Is there competition in cross-border trade of electricity? Theory and evidence from European electricity markets.

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Abstract

Spot market prices of electricity differ between European countries. This is partly due to limited physical interconnection capacity between national grids. Scarce interconnector capacity is allocated in auctions that take place before the spot market. We analyze whether the interconnector prices and the spot market prices are compatible with the predictions from a competitive benchmark. We investigate price data for the Danish-German and Dutch-German case for 2002-2006. Interconnector prices predict on average the spot market prices correctly, though with a lot of noise. The interconnector price in one direction is zero almost always. These observations are incompatible with the competitive benchmark. A theoretical prediction in line with the data is that well informed traders, e.g. large national incumbents, do not engage in cross-border trade, which would explain that interconnector data contain only little information.

Keywords: Rational expectations equilibria, electricity markets, interconnector

JEL-Classification: G14, D84, L94

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1 Introduction

A single European market for electricity is one of the major goals for the European energy policy. In its "Sector Inquiry", published in January 2007, the EU commission states:

> Well functioning energy markets that ensure secure energy supplies at competitive prices are key for achieving growth and consumer welfare in the EU. To achieve this objective the EU decided to open up Europe's gas and electricity markets to competition and to create a single European energy market. (EU, Sector Inquiry 2007, para.1)

These aims, however, are far from being reached yet: "...the objectives of the market opening have not yet been achieved."(ibid., para.2). There is no single European market for electricity: Spot market prices still differ significantly between the member countries. One reason for this is limited interconnector capacity between the national electricity grids. These scarce capacities are now usually allocated in auctions which take place before the transactions on the spot markets.

The aim of the paper is to analyze whether the prices at the interconnector auctions and the spot markets in neighboring countries in the EU are compatible with a theoretical competitive benchmark. If the spot market prices were known at the time of the interconnector auction, the competitive outcome would be that the interconnector price just equals the spot market price difference, and the price for capacity in the opposite direction (i.e. towards the lower spot price) would always be zero. However, interconnector auctions take place before the spot markets. Hence, there is still significant uncertainty about the price differential when submitting bids in the interconnector auction. Thus, we use as a benchmark the definition of rational expectation equilibrium under asymmetric information by Grossman (1981).

We compare this to the observations for 2002-2006 for the Danish–German and the Dutch–German interconnector and the respective spot markets for hourly, day-ahead contracts. The first market is one in which, on average, electricity prices are very similar; in the second market, this is not the case: spot market prices in the Netherlands are on average significantly higher than in Germany. The time 2002-2006 covers almost the whole history of interconnector auctions at these borders. The data reveal that interconnector prices predict the spot market price differentials on average quite well, but with a high degree of noise.

We calibrate our theoretical model to find out (i) whether there is significant "interim" information, arriving between the interconnector auction and the spot market auction, which might explain the noise, and (ii) whether all information about the spot market prices, which are available at the time of the interconnector auction, are contained in the interconnector prices (as it should be in the competitive benchmark).

Our main finding is that the data strongly reject the hypothesis of the competitive benchmark. They exhibit three stylized facts: First, interconnector prices predict the price difference of spot prices on average correctly. Second, there is a lot of noise. Third, the interconnector price in one direction is very close to zero almost always. Without interim information, the theoretical benchmark predicts that all information should be contained in the interconnector prices, which would then perfectly predict the spot price differences. If there was a lot of interim information, theory would predict a lot of noise. However, the noise attaches an option value to the interconnector capacity into the direction where the expected spot market price is lower. Thus, interconnector prices should always be positive in both directions.

We make this argument precise by calibrating our theoretical model. This calibration exercise reveals (i) that there is virtually no interim information (which reflects that the price in the “opposite” direction is approximately zero), and (ii) that only about 20% of the information is contained in the interconnector prices (which reflects the noise).

The only theoretical prediction in line with the data is that traders with a lot of information abstain from taking part in the interconnector auction. However, such traders would (at least on average) forego a profit they could realize by using her information.

One plausible, though speculative, motivation for this would be the following. Large electricity producers in each country abstain (e.g. in form of tacit collusion) from engaging in large scale cross border trade in order to limit competition in the respective home markets. Large producers typically have a lot of information, which would be in line with the observation that interconnector prices contain little information. Pure traders without own production capacities are not able to exploit the unused profit opportunities due to a lack of information.

Due to its high policy relevance, electricity interconnectors have drawn a lot of attention in the applied literature. An introduction to "interconnector economics" can be found in Turvey (2006), or, more generally, in Crampes and Laffont (2001). Hobbs, Rijkers, and Boots (2005) and Höffler and Wittmann (2007) discuss the effects of different institutional designs for the interconnector auctions on the market outcome. A related, but clearly distinct, strand of literature discusses the use of implicit auction ("market coupling") instead of the format used in the auctions investigated in our paper. This literature is based on the theory of nodal pricing (Schweppe, Caramanis, Tabors, and Bohn (1988), Hogan (1992)). Olsen, Amundsen, and Donslund (2006)) investigate the Danish electricity market, and the interaction with adjacent markets, with a focus on the execution of market power which might explain price levels and volatility of prices. None of these approaches directly tackles the question how to explain the relation between spot market prices and interconnector prices, which is the main contribution of our paper.

The remainder of the paper is organized as follows. In section two we describe in more details the institutional set up of the cross-border electricity trade. Section 3 contains the theoretical model and its predictions. Section 4 presents the data and derives the main stylized facts. Section 5 introduces the methodology for the calibration of the model and in section 6 we provide the results of the calibrated model. The findings are discussed in section 7. Section 8 concludes.

2 European Electricity Markets

In Europe, wholesale electricity markets are still largely national markets. There exists an electricity exchange in almost all countries. However, the spot market prices differ considerably, up to more than 100 percent. Figure 1 shows the results of an investigation by the European Commission on this issue.[1]

This illustrates that so far the EU has not achieved its aim to establish a unified European market for electricity. With establishing a geographically large market, the European Union has high ambitions. Since electricity can be transported at the high voltage level at very low cost, there could be trans-regional or trans-national electricity markets. A geographically large market, based on imports and exports of electricity, could increase the level of competition and increase efficiency by supplying electricity by the least-cost producer.

Electricity should, as far as possible, flow between Member

[1] Communication from the EU Commission to the Council and the EU Parliament. Report on progress in creating the internal gas and electricity market, COM (2005) 568 final (15/11/2005), p.5. Similar findings are in the "Sector Inquiry" of 2007, Part 2, p. 180 (European Commission (2007)).

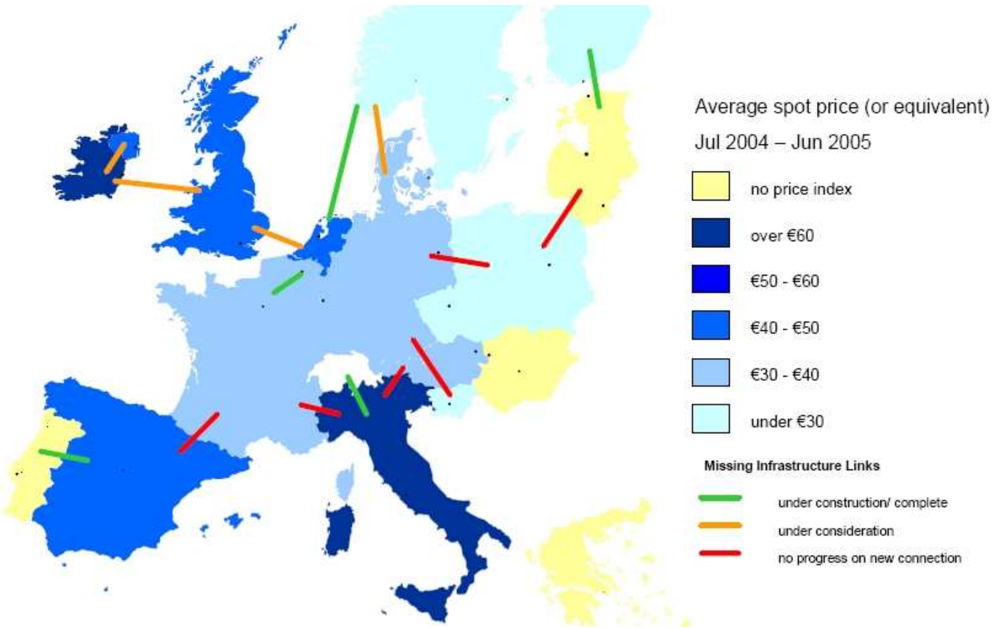

Figure 1: Differences in European Electricity Spot Market Prices

States as easily as it currently flows within Member States. Improved cross border flows will increase the scope for real competition which will drive economic efficiency in the sector... (European Commission, 2004, 3)

An important reason for the fragmentation of the European electricity market are limited interconnector capacities. In its "Sector Inquiry", the EU Commission finds that "In electricity, integration is hampered by insufficient interconnector capacity"(European Commission, 2007, para.23). While there are – usually – no bottlenecks within national electricity grids, there exist only limited capacities for the exchange of electricity between national grids. This is due to historical reasons: "Transmission networks were not developed in order to support efficient trade", but rather to optimize intra-country operations (CEER, 2003, par. 8). With the liberalization of national electricity markets, increasing interest in the international trade of electricity has turned cross-border transmission capacities into a bottleneck. At most interconnectors, the scarce capacities are now allocated in auctions.[2]

Although limited interconnector capacities set an upper bound for trading volumes between countries, an important question is, whether differences in prices between national electricity markets, and therefore limited cross-country competition, is only due to congestion. The availability of interconnector pricing data and of spot market prices allows us to investigate this question. We focus on two interconnectors and the interaction between the spot markets: (i) Denmark (West) and Germany, with the spot markets "Nord Pool West" and "EEX", and (ii) Netherlands and Germany, with the spot markets "APX" and "EEX". Figure 1 illustrates that these two examples captures the main interesting cases, i.e. the comparison of markets with–on average–similar spot prices (Denmark and Germany) and markets with–on average–different price levels (Netherlands and Germany).

Our analysis focuses on (physical) hourly contracts in which a bidder has to specify day ahead a demand / supply function for electricity of a particular hour. Thus, there are essentially 24 markets per day. Bids have to be continuous. Delivery of successful bids is on the high voltage level on a virtual trading point. This implies that for trades on the electricity exchange, no transportation cost within a country have to be incurred (any

[2]The scarcity of capacity is also due to inefficiencies in the allocation mechanism. There is clear evidence that even heavily "congested" interconnectors are rarely used up to physical capacity. For this and alternative allocation mechanisms see Höffler and Wittmann (2007).

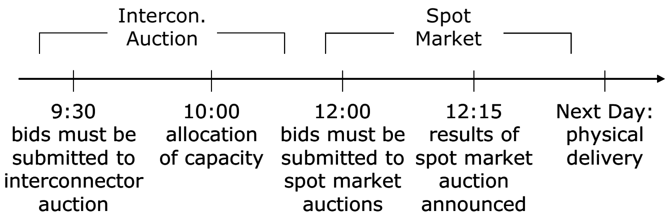

Figure 2: Timing of interconnector auction and spot market

transportation cost towards the customer on lower voltage levels has to be borne by downstream companies). The underlying assumption is that there are no bottlenecks within a national grid.

At the Danish-German interconnector and at the Dutch-German interconnector there are day-ahead auctions for hourly contracts, i.e. for the right to transport 1 Mega Watt for a specific hour the next day. Holding such a transmission right is compulsory if one wants to engage in cross-border sales on the electricity exchange; if a Danish power producer wants to offer electricity on the German EEX, it has to hold sufficient transmission rights to be able to fulfill a successful bid.

Therefore, the interconnector auction takes place first, afterwards firms get informed about the auction outcome, and on that basis might submit bids in the adjacent market's spot market. Figure 2 shows the timing of the actions. Note that there is only a time frame of 2.5 hours between the submission of the bids for the two auctions. Thus, differences in information between the two auctions must be due to interim information arriving exactly between 9:30 a.m. and 12.00 a.m.

There is certainly no aggregate uncertainty regarding the spot market prices, since all traders jointly determine the spot market prices. Any random events (e.g. like actual weather conditions, unexpected power plant outages etc.) have to be handled after the spot market has closed, on the day of delivery. This is done by the electricity system operator when actual dispatching, i.e. calling power plants to produce electricity, in real time. Unforeseen demand or supply shocks are handled by the system operator with the help "system service", that is, balancing energy. In some national markets there are also organized exchanges for balancing energy.

3 The Model

We consider the following model: There are to countries home and abroad denoted by $C \in \{H, A\}$ that both have an electricity spot market. There are I firms indexed by $i \in \{1, \ldots, I\}$, each of which can but does not have to be active in both markets. Being active means that firm i has either customers or generation capacity or both in a country. Net demand d_i^C of each firm i in each country C depends on the spot market price p^C and a state of the world s:

$$d_i^C = d_i^C(p^C, s); \tag{1}$$

Note that the net demand function can take on any real number, where a negative number indicates that a firm wants to supply rather than demand electricity at a given spot market price. We assume that

$$\frac{\partial d_i^C(p^C, s)}{\partial p^C} < 0. \tag{2}$$

The only connection between the two markets is the interconnector with maximum net capacity $\bar{K}$ in either direction. We denote the actual use of the interconnector by $K \in [-\bar{K}, \bar{K}]$ where a positive K indicates that electricity flows from H to A.

With these definitions in place we can characterize the Walrasian equilibrium in the two markets:

Proposition 1 *There is a unique equilibrium such that*

$$\begin{aligned} 0 &= \sum_{i=1}^{I} d_i^H(p_H^*, s) - K, \\ 0 &= \sum_{i=1}^{I} d_i^A(p_A^*, s) - K, \end{aligned}$$

and either

$$\begin{aligned} p_A^* &> p_H^* \text{ and } K = \overline{K}, \text{ or} \\ p_A^* &= p_H^* \text{ and } K \in \left(-\overline{K}, \overline{K}\right), \text{ or} \\ p_A^* &< p_H^* \text{ and } K = -\overline{K}. \end{aligned}$$

In equilibrium electricity always flows from the low price country to the high price country. If the difference in net demands is small the interconnector capacity is enough to equate prices and we get an interior solution.

If the difference is larger the interconnector is used at maximum capacity and a price differential remains.

Now let us consider the market for interconnector capacity. We assume the following timing: At time two the electricity spot market takes place, at time one the market for interconnector auctions opens and at time zero, each firm obtains information about s. We formalize the information structure as follows. Let

$$\mathbf{s}_t = (s_1, s_2, \ldots, s_I) \tag{3}$$

be the vector of all traders' information. We assume that

$$E_0(p^{C*}|\mathbf{s}) = p^{C*}, \tag{4}$$

that is there is no uncertainty if a traders has all pieces of information he knows the outcome of the spot market for sure.

We can now use the concept of a rational expectations equilibrium under asymmetric information introduced by Grossman (1981) to characterize the equilibrium on the market for interconnector capacity. An equilibrium consists of two connection fees f_{AH} for transfer from abroad to the home country and f_{HA} for capacity in the other direction and of two traded capacities k_{AH} and k_{HA}. We obtain the following result:

Proposition 2 *If firms $1, ..., I$ participate in the market for interconnector capacity, the equilibrium fees are:*

$$\begin{aligned} f_{HA} &= \max\{p^A - p^H, 0\} \\ f_{AH} &= \max\{p^H - p^A, 0\} \end{aligned}$$

and the capacities are

$$\begin{aligned} k_{HA} &= \begin{cases} = \overline{K} & \text{if} \quad f_{HA} > 0, \\ \in [0, \overline{K}] & \text{if} \quad f_{HA} = 0. \end{cases} \\ k_{AH} &= \begin{cases} = \overline{K} & \text{if} \quad f_{AH} > 0, \\ \in [0, \overline{K}] & \text{if} \quad f_{AH} = 0. \end{cases} \end{aligned}$$

Intuitively that means that the interconnector equilibrium price aggregates all the information the participating traders have. In equilibrium only one of the directions can be profitable and has a positive price, the other price must be zero. The interconnector price should predict the price differential perfectly, there should be no noise .

3.1 Additional Information Between Time One and Time Two

So far, we have assumed that no new information arrives between times one and two. In this section we consider the possibility that new information arrives. To do so we extend the information vector by s_p that denotes public information that arrives between time one and two. Note that we consider only public information for simplicity only, private information would be aggregated into the price and would have the exactly the same effect.

Formally,

$$\mathbf{s}_t = (s_1, s_2, \ldots, s_I, s_p) \tag{5}$$

be the vector of all traders information. We assume that

$$E(p^{C*}|\mathbf{s}) = p^{C*}, \tag{6}$$

Along the lines of Proposition 2, we can prove the following result:

Proposition 3 *If firms* $1, ..., I$ *participate in the market for interconnector capacity, the equilibrium fees are:*

$$\begin{aligned} f_{HA} &= E\left[\max\{p^A - p^H, 0\}|s_1, ..., s_I\right], \\ f_{AH} &= E\left[\max\{p^H - p^A, 0\}|s_1, ..., s_I\right]. \end{aligned}$$

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The main difference to Proposition 2 is that the smaller of the two interconnector fees is not necessarily zero. Intuitively, there is now an option value associated with interconnector capacity. Even if at time one the expectation is that the price abroad will be higher than at home, there may be a possibility that between times one and two new information arrives that inverts the price differential. If a trader has bought capacity to import electricity from abroad at time one, he can now use it and it will be profitable.

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Formally,

$$\mathbf{s}_t = (s_1, s_2, \ldots, s_I, s_p) \tag{7}$$

be the vector of all traders information. We assume that

$$E(p^{C*}|\mathbf{s}) = p^{C*}, \tag{8}$$

Along the lines of Proposition 2, we can prove the following result:

Proposition 4 *If firms* $1, ..., \widehat{I}$ *participate in the market for interconnector capacity, the equilibrium fees are:*

$$\begin{aligned} f_{HA} &= E\left[p^A - p^H \left| s_1, ..., s_{\widehat{I}}, p^A - p^H > 0\right.\right], \\ f_{AH} &= E\left[p^H - p^A \left| s_1, ..., s_{\widehat{I}}, p^H - p^A > 0\right.\right]. \end{aligned}$$

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	Denmark (West)	Mean	Standard Deviation	Min	Max
Spot Market Prices	Denmark	33,6	17,1	0	597
	Germany	35,0	29,3	0	2000
	Netherlands	43,2	59,4	0	2000
Interconnector Prices	Den -> Ger	4,3	13,3	0	500
	Ger -> Den	2,1	5,2	0	64
	NL -> Ger	0,04	0,09	0	5
	Ger -> NL	6,7	25,7	0	639

Figure 3: Spot Prices and Interconnector Prices

4 The Data

Our data for the spot prices stem from the respective electricity exchanges, APX, EEX, and NordPool. They are in current Euro / MW for each respective hour in the day ahead trading for the time from 0.00 a.m. 1/1/2002 to 24 p.m. 30/9/2006, implying 41.616 observations. Interconnector prices were provided by the operators of the interconnector auctions, and also contain 41.616 observations, one for every hour of the same time period. Figure 3 contains the summary statistics for the prices.

As noted before, the price is on average almost the same in Germany and Denmark, while they are on average 23% higher in the Netherlands than in Germany. Average interconnector prices can be ordered according to the average spot market price difference: they are on average highest for trade from Germany to the Netherlands, followed by trade from Denmark to Germany. They are on average close to zero for trade from the Netherlands to Germany.

Figures 4 and 5 show the correlation coefficients for the prices. Spot market prices are positively correlated, due to similar influences by demand patterns (peak demands from households at noon and in the afternoon, weekends, influences of the weather).Furthermore, this highlights that the difference in interconnector prices and the difference in spot prices is positively correlated, but the correlation (.69 for Denmark/German and .47 for NL/Germany) is far from perfect. The interconnector price and the price difference in the interconnector prices into the direction of the (on average) higher spot market price are very strongly correlated, in the case of the Netherlands almost perfectly. This reflects that the price in one of the two directions is almost always zero. Figure 6 shows the frequency of zero prices

	SP_{Ger} (1)	SP_{DK} (2)	$IP_{Ger->DK}$ (3)	$IP_{DK->Ger}$ (4)	Interdiff (4) – (3)	Pricediff (1) – (2)
SP_{Ger}	1	0,47	-0,14	0,62	0,68	0,80
SP_{DK}		1	0,19	0,21	0,13	-0,12
$IP_{Ger->DK}$			1	-0,13	-0,50	-0,31
$IP_{DK->Ger}$				1	0,93	0,65
Interdiff					1	0,68
Pricediff						1

Figure 4: Correlation Coefficients Germany - Denmark

	SP_{Ger} (1)	SP_{NL} (2)	$IP_{Ger->NL}$ (3)	$IP_{NL->Ger}$ (4)	Interdiff (4) – (3)	Pricediff (1) – (2)
SP_{Ger}	1	0,45	0,15	-0,06	-0,15	0,01
SP_{NL}		1	0,49	-0,07	-0,49	-0,88
$IP_{Ger->NL}$			1	-0,09	-1,00	-0,47
$IP_{NL->Ger}$				1	0,09	0,05
Interdiff					1	0,47
Pricediff						1

Figure 5: Correlation Coefficients Germany - Netherlands

	Netherlands/Germany		Denmark/Germany	
MIN = 0,00	19.242	46,2%	17.706	42,5%
MIN < 0,03	30.967	74,4%	32.505	78,1%
MIN < 0,05	33.068	79,5%	34.877	83,8%
Gesamt	41.616	100,0%	41.616	100,0%

Figure 6: Zero Interconnector Prices

Dependent variable: Pricediff	Netherlands/Germany	Denmark/Germany
Intercept	-1,95***	-1,25***
	(.236)	(.089)
Interdiff	.96***	1,22***
	(.009)	(.006)
R-squared	.22	.47

Figure 7: OLS (Standard errors in parentheses)

(or prices close to zero) for the lower of the two interconnector prices. Almost half of the time, the price for interconnector capacity is exactly zero in one direction. While in the German - Danish case this can be either direction, in the German - Dutch case it is (almost always) the price from the Netherlands to Germany which is zero, while the price in the opposite direction is strictly positive.

Finally, we can look whether a naive regression analysis (which does not account for the possibility of interim information) can "explain" the spot market price differences from the interconnector price differences. Figure 7 reports the results from such a regression and figure 8 shows the picture for the case of Denmark/Germany.

The interconnector prices predict on average the price differential in the spot market correctly (the coefficient is close to unity) and the intercept is also close (though significantly different from) zero. However, there is a lot of noise, in particular in the case of Netherlands/Germany, reflected in a rather low r-squared of 0.22. This reiterates the observation from the correlation matrix: the correlation is positive as expected, but far from perfect. We can summarize the data discussion with three stylized facts:

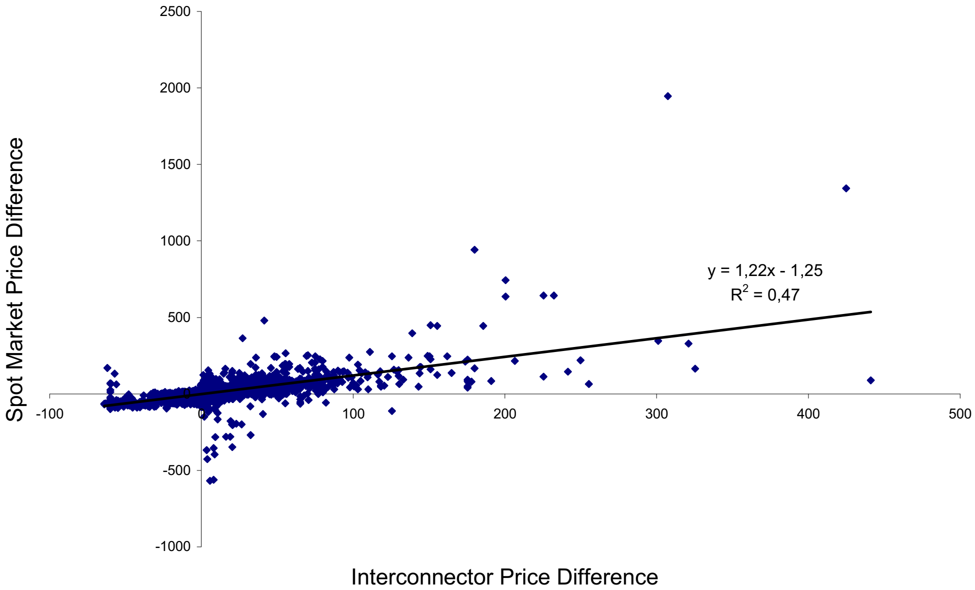

Figure 8: Denmark/Germany: Interconnector price difference vs. spot market price difference

1. the difference in the interconnector prices predicts the price differential very well in the sense that a regression of the price differential on the interconnector price yields a highly significant coefficient of about one.

2. the correlation is, however, quite weak, i.e. there is a lot of noise,

3. the lower interconnector price is close to zero almost always.

5 Calibration: A Parameterized Model

In this section we specify a version of the above model in which we make specific assumptions regarding functional forms and distribution functions. This allows us to derive more qualitative results in a straightforward fashion and to calibrate the model to the German and Danish electricity markets and to the German and Dutch electricity markets. Because the analysis of the data so far shows that the data is not consistent with the model with or without interim information, we modify our framework to include the possibility that not all firms are participating in the interconnector auction. This gives us an additional degree of freedom that we will use in the calibration of the model.

Formally we assume that only the first $\widehat{I}$ participate in the interconnector auctions while firms $\widehat{I}...I$ stay out. Along the lines of Proposition 3, we can prove the following result:

Proposition 5 *If firms* $1, ..., \widehat{I}$ *participate in the market for interconnector capacity, the equilibrium fees are:*

$$\begin{aligned} f_{HA} &= E\left[\max\{p^A - p^H, 0\} | s_1, ..., s_{\widehat{I}}\right], \\ f_{AH} &= E[\max\{p^H - p^A, 0\} | s_1, ..., s_{\widehat{I}}] \end{aligned}$$

and the capacities are

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The main difference now is that even after the interim information is revealed, the traders don't know the price differential for sure because the private information of the traders who didn't participate in the interconnector auction is only revealed in the spot market price. If a trader has bought capacity to import electricity from abroad at time one, he can still use it but it will be profitable only on average.

We know make some specific assumptions regarding functional forms and distribution functions. We assume that the spot market price differential $\tilde{\Delta p}$ is a random variable (a tilde denotes a random variable, without the tilde a particular realization is implied) given by

$$\widetilde{\Delta p} = \delta + \tilde{d}_0 + \tilde{d}_1 + \tilde{d}_2 \tag{9}$$

where all variables $\tilde{d}_t$ are random variables that can be written as

$$\tilde{d}_i = \sigma_i \varepsilon_i, \tag{10}$$

where

$$\varepsilon_i \sim N(0,1)$$

has a standard normal distribution. The ε_i's are drawn independently.

Let δ be the a priori expectation of the price differential. $\tilde{d}_0$ is time zero information, i.e. the information the firms had that took part in the market for interconnector capacity. Therefore, this information is contained in the interconnector prices. Formally,

$$\widetilde{\Delta p}|(s_1, \ldots, s_{\bar{I}}) \sim N(\delta + d_0, \sigma_1 + \sigma_2) \tag{11}$$

The realization of $\tilde{d}_1$ takes place between time one and two and is interim information arriving. Formally,

$$\widetilde{\Delta p}|(s_1, \ldots, s_{\bar{I}}, s_p) \sim N(\delta + d_0 + d_1, \sigma_2) \tag{12}$$

Finally, $\tilde{s}_2$ is time two information, i.e. information obtained exclusively by firms not taking part in the interconnector market but only in the spot markets. Formally,

$$\widetilde{\Delta p}|(s_1, \ldots, s_I, s_p) = \delta + d_0 + d_1 + d_2 \tag{13}$$

Note that the price differential conditional on d_0 and d_1 is a random variable that is normally distributed with mean

$$\delta_1 = \delta + d_0 + d_1 \tag{14}$$

and variance σ_2^2. $\tilde{\delta}_1$ in turn, conditional on d_0, is normally distributed with mean

$$\delta_0 = \delta + d_0 \tag{15}$$

and variance σ_1^2.

We can then calculate the interconnector fees as

$$f_{HA} = E(\tilde{\delta}_1 | d_0, \delta_1 > 0) = \int_0^\infty \delta_1 \frac{\phi\left(\frac{\delta_1 - \delta_0}{\sigma_1^2}\right)}{1 - \Phi\left(\frac{0 - \delta_0}{\sigma_1^2}\right)} d\delta_1 \tag{16}$$

and

$$f_{AH} = (-1) \cdot E(\tilde{\delta}_1 | d_0, \delta_1 < 0) = -\int_{-\infty}^0 \delta_1 \frac{\phi\left(\frac{\delta_1 - \delta_0}{\sigma_1^2}\right)}{\Phi\left(\frac{0 - \delta_0}{\sigma_1^2}\right)} d\delta_1, \tag{17}$$

where $\phi(\cdot)$ is the p.d.f. and $\Phi(\cdot)$ is the c.d.f. of the standard normal distribution. Note that if interim information becomes negligible probability mass of the distribution of δ_1 becomes concentrated around δ_0. This implies that

$$\lim_{\sigma_1^2 \to 0} E(f_{HA} | d_0) = \begin{cases} \delta_0, & \text{if } \delta_0 > 0; \\ 0, & \text{if } \delta_0 \leq 0. \end{cases} \tag{18}$$

and

$$\lim_{\sigma_1^2 \to 0} E(f_{AH} | d_0) = \begin{cases} 0, & \text{if } \delta_0 \geq 0; \\ -\delta_0, & \text{if } \delta_0 < 0. \end{cases} \tag{19}$$

We construct the following variables. Let

$$\bar{f} = \begin{cases} f_{HA}, & \text{if } f_{HA} \geq f_{AH}\ ; \\ -f_{AH}, & \text{if } f_{HA} < f_{AH}. \end{cases} \tag{20}$$

and

$$\underline{f} = \begin{cases} f_{HA}, & \text{if } f_{HA} \leq f_{AH}\ ; \\ -f_{AH}, & \text{if } f_{HA} > f_{AH}. \end{cases} \tag{21}$$

For $\sigma_1^2 \to 0$ we are back in the situation without interim information and the lower of the two prices will be almost always zero because there is no option value. Formally, this means that the unconditional variance of $\underline{f}$, $\underline{\sigma}^2$ goes to zero.

$$\lim_{\sigma_1^2 \to 0} \underline{\sigma}^2 = 0. \tag{22}$$

Likewise, vanishing interim information implies that $\bar{f}$ will be very close to δ_0. Formally, this means that the unconditional variance of $\bar{f}$, $\bar{\sigma}^2$ goes to σ_0^2.

$$\lim_{\sigma_1^2 \to 0} \bar{\sigma}^2 = \sigma_0^2. \tag{23}$$

Note that $\underline{\sigma}^2$ increases in σ_1^2, while $\bar{\sigma}^2$ decreases in σ_1^2.

6 Quantitative Results

These results confirm the informal analysis from above that the observations are not in line with the theoretical prediction for the case were all informed traders participate. If they do, and there is a lot of interim information, there would be noise, but no zero prices for the interconnector capacity. Without interim information, prices would be zero in one direction, but the correlation would be perfect. The only specification of the theoretical model in line with the data is that not all informed traders take part in the interconnector auction.

The aim of the following calibration exercise is to make this intuition precise by using the observed variances to calculate the underlying variances σ_0, σ_1 and σ_2. We use the following procedure:

From the data we know the unconditional expectation of the price differential δ and the unconditional variance σ^2. Moreover we know $\bar{\sigma}^2$ and $\underline{\sigma}^2$. From the latter two the two parameters σ_0^2 and σ_1^2 are identified. σ_2^2 can be calculated as the residual variance according to

$$\sigma_2^2 = \sigma^2 - \sigma_0^2 - \sigma_1^2 \tag{24}$$

We find numerically values for σ_0^2 and σ_1^2 that match $\bar{\sigma}^2$ and $\underline{\sigma}^2$ by the following simulation procedure.

1. We start with some values σ_0^2 and σ_1^2
2. We draw many (1 million) signals s_0 from a normal distribution with mean zero and variance σ_0^2
3. Using σ_1^2 we calculate $\underline{f}$ and $\bar{f}$ for each s_0
4. From the resulting sample we calculate $\underline{\sigma}^2$ and $\bar{\sigma}^2$
5. Iteratively we adjust σ_0^2 and σ_1^2 until $\underline{\sigma}^2$ and $\bar{\sigma}^2$ match the empirically observed values

Using data from the German-Danish and the German-Dutch border and denoting Germany by home and Denmark by abroad we find that:

Table 1

	Germany/Denmark	Germany/Netherlands
δ	0.74	-7.63
σ^2	351	2652
$\underline{\sigma}^2$	0.02	0.0025
$\bar{\sigma}^2$	115	512

Using the above described procedure we get:

Table 2

	Germany/Denmark	Germany/Netherlands
σ_0^2	74	506
σ_1^2	0.5	0.25
σ_2^2	276.5	2145.75

Table 2 shows how according to our calibration, the sample variance σ^2 can be split into the different elements. For both markets a very similar picture arises. The share of the information included in the interconnector prices (i.e. time zero information in our model, σ_0^2) is only about 20% (74/351 = 21% for Germany/Denmark and 506/2652 = 19% for Germany/Netherlands). The interim information (σ_1^2) is virtually zero (0.1% and 0.0001%, respectively), which accords well with the observation that lower prices are almost always zero. Given that a large part of the available information should be public (for example weather, business cycle, holidays, ...), this indicates that firms with significant amount of private information, do not participate in the interconnector market.

7 Discussion

Given the prices we observe, there seem to be firms which have private information but do not use it. These firms could make (on average) profits by trading in the market but do not do so. We can conclude that these firms do not maximize expected per period payoff. One hypothesis that would be consistent with the observed prices is that national electricity providers do not compete with each other cross-border. Such an arrangement could be an equilibrium in a repeated game.

The industry structure of the markets makes such an explanation not unlikely. Electricity markets in Denmark and Germany are highly concentrated: In Germany, the share of total production capacity (installed capacity) of the three largest firms is 69%, in Denmark it is 72%. At the same time, a large part of the electricity market is still an OTC market (for Germany, 88% of the market is OTC, in Denmark it is 62%).[3] Thus, it could be a motivation to exploit market power in the home market, in particular the OTC markets, and mutually abstain from competing in the neighboring market, where entry is easiest on the wholesale level (i.e. at the electricity exchanges). This is in line with the view of the Danish competition authority:

> Cross border trade in the Danish-German interconnector functions poorly. These elements mean that the dominant players in West and East Denmark are not exposed to effective competition.[4]

Dominant power producer thus might have a lot to loose from increased cross-border competition. At the same time it is reasonable to assume that large producers have a lot of price relevant information which is not available to pure electricity traders. While a lot information is public (like weather conditions, fuel prices), important supply side information is proprietary, in particular the actual availability of production capacity (e.g. power plant outages due to revisions, repair or maintenance).

Thus, large, well informed producers might forgo relatively small profits in the cross-border market, in order to protect the home market dominant position. This is also reflected in the view of the European Commission on the behavior of European Electricity incumbents:

> Cross-border sales do not currently impose any significant competitive constraint. Incumbents rarely enter other national markets as competitors. (European Commission, 2007, para. 21)

Thus, it is likely that mainly pure traders, who want to exploit trading opportunities between the regions, are active and determine the interconnector price. Since a significant part of the information is missing, transportation prices are only a bad predictor of the spot market prices (although correct on average).

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[3] Data are from the contributions of the Danish and German energy regulators' annual reports to the European Commission 2005. The figure for Germany includes 7% capacity of STEAG, which is long term contracted to RWE. Downloadable from ERGEG's (European Regulators Group for Electricity and Gas) website, http://www.ergeg.org/portal/page/portal/ERGEG_HOME/ERGEG_DOCS/NATIONAL_REPORTS

[4] Regulator's Annual Report to the European Commission - 2005. Contribution for Denmark compiled by Danish Energy Regulatory Authority, p. 13.

There are complementary explanations for the observations that prices are zero most of the time for interconnector capacity in one direction. One explanation might be – and this is supported by the calibration results – that there seems to be very little interim information, which does not make it worthwhile to try to exploit the (small) option value. An additional explanation might be that pure traders are not well equipped to exploit the option value contained in the transportation capacity. Since they cannot produce electricity, they must place simultaneously offsetting bids in the spot markets.

Consider the following example: a trader expects the price in Denmark to be higher than in Germany. Since this is uncertain, he should be willing to by transport capacity in the opposite direction (Denmark -> Germany), in case the price differential turns out to be different. A pure trader, who has no own production facilities, must procure the electricity at the electricity exchange. To ensure that a trade from Denmark to Germany will be possible requires to buy at all prices in Denmark and to sell at all prices in Germany – which obviously makes no sense if the expectation is that the prices will be higher in Germany.

Thus, he must place a limit order, e.g. buy in Denmark up to 40 €/MW and sell in Germany at all prices above 40€. This bears the risk to end up with electricity without having a selling opportunity (if $p^{Den} < 40$, and $p^{Ger} < 40$) or with having a selling obligation without having electricity (if $p^{Den} > 40$, and $p^{Ger} > 40$). In this case, the trader would have to buy so-called "balancing energy" from the system operator, which is far more expensive than the spot market price.

This might explain why pure traders are not able to exploit the option value from transport capacities. Note, that producers could exploit this far better: Given a spot market price p^* (and assuming that no producer sells below cost and not all producer produce up to full capacity), there must be at least one firm able to produce some additional units at marginal cost not too much above p^*, at least below some upper bound $\bar{c}$. Thus, in the example, a Danish producer with an upper bound $\bar{c}$ could always offer to sell in Denmark at all prices above $\bar{c}$. If this has positive probability (as the data suggest), the producer should be willing to invest at least some ε to acquire transport capacity from Denmark to Germany.

To summarize: If only poorly informed traders trade in the interconnector market, but all traders (including the traders of the large generator's) take part in the spot market, it would not be surprising to see a large variation between interconnector prices and the spot market prices. Zero interconnector prices could result from the inability of pure traders to exploit the option value of transport capacities. We believe that this is convincing explanation of the data. However, as far as collusion is concerned, it is mere speculation.

8 Conclusion

We have analyzed a situation in which a commodity is traded in two spot markets which are connected. The commodity can be shipped between the two markets, but this incurs transportation cost. Firms first have to buy transportation capacity and afterwards submit demand functions or supply functions in the spot market. If all markets (the market for transport capacities, and the two spot markets) are competitive, only specific combinations of transport prices and spot market prices are possible. If all firms participate in both steps (transport market and spot market), either (i) transport prices already include all information and perfectly predict the spot market prices. This obtains if no new information becomes available between the two steps. Or (ii), with interim information, transport prices do not perfectly predict the spot market prices; but then, transport prices must never be zero in one direction, since transport capacities exhibit an option value. Alternatively, if not all informed firms participate in the transport market, we expect the transport prices to correctly predict the spot prices only on average.

The data from the electricity markets suggest that the last hypothesis is the only one consistent with the data. Given the underlying market structure, it could be a plausible explanation that well informed producing companies do not participate intensively in cross-border activities in order to exploit market power in the own region. This assumes some sort of collusive behavior of large producers between the two regions.

Although this is not an example for a violation of the "no-arbitrage" principle in the strict sense (since informed trader who do not participate can make profits only on average, and exploiting the option value of the transport capacity also involves some risk), the results suggest that "inefficiencies" can persist in commodity markets. Our explanation for this empirical finding rests on the idea that traders are asymmetric. Some traders might have addition interests at stake preventing them from exploiting all profit opportunities. Furthermore, the opportunity to produce the commodity themselves at some limited cost puts some traders into a superior position.

Though our paper focuses on the electricity markets, the approach and the calibration method might be of interest also in other contexts. It is often interesting to know whether commodity markets are "global" or still mainly "regional" or "local", i.e. whether the difference in the prices observed at different commodity exchanges are only due to transportation cost, or whether firms still only buy and sell mainly in their "home market" and do not compete for supply and demand across different regions. From an efficiency point of view, global markets will usually be preferred due to the higher level of competition. For the same reason, players with market power in regional markets will usually prefer to keep markets regional and avoid cross-market competition. For instance, European national electricity incumbents probably prefer a situation with national monopolies or oligopolies to a unified European electricity market with European wide competition.

Often it will be difficult to judge from the spot market prices alone whether differences in spot market prices in different regions are due to a lack of cross-market competition or due to transportation cost. The approach used in this paper might help in providing answers with the help of market data not only from the "downstream" spot market but also from the "upstream" market for transport capacity, provided such data is available.

Even if the transport market in not organized in an exchange, data on the prices for transport capacities e.g. for shipping capacities, freight trains, road transport and the like, might also be informative and allow some conclusions on the question whether regional markets form a unified market or are distinct and whether the market outcomes are in line with the predictions of a competitive equilibrium.

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