

# ELECTRICITY SPOT TRADING IN GERMANY: PRICE FORMATION AND CONVERGENCE

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## ABSTRACT

This paper analyses the price developments between the European Energy Exchange EEX and OTC wholesale spot markets in Germany using a linear state space model based on Kalman filter analysis. Our results suggest increasingly integrated German wholesale spot markets for electricity. The results remain the same when correcting for the influence of the introduction of the emissions allowance trading.

## Keywords:

price development, market integration, electricity markets, Kalman filter

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## INTRODUCTION

The creation of organized wholesale energy exchange markets as a response to the European Directive (98/30/EC) has been an important breakthrough in the European energy market liberalization process. The Directive aimed at opening the electricity and natural gas markets across the European states to competition so that consumers would eventually benefit from a secure supply of energy for the least possible price. As a consequence, Germany deregulated its energy markets with the introduction of the German energy Act on 29 April 1998. Subsequently, two wholesale exchange spot markets, Leipzig Power Exchange (LPX) and European Energy Exchange (EEX, located in Frankfurt) started operation in the summer of 2000. The two power exchanges merged on 1 January 2002 into the present day European Energy Exchange (EEX) in Leipzig.<sup>1</sup> Previously, wholesale electricity spot trading in Germany had been organized bilaterally in the over-the-counter (OTC) market usually via telephone and facsimile and was therefore rather non-transparent. However, the changing nature of traded volumes at the wholesale electricity markets with a continuous increase in power exchange trading suggests that both the spot markets (OTC and energy exchange) have become an integral aspect of wholesale electricity trading in Germany today.

When speaking of volumes, the wholesale electricity trading has changed across the OTC and the EEX since the EEX spot market at Leipzig came into operation. In 2004, around 10 to 12 percent of the total underlying physical capacity was traded on the EEX spot market. Total turnover in the forward and future market was around 1500-1800 TWh, combining both OTC and the power exchange trading then. In 2005, around 347 TWh of the wholesale electricity trading was traded via power exchange while the remaining 90% (3123 TWh) was traded in the OTC market. As of 2007, the OTC market covered 1900 TWh of the total wholesale electricity trade. Meanwhile, the EEX also registered a trading volume of 1044 TWh in 2006 with a 200% increment from 2005. Hence, bilateral wholesale trading in the OTC market still dominates the German electricity wholesale market. But the development of the EEX power exchange has meant that the total bilateral trade is decreasing while the organized trade is rising.

The reverse pattern volumes development across both spot markets suggests that the EEX and OTC spot market are close substitutes to each other. In other words, with EEX in place, the wholesale market participants have an additional option of trading in two competing spot markets. This should result in the wholesale spot markets becoming increasingly competitive. On the other hand, the opaque characteristics of the still important OTC spot trading can hinder the development of competitive wholesale spot markets. This is because a non-transparent market can lead to the actual or potential abuse of market power. Also, the price formed in a non-transparent market may not actually depict the real economic conditions. In contrary, the power exchange spot price is an important reference price for OTC trading and thereby mitigates the disadvantage of a limited price transparency, low

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<sup>1</sup> From September 2009, the EEX spot market merged with the French Powernext to EPEX Spot SE.

levels of liquidity<sup>2</sup> and significant transaction costs involved under the OTC trading mechanism. Understanding the economic interaction between the EEX and OTC is a prerequisite for successful wholesale market development on a way to an integrated national market. Therefore this issue becomes increasingly important from both an economic and a policymaking perspective.

However depending upon the maturity of the wholesale markets, the economic interactions between these spot markets may not remain constant over time. Furthermore, the nature of price interactions may change with changing market developments and reforms in the wholesale market.

This paper studies the economic interactions over time between the spot market prices at the power exchange and the OTC market as a result of structural changes, new market designs and regulations. We therefore empirically examine if these spot market prices converge over time. Our results allow an evaluation on the success of wholesale market reforms and, by that, offer relevant policy conclusions.

Previous empirical research consists of two strands of literature that focus on either European electricity market integration or wholesale price formation in Germany. A study by Bower (2002) applied co-integration and co-relation techniques to the daily wholesale prices at various power exchanges in Europe concluding that some evidence of market integration was already in place in 2001. Similarly, Boisseleau (2004) focused on a regression and co-relation analysis to find that the level of integration of European markets was very low in 2002. Zachmann (2008) and Armstrong and Galli (2005) studied the European price developments over time. Using a Kalman filter analysis to study the price developments at the major European power exchanges, the former provided evidence of price convergence of Germany wholesale prices with the Dutch and Danish prices. The latter looked at the development of price differentials over time. With the results obtained from price differences, they conclude that prices across major power exchanges in Europe may be converging. Within the German context, a recent study by Growitsch and Nepal (2009) showed the long term evidence of co-integration between the spot prices on the EEX and OTC markets. However their study does not explain the development and convergence of the spot prices across the two markets over time.

A second strand of literature examined the level of competition on the German electricity market by means of market power analysis. Müsgens (2006) analysed the wholesale market prices in relation to the marginal cost finding evidence that strategic firm behaviour pushed the wholesale electricity prices from 2001 to 2003. On the contrary, Schwarz and Lang (2006) concluded that increasing fuel prices and 2005 emission allowance prices primarily led to an increase in the wholesale prices during the year 2004 and 2005. Weigt and Hirschhausen (2008) developed a competitive benchmark model to conclude that wholesale electricity prices at EEX were significantly above the competitive levels during most of the period of 2004 and 2006. On the other hand, Kemfert and Treber (2007) concluded that the German electricity market attained full competition by applying a strategic model to analyse market power and climate policy. Zachmann and Hirschhausen (2008)

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<sup>2</sup> An important factor for low levels of liquidity in an OTC market could be due to a restricted number of potential market participants ex ante unlike in a power exchange where there are no restrictions on the number of potential market participants.

found first evidence of an asymmetric cost pass through of emission allowance prices by examining the wholesale electricity prices in Germany. They conclude that the exercise of market power and hence a non-competitive wholesale market could be the reason behind such an asymmetric pass-through.

Amidst these contradictory findings, it is particularly interesting that none of the previous studies have studied the relation and dynamics of spot prices at the power exchange and the OTC spot prices in Germany. Thus, this paper contributes to the research on German wholesale electricity prices by assessing and understanding the price development in the wholesale market. Therefore, we empirically analyse the price formation over time across the two spots markets EEX and OTC, using the Kalman filter analysis (Kalman, 1960). Studying the path of price convergence across markets while accounting for dynamics of price developments enables us to identify market integration in the German electricity spot market as a process rather than a state. Our results give important insights about previous success and future energy market reform policy.

The paper is structured as follows. Section one discusses the fundamental wholesale market developments in Germany after the EEX at Leipzig started its operation since 2002. Section two describes the data used along with the descriptive statistics. The econometric methodology applied in this study is discussed under section three. The estimation results and discussions are elaborately carried out in section four, followed by the conclusions.

## **1. WHOLESALE MARKET DEVELOPMENTS IN GERMANY**

The German wholesale power market went through significant reforms and changes since its liberalisation in 1998. In 2000, two power exchanges started operations which have been merged to EEX in 2002. The electricity tax faced a rise in 2003.

In 2005, the trading rights for the emission of greenhouse gases were introduced within the EU as compliance towards the Kyoto Protocol. Since then, EEX provided a platform to trade the spot contracts for EU emissions allowance in the wholesale market. Since September 2006, the EEX also started operating an intra-day market increasing the overall volumes of trade in the wholesale market.

Notably as of 2009, the German transmission system operators (TSO's) are obliged to sell the entire portion of electricity generated from renewable sources on the spot market at EEX. This mandatory trading of renewable sources strengthens the importance of EEX spot markets against the OTC markets.

Similarly, the structure of the German electricity industry itself has undergone several changes since the deregulation started in 1998. Prior to deregulation, the power industry in Germany was traditionally organised in vertically integrated companies responsible for generation, transmission and distribution of electricity. Each company had a geographic monopoly and was obliged to deliver electricity within its region of operations. The liberalization of the electricity sector changed this into a competitive market where each consumer now could buy power from any electricity supply company within Germany (so-called market opening). As of 2005, around 200 new suppliers (other than renewable) had entered the German market since the deregulation in 1998. However the market opening also forced market players to engage in restructuring programs as 30 mergers (involving 80 companies)

and 100 co-operation ventures (including 500 companies) occurred, leading to a strong concentration process and profound structural change in the German electricity wholesale market. On the network regulation side, as of January 1<sup>st</sup> 2009, Germany switched to incentive regulation in the form of revenue caps from the traditionally practiced cost plus regulation. The regulatory regime in place can bear significant consequences for facilitating wholesale competition as the regulated transmission and distribution networks serve as platforms on which the competing wholesale and retail suppliers depend (Joskow, 2008). These changes in the form of market restructuring and new market rules might have affected the behaviour of the bilateral price as well as the power exchange wholesale electricity price in Germany.

## 2. DATA

The aim of this paper is to study the price development in the German electricity wholesale spot markets along with the structural market changes since the establishment of the EEX spot market. Although trading on the exchange spot market takes place on an hourly level no such information exists concerning the OTC spot trading. For this purpose we use the day-ahead spot prices for wholesale electricity traded via EEX and bilaterally at the OTC market. The day-ahead electricity prices are the daily average prices. The price data for EEX is obtained from the EEX website while the data for the OTC day-ahead prices is obtained from Energate<sup>3</sup>. The day-ahead prices is preferred against the forwards and future prices because it reflects the recent market situation and also precludes many of the uncertainties prevalent on forwards and futures markets. Also, the temporal aggregation problems experienced with the using lower frequency data (such as monthly, yearly) is avoided using the day-ahead prices.

The time frame of our analysis dates from March 3, 2003, which is the year after the start of operations of EEX at Leipzig, till May 29, 2009. The prices have been logarithmized as the spot market prices for electricity tend to be highly volatile and may be potentially heteroscedastic in nature. Figure 1 illustrates the price data graphically.

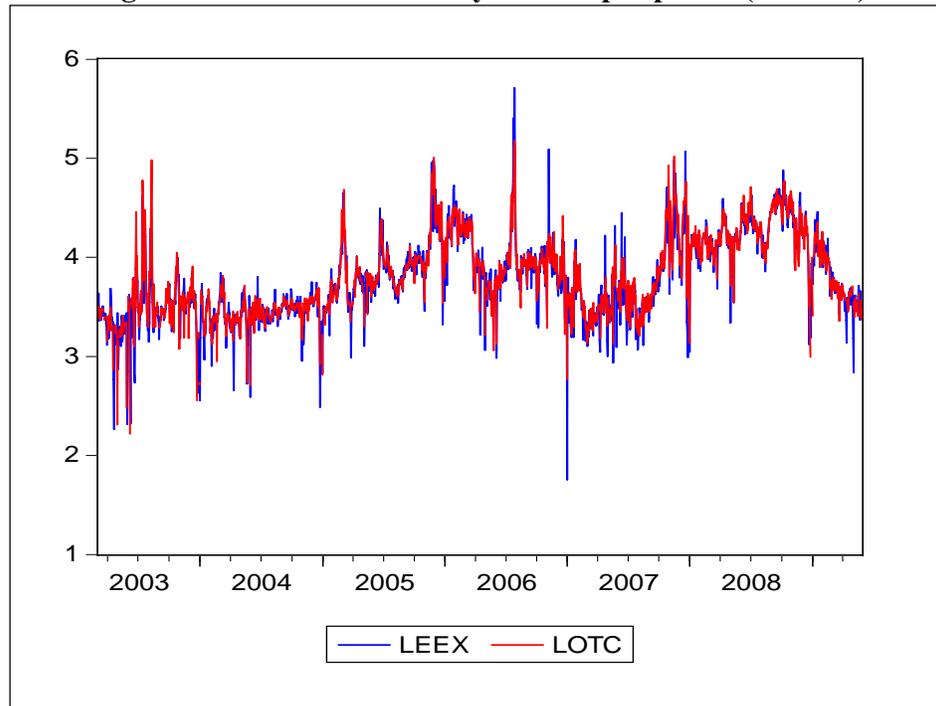
It can be observed from Figure 1 that the power exchange and bilateral prices share a similar pattern of price movements over time. But it is noteworthy to mention that the prices exhibit an inter-diurnal pattern rather than an intra-diurnal pattern due to daily average spot prices being used in our analysis. The year 2006 experienced the highest peak in the day-ahead spot prices as a result of increasing fuel and emissions allowance prices. Likewise a strong case of seasonal variation can be seen across both spot market prices. The descriptive statistics of the individual price series provide a picture on the statistical properties of the prices (Table 1).

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<sup>3</sup> Energate records the OTC price data obtained from Spectron, a brokering firm for OTC contracts.

It should be mentioned that Spectron OTC prices may or may not be truly representative of all the bilateral wholesale trading in Germany. The Spectron OTC German baseload power indices are calculated based on the volume-weighted average of all Day-ahead baseload transactions performed between 0800-1100 Central Eastern Time (CET) for delivery into the German transmission grids.

**Figure 1:**  
**Logarithmic transformed day-ahead spot prices (€/MWh)**



**Table 1:**  
**Descriptive statistics for price series (€/MWh)**

Variables	EEX	OTC
Mean	47.91	49.29
Median	41.47	42.94
Maximum	301.54	177.25
Minimum	5.80	9.20
Standard Deviation	22.23	21.51
Skewness	2.31	1.41
Kurtosis	16.98	5.81
Observation	1630	1556

A closer look at the standard deviations calculated from more than 1500 observations for each price series shows that prices on both markets are similarly volatile. The maximum price at EEX is slightly higher, the minimum price a bit lower than OTC. Overall both price series share rather similar descriptive statistics while the marginal differences might be attributed to the transparent versus non-transparent nature of trading settlement at the EEX and OTC market respectively. The next section describes the econometric methodology used in this study.

### 3. ECONOMETRIC METHODOLOGY

The aim of this paper is to study the price development across the German wholesale spot markets along with structural changes over time. Given such changes (such as new market designs, change in fundamental market rules and regulations) the markets in consideration are likely to change the pattern of their integration - either markets move towards a greater level of integration or they tend to separate from each other. Hence the notion of market integration or separation can be analysed respectively by testing for the convergence or divergence of the prices of the considered markets.

A well established method to identify price convergence is co-integration analysis. However one implicit assumption of co-integration analysis is that the structural relation among the prices is fixed over the considered time period. As mentioned in several studies, including King and Cuc (1996), the co-integration relationship completely ignores the *dynamics* of any possible price convergence or divergence. Considering the dynamic structural developments in the German wholesale electricity market as discussed previously, the assumption of a fixed relationship between spot prices over time seems indeed problematic.

Therefore we use a linear state space representation to understand the price convergence under a dynamic system. The state space approach incorporates the state variables (unobserved variables) to be estimated along with the observable model. The state space model is analysed using Kalman filter analysis which is based on a recursive algorithm. With this approach, the nature and path of price convergence across markets can be studied, explaining market integration by estimating a time-variant coefficient model. Using the day-ahead spot prices at EEX and OTC market, the following equations can be formulated constituting a linear relationship between the two markets:

$$P_{eex,t} = \alpha_{eexotc} + \beta_{eexotc,t} P_{otc,t} + \varepsilon_t \quad (1)^4$$

$$\beta_{eexotc,t} = \beta_{eexotc,t-1} + \theta_t \quad (2)$$

Equation (1) is termed as the ‘signal’ or ‘observation’ equation while equation (2) is known as the ‘state’ or transition equation. In the above set of equations,  $\varepsilon_t$  and  $\theta_t$  are normally and independently distributed random error terms (with zero mean and a normal variance  $\sigma^2$ ) or white noise.  $\alpha_{eexotc}$  captures the transaction cost between the EEX and OTC day-ahead spot markets while  $\beta_{eexotc}$  describes the price relationship between the two markets considered: if the EEX and OTC spot markets are perfectly integrated the value of  $\beta_{eexotc,t}$  equals unity at any time  $t$ . This implies that the prices across both markets are fully converged and that any price differences between the two markets can be attributed to the transaction costs involved in trading. On the other hand, if  $\beta_{eexotc,t} = 0$ , the prices of day-ahead electricity traded on both markets bear no relation with each other any time:

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<sup>4</sup> Alternatively the linear relationship of prices between the two markets can also be constituted such that the day-ahead spot prices at OTC market is a function of the spot price at the EEX:

$P_{otc,t} = \alpha_{eexotc,t} + \beta_{eexotc,t} P_{eex,t} + \varepsilon_t$ . In either case, equation two holds true.

t implying perfectly uncorrelated prices. So the case of  $\beta_{\text{eexotc},t} = 1$  is also a conformity towards the law of one price<sup>5</sup>.

If EEX and OTC day-ahead markets are fully integrated or the spot prices are in full convergence, the value of  $\{\lim_{t \rightarrow \infty} (P_{\text{eex}} - P_{\text{otc}})\} = \alpha_{\text{eexotc}}$  while the final state of convergence shall be  $\{\lim_{t \rightarrow \infty} \beta_{\text{eexotc}}\} = 1$ . The transactions costs of trading across the two markets are considered to be constant over time in our model.

Applying the time variant co-efficient model to the whole price sample ( $P_{\text{eex}}$  and  $P_{\text{otc}}$ ) will enable us to identify the joint development of prices. It provides information on the value of state variables ( $\alpha_{\text{eexotc}}$  and  $\beta_{\text{eexotc},t}$ ) for each point in time for both price series. Therefore the Kalman filter processes the data on both price series in two consecutive steps. It first estimates  $\beta_{\text{eexotc},t}$  by using available information till the period t-1. As a second step the estimates of  $\beta_{\text{eexotc},t}$  are updated by incorporating prediction errors from the first step as information at the time t is realized.

The time variant coefficient model produces linear minimum mean error estimates of  $\beta_{\text{eexotc},t}$  using observed and available data through time t. Thus, being based on a specific optimization recursive algorithm, it allows for the updating of the model estimations using newly available information (Hamilton, 1994). The filter approach ensures that the corrections made in  $\beta_{\text{eexotc},t}$  beyond t (say t+k) follow a time-varying moving average process of order k-1. The next section presents the results of our time variant co-efficient model with a detailed discussion.

#### 4. ESTIMATION RESULTS AND DISCUSSIONS

As a pre-requisite to the empirical analysis it is necessary to analyse and examine some statistical properties of the data used in the estimations. Hence, we begin with the unit roots tests as a first step of our empirical analysis. To test for the presence of a unit root we apply the Augmented Dickey Fuller (ADF) test (Dickey and Fuller, 1979). The results from ADF tests on the first difference of both price series suggest that the price series are stationary as the p-value is significant at the 1% level of significance. This implies that both the price series are integrated of order one or I(1).<sup>6</sup> The absence of a unit root can be explained by the fact that electricity is not economically storable unlike other commodities and hence cannot be allocated between different periods in time.

Given the stationary price series as suggested by the ADF test, we study the economic interactions among the price series at the day ahead OTC and EEX spot markets by means of correlation analysis. Table 2 presents the results.

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<sup>5</sup> The law of one price can be interpreted such that in well integrated markets, any price differential between the markets should eventually converge towards the transaction costs. For the OTC market the transactions costs would be the search cost, information cost and bargaining costs involved in trading among different players. Concerning exchange trading transaction costs is the fee of participating in the EEX.

<sup>6</sup> The price series being I (1) also imply that they are co-integrated which can be interpreted as a pre-test towards testing for price convergence using any co-integration tests.

**Table 2:**  
**Correlation coefficients of the price series**

Variables	EEX	OTC
EEX	1.000	0.938
OTC	0.938	1.00

The table shows a high degree of co-relation between the two prices. This result implies a strong indication of interdependence between the spot markets. This strong interdependence indicates the prices are being driven by each other or by an exogenous third factor that simultaneously affects each price series separately. To analyse the further nature of interdependence in the price series not revealed by correlation analysis, a Granger causality test (Granger 1969) is used. Table 3 shows the results.

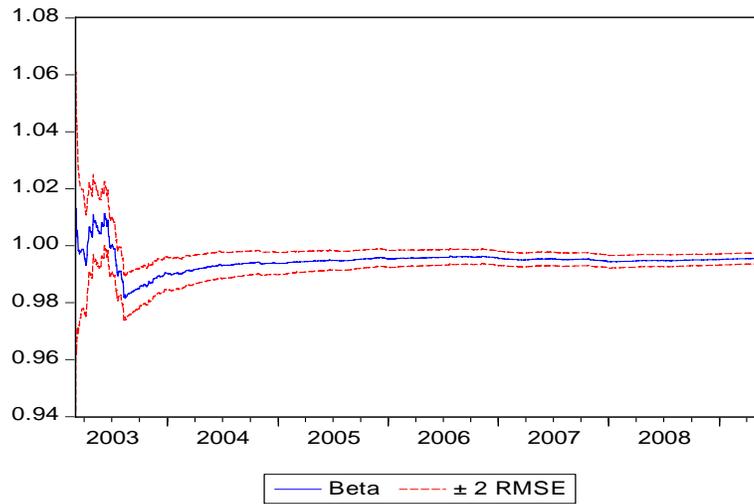
**Table 3:**  
**Granger Causality tests**

Pair-wise Granger Causality Tests		
Lags: 2		
Null Hypothesis	F-Statistic	Probability (p-value)
OTC does not Granger cause EEX	82.07	0.000
EEX does not Granger cause OTC	46.43	0.000

The results from the Granger causality test suggest a bi-directional causality between the two spot markets. This might be interpreted as that a common market exists and that both EEX and OTC spot prices are driven by the same exogenous factors. In another words a bi-directional causality might be a sign of an integrated market. However the development and dynamics of market integration cannot be detected from a Granger causality test. Therefore we use a linear state space model for this purpose.

The time variant co-efficient estimations based on a recursive algorithm allow us to analyse the convergence/divergence path of the prices series over time allowing for various structural changes discussed in section two. With the use of the Kalman filter, the effect of these structural changes on the spot markets' integration can be examined by observing the development of the  $\beta_{eexotc}$  co-efficient over time. Figure 2 demonstrates the time varying path of  $\beta_{eexotc}$  for the day-ahead prices across the German EEX and the OTC market within the stipulated (+ 2 and -2) mean square errors. The final state value of the beta co-efficient being 0.99 suggests an integrated wholesale market. The state vector also seems considerably increasingly stable after 2005, which was the year of the emissions tradings introduction.

**Figure 2:  
Time varying path of the convergence coefficient**



To specifically understand the market integration process through price convergence we also analyse the short run dynamics. Therefore, we apply a vector error correction model (VECM) in order to comprehend the long run convergence process via short term price adjustments given a certain policy shock. Table 4 reports the error correction co-efficients obtained from our VECM estimates. The error correction co-efficients (or adjustment co-efficients) being significantly large, confirm the convergence process. After a certain policy shock, around 68% of downward price adjustment occurs in the overall wholesale market by changes in the EEX spot prices alone, while 30% of upwards price adjustment occurs by changes in the OTC spot prices from one period to the next. We explain the higher magnitude and speed of price adjustment in the exchange spot by the higher information transparency and liquidity allowing the exchange spot market to absorb and incorporate new available market information quickly into the prices. Thus information efficiency, which in this paper we define as the ability of the market to respond to new market signals, is at least twice as much in the exchange spot market than in the OTC spot market. Based on this result, the increasing volumes of trade in the exchange spot market in Germany is certainly promising in enhancing the overall informational efficiency of the wholesale market as a whole.

**Table 4:  
VEC estimates**

Error Correction:	d(EEX) (in logs)	d(OTC) (in logs)
Co-integration Equation	-0.6793 (0.0633) [-10.7241]	0.2979 (0.0567) [5.2491]

The policy reforms as discussed in section 2 lead to an increase in the number of wholesale market participants, along with new products and increasing volumes of exchange electricity trading coupled with the re-design of network regulation, which seem to have facilitated the overall wholesale market integration process in Germany.

However, the convergence co-efficient shown in Figure 2 incorporates the carbon price in assessing the degree of wholesale market integration. A recent study by Zachmann and Hirschhausen (2008) has shown that rising prices of emission allowances have a stronger impact on electricity prices than falling prices, identifying strategic asymmetric cost pass-through. Hence we find it necessary to assess the degree of market integration in the absence of carbon prices to gauge the importance of allowance prices concerning wholesale market integration. Therefore we re-estimate our state space model with EEX and OTC electricity prices net of emission costs. The net prices indicate the net revenue that a generator could earn having bought the gas and required number of carbon allowances. This is calculated as  $\text{Net prices} = \text{Price of Electricity} - [(\text{Price of CO}_2) * (\text{Gas Emissions Intensity})]$  where the gas emissions intensity factor is considered to be 0.411 tCO<sub>2</sub>/MWh.

**Figure 3:**  
**Time Varying Path of the convergence coefficient ( $\beta_2$ ) for net prices**

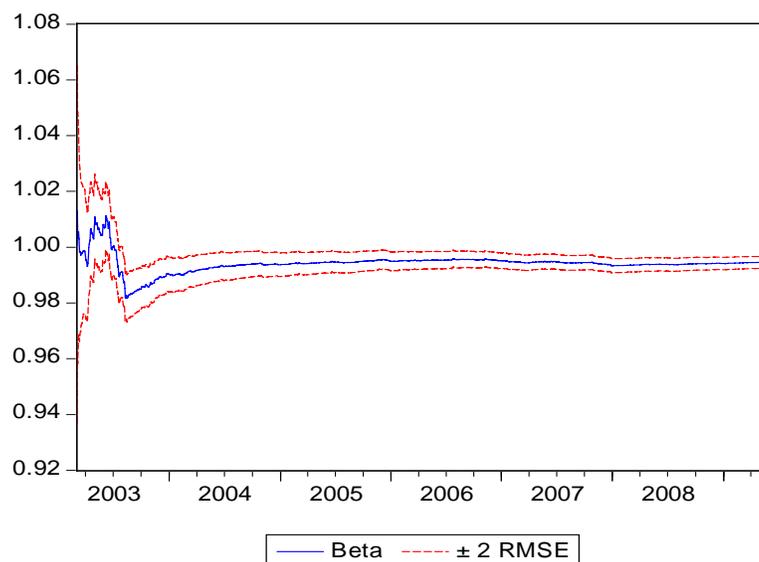


Figure 3 displays the results obtained for the net wholesale prices of electricity for EEX and OTC. The final state co-efficient being 0.99 confirms the result of the previous estimation confirming the development path established to our first model. Nonetheless, the current state of market integration from our results suggests that the arbitrage opportunities across the two markets have exhausted over time with strong price convergence. However the results should not be interpreted as if the wholesale spot markets are entirely efficient yet, as market integration is an on-going process.

## CONCLUSION

In 2002, the European Energy Exchange (EEX) started operations, changing electricity spot trading in Germany fundamentally. Since then, the previously dominant form of trading OTC is declining. The aim of this paper was to study the price development and convergence of the EEX and OTC day-ahead spot markets in relation to new market developments and structural changes over time. Therefore we applied a linear state space model based on a Kalman filter approach. This procedure allowed us to comment on the degree of market integration between the markets via an analysis of price convergence. Our results suggest an integrated wholesale spot market of electricity in Germany. The operation of EEX at Leipzig starting 2002 followed by extensive wholesale market reforms indeed contributed to the wholesale spot markets integration in Germany. These results also hold when the prices are corrected for the emissions prices. Applying a Vector Error Correction Model confirmed the importance of the EEX as a driver of price adjustments at the OTC spot market.

While market integration is a result of increasing market competition, our results however should not be interpreted as the wholesale markets being perfectly competitive yet. Further research is recommended to diagnose the exact competitive nature of the wholesale spot markets in Germany. Although we believe the results will not change significantly, alternative OTC hourly spot price data may provide additional insights in understanding the whole market integration process especially in the price adjustment process. Also the effect of the EEX spot market having merged with the French Powernext might be an interesting field for future analysis.

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