firm i has two additional incentives: a) the loss of profits associated with the higher gas price for her own gas-fired power plants and b) the increase of profits associated with the increase in infra-marginal rents.*

The equilibrium contains the following pricing condition for the short-term gas market:

$$\begin{aligned}\pi^g - p^g =& \alpha^g (V^i - E^{i,*}[q^{G,i}]) + \\ & \alpha^g E^{i,*}\left[\left(\frac{K}{N+1}(q^{N,i} + q^{G,i} + q^{C,i})\right)\right] - \\ & \sum_s \mu_s^{gas,i}\end{aligned} \tag{5}$$

This result is also derived in the Appendix.

As shown in the Appendix, $E^{i,*}$ represents the risk-neutral expectation of player i for the power market. In addition, the Lagrange multiplier $\mu_s^{gas,i}$ represents the trade-off between increasing marginally V^i (supplying one megawatt more to the short-term gas market) and using the contracted gas to produce electricity. Hence, when firms are deciding on short-term sales in the gas market, they take account of the opportunity costs of selling in the future power market. That opportunity cost is given by (see the Appendix for the details of the derivation):

$$\sum_s \mu_s^{gas,i} = E^{i,*}[\pi^p - \alpha^p(q^{N,i} + q^{G,i} + q^{C,i})] - p^g$$

which is the risk neutral expectation of marginal profits in the power market associated with using contracted gas to produce electricity. Note that if there is spare long-term gas in all states of nature, $\sum_s \mu_s^{gas,i} = 0$ and the expression reduces to the (risk-affected) Cournot pricing equation of the power market, using the long-term gas price as the cost for firing the power plant.

By analogy with the first result, we observe two additional terms, which represents the effects of vertical integration. In particular:

- The term $\alpha^g E^{i,*}[q^{G,i}]$ describes player i's valuation of the possibility of using opportunity gas in the future power market. And this player's valuation is the risk-neutral expectation of future consumption of opportunity gas.
- The term $\alpha^g E^{i,*}\left[\left(\frac{K}{N+1}(q^{N,i} + q^{G,i} + q^{C,i})\right)\right]$ describes how changes in the oligopolistic behavior in the electricity market affect the agent's profit. It represents the increase in profits due to the increase in power prices associated with raising rivals' fuel costs. As shown in the Appendix, $\frac{K_s}{N+1}\alpha^g$ describes the increase in power prices in state s when gas sales decreases marginally, i.e. the ability of firm i to raise the power price through decisions in the gas market. Firm i's electricity production $q^{N,i}+q^{G,i}+q^{C,i}$ represents the incentives of the power price.

This last term is the increased market power due to the fact that raising the price of the gas market affects the electricity market. The value of this latter term depends on the value of K, i.e. the number of firms producing with opportunity gas, which is uncertain when deciding in the gas market. If all the generating firms are using this gas K and input foreclosure is maximized. The more opportunity gas consumers, the more additional market power for the firm i.

Consequently, the oligopolistic effects described by (*Result 2*) is threefold. On the one hand it represents the usual horizontal effect of the market power, that is, withholding gas output forces the gas price to raise. On the other hand, it shows one of the effects of vertical integration: when the firm raise the gas price, the marginal cost of its electricity production is risen as well. This would tend to lower gas prices. And finally, the ability of gas suppliers to affect the behavior of other players in the electricity market and to benefit from it.

4. Network allocation mechanisms and transmission services flexibility

The key parameter to define input-foreclosure effects is the amount of firms buying opportunity gas in the short-term market, defined by K. These power producers have to choose between limiting themselves severely to the gas the have bought in the long term, or buying to some of the firms controlling the short-term gas market (and thus creating the incentives for input foreclosure). Hence, the additional potential for input foreclosure that we had identified is based on the idea that a part of the gas for these combined cycles has to be bought in a small market controlled by incumbents. This creates a local oligopoly for these sales that results in the conflictive incentives.

We will next analyze the different schemes to implement mechanisms to allocate network resources, in order to identify the determinants of the creation of such local oligopolies. In that view, gas market liberalization has been implemented in significantly different ways, and most of those differences can be traced to the different mechanisms designed to allocate network services. Gas networks operation is characterized by tight technical constraints, and hence the contracting architecture required to implement the commodity delivery at different points of the network must be complex. This is the source of significant transaction costs. In particular, dealing with spatial specificity has motivated a wide range of design solutions, Vazquez et al. (2012).

In that view, it is possible to reduce the specificity of each feasible trade by simplifying its spatial characteristics. By doing so, the difficulties to trade are reduced and the number of market players trading the same product increases. That simplification strategy, on the other hand, implies that several network services will be allocated equally among all network users regardless their preferences. This in turn creates inefficiencies that may result in barriers to cross-border trade.

4.1. Spatial flexibility and capacity allocation

The less simplified mechanism to allocate network resources is a point-to-point gas transmission arrangement. In it, a large part of the spatial characteristics of the trade is defined in the agreement. Hence, point-to-point transmission is relatively difficult to trade. This is the typical scheme followed in the US and Australian gas markets. Both systems are supposed to allocate most of the spatial characteristics of the network using market-based mechanisms, although both systems differ in several fundamental features. The US system is based on long-term bilateral agreements between pipeline operators and network users, complemented with liquid short-term trading of capacity, Makholm (2012). The Australian system, on the other hand, uses an implicit mechanism to allocate capacity in the short run. The mechanisms can be viewed as a combinatorial auction where network capacity is allocated implicitly according to gas prices, Ruff (2012). Under sufficiently liquid secondary trading and absence of transaction costs, it is possible to consider that both schemes are equivalent in terms of short-term efficiency[2], as they both consider the spatial characteristics of the network.

The EU design may be viewed as a third way that aims to combine the characteristics of the two schemes. It is characterized by a combination of explicit and implicit allocation of gas transmission services, Vazquez et al. (2012). Such combination is built on the explicit allocation of only some of transmission services. The allocation mechanism is called entry/exit allocation. The idea behind it is to simplify the network topology to a simpler set of entry and exit points (a "commercial" network that represent partially the physical network). All explicit allocation is reduced to buying separately entry and exit rights. After that, shippers do not need to buy additional transmission rights (such as flexibility rights) but they are allocated implicitly according to a set of rules defined by the regulator. Such allocation mechanism is called virtual hub. With it, one avoids the explicit allocation and renegotiation of complex spatial characteristics of the network, but it comes at the cost of the creation of trading zones, which concentrates network constraints at the zone borders.

4.2. Identifying barriers to cross-border trade in European systems

Entry/exit schemes market players only reveal preferences on the right to enter and exit the gas systems. Within the system, all injections and withdrawals are considered to have the same price. From the point of view of this paper, the main characteristic is that it gives network users free spatial flexibility within the system, which in turn creates barriers to cross-border trade.

4.2.1. Capacity allocation

Entry-exit regimes may be thought of as a system where transmission constraints are moved to the borders. That is, entry-exit capacity allocation calculates the network capacity that allows shippers to trade within the zone without transmission constraints. In practice, the transmission capacity offered to market participants has to be lower than the physical limits

[2]See Hallack and Vazquez (2012) for discussion on additional effects of those two different schemes.

of the transmission system. This under-use of transmission capacity is part of the design, which bears that cost in order to promote zonal market liquidity (by giving spatial flexibility). But the entry/exit system also implies an increase of the transmission constraints in the cross-border. The capacity made commercially available at the borders has to be lower than the physical capacity of interconnection. Hence, the within-zone network flexibility entails a barrier for cross-border trade.

Consider for instance an injection at a certain entry point A. Giving the right to the shipper of trading everywhere within the zone containing A implies that the capacity sold at A is lower than the physical capacity. Consider the same situation in a different zone with an entry point B. If a trader were willing to enter through point A, but to sell in the zone of point B, the trader would be facing a reduction of capacity twice. That is, the problem of underused capacity is faced twice with cross-border trade between two entry/exit zones: a first one when injecting at A and a second one when injecting at B. This represents a barrier to cross-border trade.

4.2.2. Network tariffs

In entry/exit systems, the costs of the network cannot be allocated according to the actual use of the network, because the prices for entry and exit points on the commercial network do not represent the costs generated by the physical gas flows that they generate. Consequently, one always finds cross-subsidies among shippers, which are caused by the spatial flexibility given inside the trading zone. In that view, tariffs are not cost-reflective, but that may be a bearable cost when compared to the increase of within-zone liquidity.

However entry/exit systems create tariff distortions that are especially relevant when crossing zones. This often results in higher costs for a cross-zone trade. Actually, network users are charged several entry and exit charges in multiple zones, which may result in 'pancaking', meaning that multiple tariffs are added on a single transaction. Put it differently, spatial flexibility is given to shippers at the entry to all zones. And the network tariffs paid at each entry cannot be cost-reflective, often resulting in cross-subsidies. Therefore, a shipper crossing two zones would face the difficulty twice. Thus, those non-cost-reflective tariffs increase the costs of cross-zone trade as compared to the costs of gas trade within the zone. The effects of tariff distortion increase when crossing zones, creating additional barriers to trade[3].

[3]Besides, costs associated with imbalances are also paid according to zones, so being imbalanced in a trade within a zone requires the payment of one charge. The same imbalance in a cross-zone trade means the payment of two charges.

5. Implications: Effects of different designs of network services

Summing up, we have identified additional potential for short-term input foreclosure with local oligopolies that exist only in the short run. Besides, we have showed that markets designs providing spatial flexibility to shippers facilitate the existence of those local oligopolies. In that view, the US and Australia markets rely on point-to-point transmission allocation. This in turn implies that the spatial flexibility provided by the network rules is minimal. So if the network is meshed enough, it is difficult to find situations where a certain consumption point is subject to input foreclosure. But if that consumption point is connected to the network through, for instance, a single pipeline, it is possible to find situations where a large gas supplier purchase gas in the hub and exercise market power at the isolated consumption point.

On the other hand, in the EU gas systems, market designs do provide ample spatial flexibility. Moreover, the zone where free spatial flexibility is given is limited to zone borders, which are often equivalent to national borders. That is, within a certain national system, market participants can trade gas without network constraints. This in turn implies that network constraints are moved to national borders, creating barriers to cross-border trade. Those barriers to cross-border trade represents additional potential for the existence of isolated national systems.

Put it differently, the definition of network services within zones of trade creates advantages for within-zone trading, but discourages cross-zone trading. This reinforces the incentives of players in specific zones to keep their trade within the zone. The difficulties to cross-zone trade can be softened by increasing the size of the zones (increasing the network simplification and its associated costs) or by decreasing the simplification. Usually, increasing the size of the zones is considerably difficult, as the costs of the inefficiency associated with that strategy are often thought to be prohibitively large.

In that view, assume that we could implement a more efficient (in the sense of giving less free spatial flexibility) management of the gas network, so international traders (players outside the initially isolated national market) would face the same network costs as any other player. That would allow them to make opportunity deals with the national companies without committing to very long-term agreements of network capacity. If the international traders had easy access to the national gas grid, then there would be plenty of potential sellers willing to participate in the opportunity gas market. As the supply side of the short-term market is more competitive, most of the gas of the electricity producers would be priced at values that could not be influenced by gas suppliers, thus eliminating the potential for input foreclosure. Therefore, as entry/exit capacity allocation creates barriers to cross-border trade, it facilitates the existence of local oligopolies, and local oligopolies was the source of the case for input foreclosure that we identified in the previous section. Hence, entry/exit capacity allocation increases the potential for input foreclosure.

In general, determining the relevant market in the short run is critical to assess the potential for input foreclosure. Even when long-term markets are competitive enough, lack of liquidity in short-term trading of network capacity may create opportunities for input foreclosure. Put it differently, if transmission capacity may not be available in the short run, one may find isolated oligopolies where potential for input foreclosure exists, regardless the competitiveness of the long-term markets. But, if transmission allocation mechanisms provide free spatial flexibility, these isolated zones may be motivated by the rules of network use defined in the regulation. Hence, this is an additional cost that should be taken into account when deciding on the rules of network use.

6. Conclusion

The analysis above shows that the key factor in the existence of a case for input foreclosure is the ability of a gas agent to manipulate the gas price faced by her competitors in the power market. There are essentially two cases for input foreclosure. The first one is related to a certain firm with position both in the upstream gas market and in the power market. This is the case described in Hunger (2003). The second one, described in this paper, has to do with a market structure where several firms need to purchase short-term gas supplies in a local oligopoly. In that situation, power producers have to choose between limiting themselves severely to the gas they have bought in the long run, or buying from some of the firms operating in the local short-term market.

By identifying the second type of input-foreclosure situations, we have shown that the particular design of the gas market has a critical influence on the existence of cases for input foreclosure. In particular, giving free spatial flexibility moves congestion to national borders, creating in turn barriers to trade in the short run. Thus, EU market designs, which builds on ample provision of free spatial flexibility, creates barriers to cross-border trade, and hence potential for the existence of isolated national markets where there are opportunities to foreclose the market. This is not the case of systems based on point-to-point transmission.

Therefore, if cross-border barriers are weaken, so that international traders have easy access to the national gas grid, then there will be more potential sellers willing to participate in the short-term gas market. Competition among them would limit the ability of national firms to manipulate the short-term price. Hence, electricity producers would be priced at values that could not be influenced by the national companies, eliminating the potential for input foreclosure. This is an additional cost that must be taken into account when deciding on the design of the capacity allocation mechanism.

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Appendix

A. Representation of players' behavior

In this section we characterize the opportunities of players to behave strategically. To do so, we analyze the optimality conditions of problem (1). The Lagrangean function of problem (1) is given by:

$$
\begin{aligned}
\mathcal{L} =&(\pi^g - p^g)V^i + U(R^i_s) + \\
&\mu^i_s\{R^i_s - (\pi^p_s - c^i_s)q^{N,i}_s - (\pi^p_s - \pi^g)q^{G,i}_s - (\pi^p_s - p^g)q^{C,i}_s\} + \\
&\mu^{N,i}_s\{q^{N,i}_s - q^{N,i}_{max}\} + \\
&\mu^{gas,i}_s\{V^i - A^i + q^{C,i}_s\} + \\
&\mu^{min,i}_s\{0 - q^{G,i}_s\}
\end{aligned}
$$

In addition, using the inverse demand equation (2) and (3), we have the following price derivatives:

$$\frac{\partial \pi^p_s}{\partial q^{x,i}_s} = -\alpha^g \quad and \quad \frac{\partial \pi^g}{\partial V^i} = -\alpha^g$$

where $q^{x,i}_s$ is power production with any kind of fuel.

A.1. Risk-neutral expectations

The optimality of problem 1 with respect to revenues R^i_s gives the definition of the Lagrange multipliers μ^i_s:

$$\frac{\partial U(R^i_s)}{\partial R^i_s} = \mu^i_s \tag{6}$$

As Lagrange multipliers are marginal utilities at date 0 of an additional unit of spot profits, they can be thought of as discount factors for each state of nature. No-arbitrage conditions impose that each μ^i_s are positive values. That is equivalent to the condition that the problem has a solution, see for instance Magill and Quinzi (2002).

The relationship between the previous discount factors and risk-neutral probabilities is straightforward. Consider the values $\lambda^i = \sum_{s=1}^{S} \mu^i_s$ and define the parameters $\phi^i_s = \frac{\mu^i_s}{\lambda^i}$. As each ϕ^i_s are positive values and they sum up to one, they can be thought of as probabilities. Thus, a certain value defined by $X = \sum_s \mu^i_s x_s$ can be rewritten as $X = \lambda^i \sum_s \phi^i_s x_s = \lambda^i E^N[x]$, where E^N denotes the expectation with respect to the previously defined probabilities, and λ^i can be interpreted as the discount on the riskless asset. That is, the forward price is its discounted expected payoff in the sense of artificially constructed probabilities. We will use E^* to denote discounted expectations, $E^{i,*} = \lambda^i E^N$.

A.2. Optimality with respect to gas sales in the short-term gas market (V^i)

$$\pi^g - p^g - \alpha^g V^i + \sum_s \mu_s^{gas,i} = \sum_s \mu_s^i \left(\frac{\partial \pi_s^p}{\partial V^i}(q_s^{N,i} + q_s^{G,i} + q_s^{C,i}) - \alpha^g q_s^{G,i} \right) \quad (7)$$

From the above equation, it is possible to identify a first expression of the effects of vertical integration between gas and electricity. That is, a problem where $\frac{\partial \pi_s^p}{\partial V^i} = 0$ would yield

$$\pi^g - p^g - \alpha^g (V^i - \sum_s \mu_s^i q_s^{G,i}) + \sum_s \mu_s^{gas,i} = 0$$

The Lagrange multiplier $\mu_s^{gas,i}$ represents the trade-off between increasing marginally V^i (supplying one megawatt more to the short-term gas market) and using the contracted gas to produce electricity. Hence, this equation states that the costs taken in to account when deciding on short-term sales in the gas market are made up of the price in the long-term market p^g and the opportunity costs of selling in the future power market $\sum_s \mu_s^{gas,i}$.

The incentive to raise the gas price is defined, on the one hand, by the benefits for the firm's gas sales V^i, and on the other by the additional costs of buying opportunity gas at a higher price, $q_s^{G,i}$. As the power market is subject to uncertainty, that incentive is defined by $\sum_s \mu_s^i q_s^{G,i}$, which is the player's valuation of the possibility of using opportunity gas in the future power market. This player's valuation is the risk-neutral expectation of future consumption of opportunity gas, so that

$$\pi^g - p^g - \alpha^g (V^i - E^{i,*}[q^{G,i}]) + \sum_s \mu_s^{gas,i} = 0$$

Therefore, when $\frac{\partial \pi_s^p}{\partial V^i} = 0$, market participants play Cournot strategies, taking into account the extra cost associated with the fuel used to produce electricity. In that view, the main effects of vertical integration that we are considering in this paper are represented by the term $\frac{\partial \pi_s^p}{\partial V^i}$.

A.3. Optimality with respect to the electricity production from gas contracted in advance ($q_s^{C,i}$)

$$\mu_s^i \{\pi_s^p - p^g - \alpha_s^p (q_s^{N,i} + q_s^{G,i} + q_s^{C,i})\} = \mu_s^{gas,i} \quad (8)$$

As $\mu_s^{gas,i}$ represents the opportunity costs of selling in the future power market, this condition states that an optimal amount of gas is allocated to the short-term gas market when the marginal value of gas in this market $\mu_s^{gas,i}$ is equal to the marginal value of gas in the electricity market. Summing over all states of nature, the previous condition can be rewritten as

$$E^{i,*}[\pi^p - \alpha^p(q^{N,i} + q^{G,i} + q^{C,i})] - p^g = \sum_s \mu_s^{gas,i} \tag{9}$$

That is, the expected marginal value in the power market is equal to the opportunity cost with respect to the gas market.

A.4. Optimality with respect to power production with from opportunity gas ($q_s^{G,i}$)

$$\mu_s^i\{\pi_s^p - \pi^g - \alpha_s^p(q_s^{N,i} + q_s^{G,i} + q_s^{C,i})\} = -\mu_s^{min,i} \tag{10}$$

$\mu_s^{min,i}$ measures the extra costs associated with producing using opportunity gas. Hence, this condition states that the marginal value of producing with opportunity gas in the power market equals the cost associated with it.

A.5. Optimality with respect to power production with non-gas-fired power plants ($q_s^{N,i}$)

$$\mu_s^i\{\pi_s^p - c_s^i - \alpha_s^p(q_s^{N,i} + q_s^{G,i} + q_s^{C,i})\} = \mu_s^{N,i} \tag{11}$$

For the sake of simplicity, we assume in the paper that some production with gas-fired power plants is always required, so that $\mu_s^{N,i} \neq 0$. If $\mu_s^{N,i} = 0$, the marginal cost of the power system would be c_s^i, so that and $\mu_s^{min,i} = \mu_s^i(\pi_s^g - c_s^i)$. However, to have a coherent representation of such situation, it would be necessary to add a constraint on the minimum value of production from contracted gas. The assumption has no effect on the results developed in the paper, but it is convenient for the sake of simplicity.

B. Power price sensitivity with respect to gas sales

We may identify the effects associated with vertical integration as

$$\sum_s \mu_s^i \left(\frac{\partial \pi_s^p}{\partial V^i}(q_s^{N,i} + q_s^{G,i} + q_s^{C,i}) - \alpha^g q_s^{G,i} \right)$$

That expression will be next analyzed in detail.

The price equation in the power market is given by

$$\pi_s^p = \pi_0^p - \alpha_s^p \sum_i (q_s^{N,i} + q_s^{G,i} + q_s^{C,i})$$

and the optimality condition (10) can be rewritten as

$$q_s^{N,i} + q_s^{G,i} + q_s^{C,i} = \frac{1}{\alpha_s^p}(\pi_s^p - \pi_s^g) + \frac{1}{\mu_s^i \alpha_s^p}\mu_s^{min,i} \tag{12}$$

Putting together the equations (8) and (10), it is possible to obtain

$$\mu_s^i(\pi^g - p^g) = \mu_s^{gas,i} + \mu_s^{min,i}$$

We can identify two basic cases:

- A certain state of nature s has spare long-term gas. In this case, $\mu_s^{min,i} > 0$ as the minimum production constraint of opportunity gas will be active. Besides, $\mu_s^{gas,i} = 0$ because the firm is using less gas than contracted, so the corresponding constraint will not be active. From above we have that

$$\mu_s^{min,i} = \mu_s^i(\pi^g - p^g)$$

- A certain state of nature s has spare long-term gas. This is the complementary case of the previous one. As firms are producing with opportunity gas, $\mu_s^{min,i} = 0$. On the other hand, as all contracted gas is used, $\mu_s^{gas,i} > 0$. In particular,

$$\mu_s^{gas,i} = \mu_s^i(\pi^g - p^g)$$

B.1. Price sensitivity when no firm is using opportunity gas

If the firm is not using opportunity gas, because the gas contracted in the long-term is enough to serve the gas and electricity markets, then $\mu_s^{min,i} > 0$. In those scenarios, $V^i < A^i - q_s^{C,i}$ because there will be spare gas, and thus $\mu_s^{gas,i} = 0$. Using the optimality conditions

$$q_s^{N,i} + q_s^{G,i} + q_s^{C,i} = \frac{1}{\alpha_s^p}(\pi_s^p - \pi_s^g) + \frac{1}{\alpha_s^p}\pi_s^g = \frac{1}{\alpha_s^p}\pi_s^p \tag{13}$$

As the power price equation does not depend on the gas price,

$$\frac{\partial \pi_s^p}{\partial V^i} = 0$$

B.2. Price sensitivity when firms need to use opportunity gas

If firm i is actually consuming opportunity gas at that state s, $\mu_s^{min,i} = 0$. Thus

$$\pi_s^p = \pi_0^p - \alpha_s^p \sum_i \frac{1}{\alpha_s^p}(\pi_s^p - \pi_s^g)$$

In that view, the price sensitivity will depend on the number of firms that are consuming opportunity gas. Let us use the parameter K_s to denote the number of firms purchasing gas in the short run, at state s. Thus,

$$\pi_s^p = \pi_0^p - (N\pi_s^p - K_s\pi_s^g)$$

Hence,

$$\pi_s^p = \frac{1}{N+1}\pi_0^p + \frac{K_s}{N+1}\pi_s^g \tag{14}$$

From the previous expression,

$$\frac{\partial \pi_s^p}{\partial V^i} = \frac{K_s}{N+1}\frac{\partial \pi_s^g}{\partial V^i} = \frac{K_s}{N+1}\alpha_s^g \tag{15}$$

That is, the power price reacts proportionally to the amount of firms using opportunity gas, divided by the number of firms plus one, because it takes into account also the demand reaction. Note that if no firm is using opportunity gas, $K_s = 0$ and hence $\frac{\partial \pi_s^p}{\partial V^i} = 0$.

C. Representation of input foreclosure opportunities

Combining both results we can derive (*Result 1*) and (*Result 2*). In particular, optimality condition (7) can be written as:

$$\pi^g - p^g - \alpha^g V^i + \sum_s \mu_s^{gas,i} = \sum_s \mu_s^i \left(\frac{K_s}{N+1}\alpha^g (q_s^{N,i} + q_s^{G,i} + q_s^{C,i}) - \alpha^g q_s^{G,i} \right)$$

Reordering the term and using the expression for risk-neutral expectations, we obtain (*Result 2*):

$$\begin{aligned} \pi^g - p^g =& \alpha^g (V^i - E^{i,*}[q^{G,i}]) + \\ & \alpha^g E^{i,*}\left[\left(\frac{K}{N+1}(q^{N,i} + q^{G,i} + q^{C,i}) \right) \right] - \\ & \sum_s \mu_s^{gas,i} \end{aligned}$$

When no firm is attending to the short-term gas market, both $E^{i,*}[q^{G,i}] = 0$ and $K_s = 0$. Moreover, as not buying opportunity gas means that the firm has spare contracted gas, $\sum_s \mu_s^{gas,i} = 0$. Thus, we obtain (*Result 1*):

$$\pi^g = p^g + \alpha^g V^i$$

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