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Implicit auctioning on the Kontek Cable: third time lucky?

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Abstract

Implicit auctioning in Europe is about eliminating cross-border trade inefficiencies by internalizing cross-border trade into the day-ahead auction procedures of the Power Exchanges that are already organizing trade nationally. On the Kontek Cable, implicit auctioning has first been implemented with "no coupling" between the relevant Power Exchanges, followed by a "volume coupling" implementation, and finally a "one way price coupling" implementation that is still operational today. The main contribution of this paper is to compare the theoretical properties of these three implementations and to analyze their performance empirically. We find that the third implementation is significantly outperforming the previous two implementations, but in this third implementation stakeholders partly abandoned the "volume coupling" approach they initially believed to be a viable alternative and institutionally easier to implement.

Keywords

Electricity markets, implicit auctions, cross-border trade.

JEL classification

L94; D44; C12;

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1. Introduction

The European experience is increasingly evidencing the inadequacy of the explicit auctioning method, which is to allocate cross-border capacities to traders and relying on them to arbitrate between the different national electricity markets. Cross-border capacities are currently underpriced (Newbery and McDaniel, 2002; Neuhoff, 2003; Purchala, 2004), underused, and even frequently misused increasing price spreads instead of reducing them (Creti et al., 2010; CRE, 2009; Frontier economics and Consentec, 2004; Kristiansen, 2007a; and Turvey, 2006), resulting in a lack of day-ahead hourly price convergence in Europe (Zachmann, 2008). Bunn and Zachmann (2010) explain that market power is one of explanations for the inefficiencies of explicit auctions and also empirically support their arguments.

Implicit auctioning is about eliminating these cross-border trade inefficiencies by internalizing the arbitrage into the auction procedures of the Power Exchanges that are organizing trade nationally (Meeus et al., 2005). Traditionally the debate in the literature has mainly been about explicit versus implicit auctioning. Bohn et al. (1983) demonstrated that implicit auctioning leads to a welfare-maximization. Chao and Peck (1996) in turn showed that explicit auctioning does not necessarily reduce welfare, if there is continuous trading of electricity and cross-border capacities contracts. Gilbert et al. (2004), Parisio and Bosco (2008), and Ehrenmann and Neuhoff (2009) analyze the difference between explicit and implicit auctioning under imperfect competition, and conclude that implicit auctioning reduces market power. Hobbs et al. (2005) showed the opposite can be true, arguing that abusive behaviour is more difficult to monitor in implicit auctions.

This paper contributes to the more recent debate on how to implement implicit auctioning in the European context by analyzing the experience on the Kontek Cable that interconnects East Denmark with Germany. The Kontek Cable experience is relevant for three main reasons. First, it is the first implementation of "volume coupling" which has been promoted by stakeholders[2] as institutionally easier to implement and a viable alternative to "price coupling". Second, contrary to the successful "price coupling" implementations of implicit auctioning within the Nordic area, between Spain and Portugal, and between France, Belgium and the Netherlands (Vandenborre, 2008), the Kontek Cable implementations have not been without problems (Kristiansen, 2007b; and FGH/IAEW, 2009). Third, implicit auctioning in Europe is gaining momentum[3] so that analyzing the Kontek Cable case will help anticipating and remedying the same problems elsewhere.

The paper starts with a theoretical description of implicit auctioning on the Kontek Cable (section 2), followed by a discussion on the performance of an implicit auction and how to measure it (section 3). The paper then introduces the three implementations of implicit auctioning on the Kontek Cable,

[2] See for instance the 2009 paper by the European Power Exchanges (Europex) and TSOs (ETSO) associations: "development and Implementation of a coordinated model for regional and inter-regional congestion management," available at www.europex.org.

[3] In 2010, Power Exchanges announced cooperation aimed at implementing implicit auctioning across the Nordic, Central West and Southern European regions.

assessing where they deviate from the theoretical implicit auction and discussing the expected impact of these deviations on the performance of the auction (section 4). The paper finally checks whether the empirics are in line with what could have been expected to conclude with the most relevant lessons learned for the many ongoing initiatives to implement implicit auctioning in Europe.

2. Theoretical description of implicit auctioning on the Kontek Cable

An implicit auction receives demand ($d \in D$) and supply ($s \in S$) orders with a certain volume (Q_{dz}^h, Q_{sz}^h) and price (P_{dz}^h, P_{sz}^h) limit for the delivery or off-take of energy during a certain hour ($h \in H$) in the different zones[4] that are included in the auction ($z \in Z$). In what follows, we formalize the “matching” and “pricing” of an implicit auction, taking into account also other issues that are relevant on the Kontek Cable.

2.1. Matching

An implicit auction decides the volume to accept of each order (q_{dz}^h, q_{sz}^h) for every hour of the next day by maximizing the surplus generated by the auction across zones:

$$\max_q \left(\sum_z \left(\sum_d q_{dz}^h P_{dz}^h - \sum_s q_{sz}^h P_{sz}^h \right) \right) \qquad (1)$$

Subject to three sets of constraints. First set of constraints are the order constraints:

$$\forall z,d : q_{dz}^h \le Q_{dz}^h;\ \ \forall z,s : q_{sz}^h \le Q_{sz}^h \qquad (2) \qquad\qquad \forall z,d : 0 \le q_{dz}^h;\ \ \forall z,s : 0 \le q_{sz}^h \qquad (3)$$

The second set of constraints makes sure that what is supplied in a certain zone is demanded locally or exported ($inj_z^h > 0$), or what is demanded in a certain zone is supplied locally or imported ($inj_z^h < 0$):

$$\forall z : \sum_d q_{dz}^h - \sum_s q_{sz}^h + inj_z^h = 0 \qquad (4)$$

The third set of constraints represents the limited capacities of the different interconnections between the zones included in the auction (Cap_{z-z}^h). Because the Kontek Cable is a direct current interconnection that can control the volume that is exchanged between Germany ($z = du$) and East Denmark ($z = dk$), these constraints are:

$$inj_{du}^h \le Cap_{du-dk}^h \qquad (5) \qquad\qquad -inj_{du}^h \le Cap_{dk-du}^h \qquad (6)$$

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[4] Trade between locations in Europe is typically unlimited within the zone of a Transmission System Operator (TSO), but limited between zones, i.e. trade is “zonal”.

2.2. Pricing

The hourly zonal prices (λ_z^h) set by the implicit auction are the dual variables of equation (4). The properties of these prices follow from the KKT conditions (Kuhn and Tucker, 1951) of the optimization problem (1)-(6), i.e. primal feasibility, dual feasibility, stationarity, and complementary slackness. Primal feasibility is expressed by the constraints (2)-(6). Dual feasibility requires that the dual variables are non-negative, with λ_z^h the dual variable of equation (2), $\gamma_{s/d,z}^h$ the dual variable of equation (3), $\eta_{s/d,z}^h$ the dual variable of equation 4, μ_{du-dk}^h the dual variable of equation (5), and μ_{dk-du}^h the dual variable of equation (6).

Complementary slackness is expressed by the following equations corresponding to the respective inequality constraints (2)-(3) and (6)-(7):

$$\forall z, d/s : (q_{d/s,z}^h - Q_{d/s,z}^h)\gamma_{d/s,z}^h = 0 \qquad (7) \qquad \forall z, d/s : -q_{d/s,z}^h \eta_{d/s,z}^h = 0 \qquad (8)$$

$$(inj_{du}^h - Cap_{du-dk}^h)\mu_{du-dk}^h = 0 \qquad (9) \qquad (-inj_{du}^h - Cap_{dk-du}^h)\mu_{dk-du}^h = 0 \qquad (10)$$

Stationarity, as derived from the Lagrangian, expresses the properties of the hourly zonal prices (λ_z^h) in relation to the price limit of the supply and demand orders:

$$\forall z, d : \lambda_z^h = P_{dz}^h - \gamma_{dz}^h + \eta_{dz}^h \qquad (11) \qquad \forall z, s : \lambda_z^h = P_{sz}^h + \gamma_{sz}^h - \eta_{sz}^h \qquad (12)$$

And also expresses their properties in relation to each other:

$$\lambda_{du}^h - \lambda_{dk}^h = \mu_{dk-du}^h - \mu_{du-dk}^h \qquad (13)$$

The following five zonal price properties can then be derived from the above optimality conditions (2)-(14), using "eq" as an abbreviation for equation, and the number referring to the above equations:

1) In hours with unused capacity on the Kontek Cable, the zonal prices in Germany and East Denmark are equal:
$$(inj_{du}^h - Cap_{du-dk}^h) \neq 0 \Rightarrow (eq10, eq11) : \mu_{du-dk}^h, \mu_{dk-du}^h = 0 \Rightarrow (eq14) : \lambda_{du}^h = \lambda_{dk}^h$$
2) In hours with congestion on the Kontek Cable, the zonal prices in Germany and East Denmark can differ, but only in the direction of the cross-border exchange, i.e.
    a. For hours with congestion in the direction of East Denmark:
$$(inj_{du}^h - Cap_{du-dk}^h) = 0 \Rightarrow (eq7+10) : \mu_{du-dk}^h \geq 0 \,\&\, (eq11) : \mu_{dk-du}^h = 0 \Rightarrow (eq14) : \lambda_{du}^h \leq \lambda_{dk}^h$$
    b. For hours with congestion in the direction of Germany:
$$(-inj_{du}^h - Cap_{dk-du}^h) = 0 \Rightarrow (eq7+11) : \mu_{dk-du}^h \geq 0 \,\&\, (eq10) : \mu_{du-dk}^h = 0 \Rightarrow (eq14) : \lambda_{du}^h \geq \lambda_{dk}^h$$
3) The price limit of not accepted demand/supply orders in a certain zone during a certain hour provides an lower/upper bound for the zonal price in that zone during that hour:
$$q_{d/s,z}^h = 0 \Rightarrow (eq8) : \gamma_{d/s,z}^h = 0 \,\&\, (eq7+9) : \eta_{d/s,z}^h \geq 0 \Rightarrow (eq12) : P_{dz}^h \leq \lambda_z^h \,\&\, (eq13) : \lambda_z^h \leq P_{sz}^h$$

4) The price limit of a fully accepted demand/supply orders in a certain zone during a certain hour provides a upper/lower bound for the zonal price in that zone during that hour:
$$q_{d/s,z}^{h}=Q_{d/s,z}^{h}\Rightarrow(eq7+8):\gamma_{d/s,z}^{h}\geq 0\,\&\,(eq9):\eta_{d/s,z}^{h}=0\Rightarrow(eq12):\lambda_{z}^{h}\leq P_{dz}^{h}\,\&\,(eq13):P_{sz}^{h}\leq\lambda_{z}^{h}$$
5) The price limit of a partially accepted supply or demand order in a certain zone during a certain hour sets the zonal price in that zone during that hour:
$$0<q_{d/s,z}^{h}<Q_{d/s,z}^{h}\Rightarrow(eq8):\gamma_{d/s,z}^{h}=0\,\&\,(eq9):\eta_{d/s,z}^{h}=0\Rightarrow(eq12):\lambda_{z}^{h}=P_{dz}^{h}\,\&\,(eq13):\lambda_{z}^{h}=P_{sz}^{h}$$

Note that the above price properties also hold in a meshed alternating current gird, except for properties 1 and 2. For a detailed discussion on how these price properties change in such meshed grids, see Wu et al. (1996) and Meeus et al. (2009a).

2.3. Other issues

An implicit auction on the Kontek Cable will also be confronted with other issues, such as price caps, the dead-band and the computational complexity of the implicit auction optimization problem that are discussed in what follows.

2.3.1. Price caps

An implicit auction is typically implemented at the day-ahead stage when Power Exchanges organize auctions around midday for every hour of the next day. In the case of the Kontek Cable, it is the Nordic Power Exchange Nord Pool that organizes this auction on the East Danish side of the Cable, and on the German side of the Cable this is the Power Exchange EEX[5].

EEX prices can go from -3,000 €/MWh to +3,000 €/MWh, while Nord Pool prices could initially only go from 0€/MWh to +2,000 €/MWh. Since 2009, Nord Pool also allows negative prices down to -200€/MWh. Even though the motivation behind these caps and floors is to limit the consequences of human error in submitting orders, they can also constrain prices and thereby reduce the surplus generated by the implicit auction.

From September 2008 to April 2010 (i.e. the period we analyze in this paper, see section 5.1), the EEX day-ahead hourly prices for Germany varied from about 299 €/MWh down to almost -500 €/MWh, while the Nord Pool day-ahead hourly prices for East Denmark in the same period ranged from almost 1400 €/MWh down to almost 0 €/MWh. Except for 3 hours (less than 1% of the time) during which prices have been zero in East Denmark, the floors or caps have not been reached.

2.3.2. Dead-band

An implicit auction only generates revenue for the capacity owners in hours where there is congestion. From price property 2 follows that in these hours what is exported at a certain price is imported at a possibly higher price resulting in so-called congestion revenue ($(\lambda_{dk}^{h}-\lambda_{du}^{h})inj_{du}^{h}$).

[5] European Energy Exchange, which merged with the French Powernext in 2009, creating the European Power Exchange (EPEX).

In the case of the Kontek Cable, the owners have introduced a so-called dead-band that is designed to also generate revenues in hours where there is no congestion[6]. The most effective way to implement a dead-band would be to put a floor on the hourly congestion revenue generated by the auction or on the hourly zonal price difference. However, from September 2008 to April 2010 (i.e. the period we analyze in this paper, see section 5.1), there have been hours with negative congestion revenue (17% of the time) and there have been hours with equal prices (1% of the time), even though the dead-band was in place, which can only imply that the dead-band has not been implemented effectively.

2.3.3. Computational complexity

The computational complexity of the implicit auction problem (1)-(6) is limited, but in the case of the Kontek Cable there are two main issues that complicate the optimization. First, the involved Power Exchanges allow the submission of so-called block orders, which are multi-period and indivisible. With blocks, the implicit auction becomes a Mixed Integer Problem that cannot always be optimized within a reasonable time (Meeus et al., 2009b; and Tersteegen et al., 2009). Second, the dead-band discussed in the previous section makes the problem non-linear, at least if it were to be firmly implemented, as discussed in section 2.3.2.

Note that because of these "other issues", any implementation of implicit auctioning on the Kontek Cable will perform imperfectly because the surplus maximization can be constrained by prices caps, the dead-band, and computational complexity. For the period we analyze in this paper, we found in this section that the first issue is not relevant, while the second and the third issue are relevant. A specific implementation can then further reduce the performance of the auction (see section 4).

3. Measuring the performance of implicit auctioning on the Kontek Cable

In this section, we respectively discuss how to measure the performance of the "matching" and the "pricing" of an implicit auction on the Kontek Cable.

3.1. Measuring performance in terms of matching

The performance (or the lack of it) of an implicit auction can be measured by the surplus or welfare the auction generates (or fails to generate) with its "matching". Figure 1, which is adapted from Hakvoort and de Jong (2007), represents the aggregated supply and demand orders as a net export curve for the lower priced region and net import curve for the higher priced region. The Figure illustrates the two possible cases, i.e. unused and misused capacity.

In the case of unused capacity (Figure 1, left side), there is a cross-border exchange that is lower than the available capacity, while there is a price difference. The exchange increases total welfare (ADIHA), including a welfare increase for the importing region (ABHA), a welfare increase for the exporting region (CDIC), and congestion revenue (BCIHB). HIFEH is the welfare that has been lost in comparison with an

[6] EMCC News archive 29/09/08. (http://www.marketcoupling.com/market-info-and-press/news/news-archive/date/2008-3).

optimal use of the available capacity. In the case of misused capacity (Figure 1, right side), there is a "counter exchange", i.e. a cross-border exchange in the opposite direction of the price spread increasing this spread rather than reducing it. The exchange decreases total welfare (JKDAJ), including a welfare decrease for the importing region (JLNAJ), a welfare decrease for the exporting region (MKDOM), and negative congestion revenue (LMONL). JKFEJ is the welfare that has been lost in comparison with an optimal use of the available capacity.

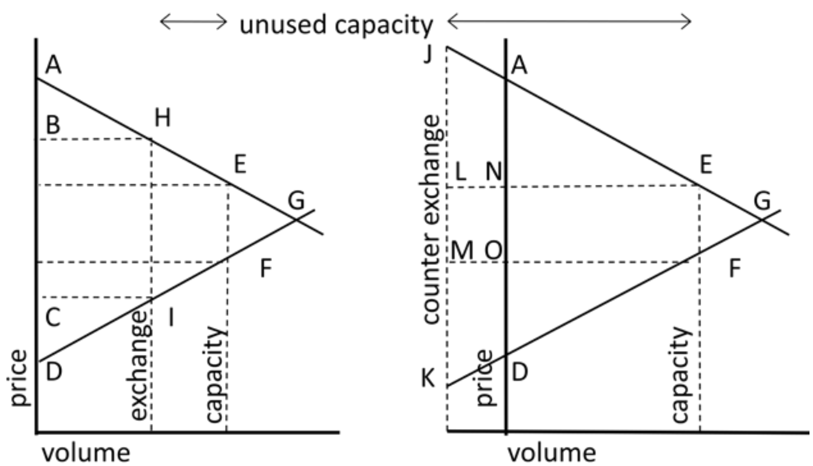

Figure 1: welfare implications of unused (left) or misused (right) capacity on the Kontek Cable

Measuring the welfare the implicit auction failed to generate in the way that has been illustrated above has three main limitations. First, the orders submitted by market parties to the Power Exchanges and the capacities available to the implicit auction are taken as given, i.e. we do not account for possible changes in strategic behaviour of the auction participants or Cable owners. Several authors have argued that strategic behaviour is different in implicit as opposed to explicit auctions (as in Gilbert et al., 2004; Parisio and Bosco, 2008; Ehrenmann and Neuhoff, 2009), but we are comparing different implementations of implicit auctioning so that this is a reasonable assumption. Second, the approach cannot be generalized to meshed alternating current grids because it relies on price properties 1 and 2, which do not necessarily hold in such a grid.

Third, publicly available data is limited, i.e. we cannot calculate the welfare the implicit auction failed to generate (HIFEH and JKFEJ). Therefore, we need to make an approximation based on what we know, which are the hourly values of the zonal prices (H and I), the volume that has been exchanged, and the capacity that was available. Figure 2 illustrates that if we observe that there is unused capacity in a certain hour (exchange < capacity), while there is a price spread (i.e. violation of price properties 1 and/or 2), the resulting welfare loss can go from the unused capacity times the price spread (Figure 2, left) to zero (Figure 2, right). The first case (Figure 2, left) illustrates an hour where the zonal prices would have remained the same if the Kontek Cable would have been used optimally. The second case (Figure 2, right) illustrates an hour where the volume that is exchanged across the Cable is optimal and the zonal prices could have been equalized but they were not[7], which can happen in implementations of implicit auctioning without "price coupling", as will be discussed in the next section for the "volume coupling" and "one way price coupling" implementations. In practice, these two extreme cases can occur, and of course also the intermediate cases, depending on the slopes of the curves, and the size of the unused capacity.

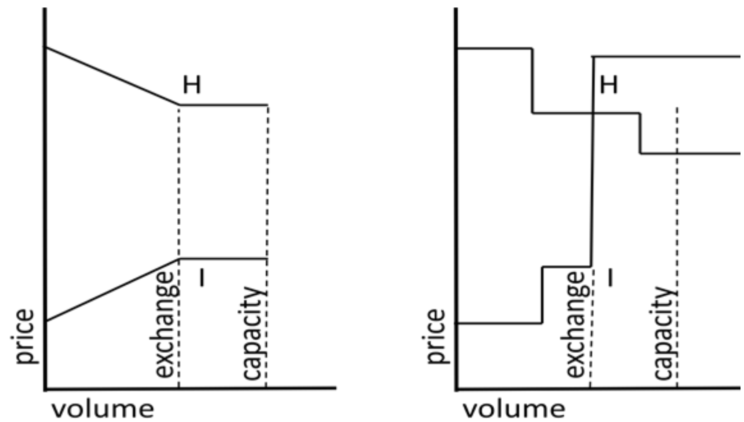

Figure 2: upper and lower bound for the welfare loss from inefficient use of the available Kontek Cable capacity

3.2. Measuring performance in terms of pricing

The performance (or the lack of it) of an implicit auction can also be measured by the properties of the prices it produces (or fails to produce) with its "pricing". The limited data that is publicly available is enough to check whether the zonal prices (H and I) violate price properties 1 and/or 2. An indicator can then be used to measure on an hourly basis to what extent the actual prices deviate from the optimal prices. The indicator that captures this deviation is "unused capacity times the price spread", which should be zero following price properties 1 and 2.

In what follows, we will use this indicator ("unused capacity times the price spread") in our analysis. To sum up, the indicator correctly captures the performance of the pricing of an implicit auction, but has its limitations with regards to the performance of the "matching of an implicit auction (it is "only" an upper bound for the welfare the auction failed to generate). Still it is a good indicator for our analysis because pricing is at least as important as matching for the day-ahead stage. The reasons is that the day-ahead stage in power markets has traditionally been functioning as the spot market and only a fraction of total trade is spot, but the spot prices are a reference prices for most contracts traded in power markets (Meeus et al., 2005).

[7] Prices could have been equalized at "H". The importing zone has a partially accepted order that sets the price at "H". The exporting zone does not have a partially accepted order that sets the price, but it does have accepted and rejected orders that set an upper bound (just above "H") and a lower bound ("I") for the zonal price. Therefore "H" could have been the price in the exporting zone, which would have equalized prices, but instead "I" has been chosen in the illustration.

4. Three implementations of implicit auctioning on the Kontek Cable

In this section, we introduce the three implementations of implicit auctioning on the Kontek Cable, assessing where they deviate from the theoretical implicit auction (as formalized in section 2) and discussing the expected impact of these deviations on the performance of the auction (as discussed in section 3).

4.1. First implementation: "no coupling"

The first implementation has been operational from 2005 until the end of 2008, and also during the transition from the second towards the third implementation. In the first implementation, Nord Pool received orders from both sides of the Kontek Cable, but EEX also continued to receive and match its own orders on the German side of Cable independently from Nord Pool. Orders submitted to EEX could therefore not be matched with orders submitted to Nord Pool and vice versa (hence: "no coupling").

Nord Pool based on its own matching quoted day-ahead hourly prices for East Denmark and Germany, with EEX quoting a different day-ahead hourly price for Germany based on its own matching. As the first implementation deviated fundamentally from the theoretical matching (section 2.1) and pricing (section 2.2) of an implicit auction, a relatively poor performance could have been expected.

4.2. Second implementation: "volume coupling"

The second implementation has been operational at the end of 2008, but only for 10 days. In the second implementation, Nord Pool received orders from the East Danish side of the Kontek Cable and EEX from the German side. A joint venture between the Power Exchanges (EMCC) then received the orders from both Power Exchanges and ran the matching. However, the two Power Exchanges consequently also ran their own matching of their own orders, updating their order book with an import or export volume coming from the EMCC matching (hence: "volume coupling"). In other words, EMCC scheduled the exchange across the Kontek Cable, while the Power Exchanges decided which orders to accept in their respective zones. Nord Pool and EEX based on their own matching calculated and quoted the day-ahead hourly prices for respectively East Denmark and Germany.

As the second implementation only deviates from the theoretical pricing (section 2.2) of an implicit auction, an improved performance could have been expected in comparison with the first implementation. Still, remaining problems with matching and pricing could also have been anticipated. First, splitting a computation in separate interacting computations (first scheduling of the exchange across the Cable and then a separate matching to determine which orders to accept) executed by three different calculators (EMCC, Nord Pool and EEX) increases the room for errors. The problem to be solved is also computationally complex (section 2.3.3) so that different calculators can find different suboptimal solutions in the limited time that is available.

Second, a Power Exchange that does not have a partially accepted order only has lower and upper bounds for its zonal hourly price coming from the rejected and accepted orders in that hour in its own zone (price properties 3 to 5). This then implies that this Power Exchange has to arbitrarily "choose" the zonal hourly price between these boundaries. However, in hours without congestion the chosen price also has to be the same price as the price set by the other Power Exchange to avoid that there is a price spread even though there is no congestion (i.e. to avoid violating price property 1 and/or 2). A lack of price coordination can therefore be an issue, even if the matching is optimal (as also illustrated in Figure 2, right).

4.3. Third implementation: "one way price coupling"

The third implementation is operational since the end of 2009. In the third implementation, matching is conceptually the same as in the second implementation with EMCC scheduling the exchange across the Cable and Nord Pool and EEX then running a separate matching to determine which orders to accept. In the third implementation, Nord Pool started to take into account the pricing of EEX when determining its own price based on its own matching, but not vice versa (hence: "one way price coupling")

As the third implementation is an improved version of the second implementation with its pricing approaching the theoretical pricing of an implicit auction (section 2.2), a further improved performance could have been expected. Still, also for the third implementation remaining matching and pricing problems could also have been anticipated.

The implementation continues to be prone to calculation errors or suboptimal solutions that can have an impact on the matching and despite the "one way price coupling," the lack of price coordination in the other direction can still be an issue, only the likelihood has been reduced to hours where EEX is the Power Exchange that does not have a partially accepted order that sets the price in hours without congestion.

5. Empirical analysis of implicit auctioning on the Kontek Cable

In this section, we check whether the experience with the three implementations of implicit auctioning on the Kontek Cable is inline with what could have been expected (as discussed in section 4). We first introduce the dataset and then discuss the main results.

5.1. Dataset

The dataset we analyze spans from September 2008 to April 2010 and includes the day-ahead hourly prices for Germany and East-Denmark as quoted respectively by EEX and Nord Pool (€/MWh), the day-ahead hourly Kontek Cable capacities that were available to the implicit auction (MWh)[8] and the hourly exchanges over the Cable scheduled by the implicit auction (MWh)[9].

Nord Pool and EEX are two of the most liquid Power Exchanges in Europe with the day-ahead auction volumes of respectively more than 60% and 20% of consumption in their zones (European Commission, 2006; Rademaekers et al, 2008). As these markets have matured, the day-ahead hourly prices these Power Exchanges quote are reliable references to use for our analysis.

Table 1: descriptive statistics of the data set

	EEX Germany	*Nord Pool East Denmark*	*Cross-border exchange*	*Capacity*	*Performance indicator*
Mean	40,4	46,5	137,2	520,0	225,8
Standard deviation	20,4	44,4	415,3	116,9	320,3
Kurtosis	60,1	520,6	-1,3	14,1	0,4
Skewness	-1,1	19,8	-0,5	-3,9	1,3
Minimum	-500,0	0,0	-550,0	0,0	-0,1
Maximum	299,1	1400,1	550,0	550,0	1100,0

In the period we analyze (Table 1), on average the hourly price in East Denmark has been higher than the price in Germany and on average the flow has also been in this direction. In the hours that the Cable was available (we have excluded days or hours where the Cable was not available, see also section 5.2.), the average available capacity was almost always at its maximum of 550 MW in both directions, resulting in an average of 520 MW. The descriptive statistics also indicate that the dataset is not normally distributed (Table 1, Kurtosis, and Skewness), which is confirmed by the Shapiro Wilk normality test (Shapiro and Wilk, 1965) that returns a p-value of lower than 0.0001 for each variable in the dataset so that the probability that they are normally distributed is almost zero.

5.2. Results

Table 2 indicates that our performance indicator is different from zero on average for all three implementations of implicit auctioning on the Kontek Cable, which is inline with the expected. Also as expected is that the third implementation ("one way price coupling") is outperforming the previous two implementations ("no coupling" and "volume coupling"). However, contrary to the expected, the "no coupling" implementation outperformed the "volume coupling implementation"[10].

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[8] Note that long term contracts play no role on the Kontek Cable so that the available capacity goes entirely to the implicit auction at the day-ahead stage.

[9] The data can be found here (last time consulted 05/09/2010): http://www.energinet.dk/en/menu/Market/Download+of+Market+Data/Download+of+Market+Data.htm

[10] Kristiansen (2007a) studies the performance of the explicit auction on the Kontek Cable with descriptive statistics. He for instance reports that during 14% of the time in 2003 and 2004, the capacity was misused. In the

As our performance indicator is not normally distributed, the most suitable test to check whether these findings are statistically significant is the Kruskal-Wallis hypothesis test (Conover, 1999; and Sheskin, 2003). The probability of rejecting the null hypothesis, that the samples have the same median, when it is in fact true is respectively 0.037, and smaller than 0.0001 when comparing "no coupling" with "volume coupling" and "volume coupling" with "one way price coupling". In other words, the findings are statistically significant.

Table 2: main results for the three implicit auctioning implementations on the Kontek Cable

	"No coupling"	"Volume coupling"	"One way price coupling"
Hourly observations	08/10/08- 08/11/09(*)	29/09/08 - 07/10/08(**)	09/11/09 - 16/04/10(***)
Mean	1228	3246	67
KW test	Comparing "no" with "volume" coupling: 0.037	Comparing "volume" with "one way price" coupling: <0.0001	Comparing "volume" with "one way price" coupling: <0.0001

(*): we do not consider the first period that this implementation was operational because in this first period the dead-band was not yet in place, and we have enough observations without this first period
(**): six days (08/10/08-13/10/09) are not considered because during these days there was no implicit auction operational in the transition from one implementation to the other
(***): one day 11/11/09 is not considered because there was no implicit auction on this day due to a technical difficulty with the implicit auction

Note that the unexpectedly bad performance of "volume coupling" on the Kontek Cable does not necessarily imply that it cannot be implemented more successfully elsewhere because of three main reasons. First, it has only been in operation for 10 days so it cannot be excluded that it would have performed better if it would have been launched at another moment in time. Second, the matching will be less problematic if the calculators are well coordinated. FGH/IAEW (2009) discusses that part of the problems with "volume coupling" on the Kontek Cable were indeed caused by the fact that EMCC, Nord Pool, and EEX were calculating with different rounding precision, they used different currency conversion rates for the order books, they used different block order selection procedures, etc. Third, the pricing will be less problematic if the curves have smaller steps (Figure 2, right: so that the price range "I" to just above "H" is smaller). Note that the more orders are submitted to a Power Exchange, the more the curves will become continuous, and with continuous curves, there is no need for price

period we analyze, this has been 22%, 1.25% and 7.3% of the time respectively for the "no coupling", "volume coupling", and "one way price coupling" implementations of implicit auctioning.

coordination, although matching can still be an issue. Some stakeholders did suggest that especially the curves in East-Denmark have significant steps (it is a relatively small zone), although there is no publicly available information to support this claim.

6. Conclusions and policy implications

The Kontek Cable hosted three implementations of implicit auctioning that can be clearly distinguished in terms of their theoretical properties and expected performance. The Power Exchanges that were already organizing trade nationally in the zones that the Cable interconnects have increasingly coordinated their day-ahead auction procedures, going from no coordination (first implementation: "no coupling"), to a coordination restricted to order matching (second implementation: "volume coupling), and finally a coordination that also partly encompasses pricing (third implementation: "one way price coupling").

"Volume coupling" is an attractive way for Power Exchanges to coordinate their day-ahead auction procedures because it implies that they can continue to calculate the hourly price reference in their own zone. Still, the stakeholders partly abandoned this approach they initially believed to be a viable alternative to "price coupling", which can be explained by its unexpected bad performance during the ten days that it has been operational on the Kontek Cable. In theory, "volume coupling" should have performed better than the "no coupling" implementation it was replacing on the Cable, but it did not due to mistakes that have been made with the first implementation of this approach.

The third time did turn out to be lucky for the stakeholders in the sense that the current "one way price coupling" approach is significantly outperforming its predecessors, but the stakeholders are not lucky in the sense that the implicit auction on the Kontek Cable continues to have cross-border trade inefficiencies, which can be explained by the "dead-band" that the owners of the Kontek Cable have imposed on the auction to generate enough revenue for them, and by the fact that in order for "price coupling" to perform perfectly, it needs to be implemented both ways.

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