Natural Gas Market Integration in Germany

Christian Growitsch[1*]

Rabindra Nepal[1]

Marcus Stronzik[1]

[1] WIK GmbH, Department of Energy Markets and Energy Regulation, Rhöndorfer Strasse, 53604, Bad Honnef, Germany.

*Corresponding author. Email c.growitsch@wik.org

Abstract:

In 2006, Germany changed the network access regulation in the natural gas sector and introduced a so called entry-exit system. While the number of balancing areas and corresponding wholesale trading hubs has been reduced from 19 to 10 thereafter, its subsequent effect on market integration and competitiveness remains to be examined. This paper empirically analyses the impact of common market operation between the entry-exit zones and market integration via price convergence analysis. We use the econometric techniques of cointegration and time varying coefficient estimation based on Kalman filter to study the development of market integration between the two major entry-exit zones in Germany. Our results suggest a fair price convergence between the entry-exit zones implying an increasingly integrated market. The results thus support the notion of a competitive natural gas wholesale market through greater market integration in Germany.

Keywords: entry-exit, cointegration, Kalman filter, price convergence, market integration

1. Introduction

The introduction of the European Gas Directive (see 98/30/EC) and the EU ‘Acceleration Directive’ (see 2003/55/EC) has brought fundamental changes in the natural gas sector across many European countries. As such, the natural gas industries have been transformed from the vertically integrated monopolies to more competitive structures in the liberalisation process. While some countries have been relatively progressive in the liberalisation process such as the UK and the Netherlands Germany opened its natural gas market effectively not until the EU directive 2003/55/EC had been transferred into the national law.

The German Energy Law (Energiewirtschaftsgesetz), introduced in July 2005, actually aimed at accelerating the process of market opening in the natural gas sector. It established network access based on an entry- exit system. As of October 2006, an agreement on the institutional design of that new regime was decided upon between the network operators and the German energy regulator (Bundesnetzagentur). The implementation of the entry-exit system has led to the establishment of different virtual trading points (hubs) for trading natural gas in Germany.

This paper evaluates the regulatory redesign in terms of its impact on wholesale market development. Given the varying nature and patterns of trades at most of trading hubs, it remains an open question whether a sufficient liquidity or a satisfactory degree of market integration has been reached so far. On the other hand, it is necessary to examine whether the desired level of competition in the market areas has been attained, yet. Nonetheless, at two of the German hubs, a functioning market for natural gas seems to have evolved. Whether these two sub-national markets are yet competitive remains to be empirically tested.

Competitive connected markets should show equal prices for a certain good (law of one price). Such markets are economically integrated. Given that market integration is a state as well as a process towards an economic equilibrium, one way to analyse the presence of a competitive and integrated natural gas market with open network access is testing price convergence across different market areas. In this paper we study whether the introduction of the entry-exit system in Germany has facilitated the market integration and hence competition in the German natural gas wholesale market via analysing price convergence, therefore. To test for price convergence, cointegration analysis is used. To examine the convergence path of the price series and the degree of market integration, we use Kalman filter analysis (Kalman, 1960). It is used to support the results obtained from cointegration analysis by taking into account possible dynamic structural changes along the path towards market integration.

However, analysing the price convergence of the two German hubs might be misleading, as it neglects the possible importance of other connected European gas trading places. Hence, as the Netherlands plays a pivotal role in the natural gas market in the continental Europe, it is included in the analysis. Its extensive cross border connections especially with Germany make the Netherlands to act as a gas roundabout for natural gas flows across northern Europe. So, we consider the Dutch hub Title Transfer Facility (TTF) as an anchor to test for cointegration in our cointegration analysis.

Summing up we use the static Johansen method of cointegration as well as the dynamic Kalman filter technique to study the fixed and time varying structural relationships between the prices across two main market areas in Germany which is Europe's largest gas importer and consumer and the Netherlands, Europe's largest gas exporter after Norway. The two German market areas studied in this paper are Net- Connect –Germany (NCG) covering central and Southeast Germany and Gasunie Deutschland (GUD) covering northern Germany. The prices of natural gas across the German markets are subsequently studied against the Dutch hub. The Dutch TTF market can be considered to be one of the most liquid wholesale gas trading hubs (Wood, 2008) in continental Europe besides Zeebrugge. So, the Dutch local gas trading place can serve as a competitive benchmark for the German gas spot market.

The paper is structured as follows. Section two describes the institutional design of the German natural gas market. Section three discusses the previous literature involving the fixed and time varying structural relationships across different markets testing for price convergence and market integration. The econometric methodology is discussed in section three. The data description along with the descriptive statistics is carried out in section four. Section five includes the results estimation and discussions. Finally, section six concludes with potential policy recommendations.

2. The German Natural Gas market's institutional design

The German Energy Law (Energiewirtschaftsgesetz), introduced in July 2005, actually aimed at accelerating the process of market opening in the natural gas sector. It established network access based on an entry- exit system. As of October 2006, an agreement on the institutional design of that new regime was decided upon between the network operators and the German energy regulator (Bundesnetzagentur). The agreement initially divided Germany into 19 entry-exit zones[2] (also called the market areas or transmission system zones). The entry-exit system required that the natural gas shippers book capacity at the relevant entry and exit points separately. Hence, the fees to be paid for the transportation of natural gas (so called entry and exit charges) should therefore no longer be based upon the distance between the entry and exit points (also known as the contractual path) as practiced in Germany, before. The abolition of such a 'path based' charging system was meant to promote price transparency as shippers need not obtain individual quotations for each separate customer, thereby reducing pricing complexity. Also, the trading possibilities at multiple hubs as a result of an entry-exit system should deliver a competitive price signal to the German natural gas market as a whole. It should facilitate both domestic as well as cross border transports for third parties thus encouraging market entry and eventually competition. Furthermore, the market redesign aimed at increasing the flexibility and comfort in booking procedures as no capacity reservation is required for individual pipeline sections used for the fulfilment of transport contracts. So, consumers and distributors were intended to benefit from increasing gas-to-gas competition as a result of entry-exit practice after gas market liberalisation.

The reform's economic success faces certain risks, however. A high number of market areas complicates market operations. Also, the dominant players may continue to operate in their own zones while smaller companies may be deterred. The transmission of natural gas via the network may become expensive due to pancaking and also may be impossible due to congestion and grandfathered capacity rights held by the incumbents. Such market barriers could effectively rule out the aim of achieving competition and liquidity in the natural gas sector even with the introduction of the entry-exit regime.

3. Literature Review

Different studies have been carried out worldwide on natural gas markets integration and convergence as an aftermath of market liberalisation. However, the methodology to account for market integration and price convergence differs across studies. Walls (1994) finds using cointegration analysis that the opening of network access led to greater market integration as

[2] Currently, Germany has 10 market areas operated by a certain transmission system operator transporting both H and L gas (as of May 2009). H-gas is high calorific natural gas primarily delivered from Norway and Russia to Germany. L-gas is a low calorific natural gas and has a lesser energy content than H-gas. L-gas is imported from Netherlands to Germany.

prices across different locations converged in the North American natural gas markets. Similarly, Ripple (2001) studied the extent of market integration for the US West Coast with Asia and US Gulf coast through cointegration analysis. Likewise, King and Cuc (1996) examined the degree of pair wise price convergence using a Kalman Filter approach in the North American natural gas spot markets. They conclude that the price deregulation of the mid – 1980s has indeed led to price convergence in the natural gas spot markets.

In the European context Neumann et al. (2005) study the relation between spot markets for natural gas in Europe using the Kalman filter analysis based on a specific recursive optimization algorithm. Using the time varying coefficient they conclude the presence of a full convergence of prices between the spot markets in the UK (National Balancing Point) and Belgium (Zeebruge). Also, a recent paper by Neumann (2008) has examined the natural gas price convergence across the transatlantic natural gas using the Kalman filter analysis. The results suggest integrating markets via creasing convergence of spot prices on either side of the Atlantic Basin. Similarly, Asche, Omundsen and Tveteras (2001) applied cointegration technique to test for the law of one price across the French, German and Belgian market. Their results show an integrated gas market as prices across several markets follow a similar pattern over time. Furthermore, Schieb et al. (2006) have carried out an analysis of the liberalised German gas market based upon a model looking at transit flows between entry-exit zones. They conclude that third party network access is a pre-requisite for an efficient gas market. However, they do not explicitly test for price convergence and competitiveness. So, the current study differs from the growing and already existing literature on natural gas market integration as it describes the dynamic price interactions among two major German gas spot markets using cointegration and Kalman filter analysis[3] allowing conclusions about the progress of competitive development in the German wholesale gas market.

4. Econometric Methodology

In well connected and competitive market networks with zero transportation and transaction costs, the law of one price should hold for similar or almost identical products across the markets (Hasbrouck, 1995). However, real world complexities in trading imply that transaction costs are usually not zero and markets are not perfectly competitive in general[4].

[3] Please refer to Zachmann (2005) for a thorough analysis of the Kalman filter approach studying the convergence of electricity wholesale prices in Europe.

[4] A more realistic understanding of the law of one price would be that in the absence of market power abuse prices across identical products across two markets should converge in such a way that the difference should only reflect the transportation costs in the long run.

So, applying well established techniques in empirical market analysis, we use the cointegration technique to test for price convergence. The cointegration of price series implies a stable long run relationship between the prices. Therefore, cointegration is conclusive of price convergence and thereby market integration. In contrary, the absence of cointegration between the prices series implies that the markets in consideration are not integrated. Although different methods of cointegration exist, we have used the standard Johansen (1988) and Johansen and Juselius (1990) test to examine any evidence of cointegrating relationship among the price series.[5]

However, the various tests for cointegration are built upon a fundamental assumption that the cointegrating vector is constant over time. On this note, previous studies by King and Cuc (1996) and Caporale and Pittis (1993) have pointed out that the cointegration test relies on an implicit assumption that the structural relation among the variables is fixed over the considered time period. In practice, however, the cointegrating vector should be able to change or shift allowing for a change in the long run relationship across the price series. Also, when the observation period is long, dynamic structural changes (technological, economic, political and institutional) may cause a change in the long-run equilibrium relationship. So, the legacy of the cointegration test tends to diminish when there are dynamic structural changes in the market. Hence, it is also unable to detect market integration when the integrated period is not a long enough subset of the entire period of study. Li (2008) argues that even though one may try to break down the data into different sub-samples and repeat the cointegration test, the degrees of freedom can be thoroughly exhausted and hence the test may lack power. Also, a study by Kleit (2001) explicitly criticises the uses of cointegration analysis in explaining the degree of market integration via price convergence. Kleit argues that cointegration is just able to determine whether the prices series are converged or not without shedding any lights on the dynamics of possible price convergence or divergence. Kleit further argues that cointegration test may probably reject cointegration even though convergence has occurred towards the end of the sample period.

A technique which accounts for the dynamics of parallel price development from market separation towards market integration is the so called Kalman filter analysis. It is used to

[5] The Johansen procedure estimates the parameters of cointegrating relationships across the price series by testing for a number of distinct cointegrating vectors.

understand the nature and path of price convergence in explaining market integration using a time-varying recursive coefficient.

Applying the Kalman filter allows us to analyse the extent of market integration studying the path of price convergence. This is done by introducing a time varying coefficient into the linear relationship of prices without having the need to break down the data into sub-samples.

Consider a stochastic equation (1) where the relationship between the prices across two markets is analysed using the Kalman filter. The price of good in market X (P_x) can be expressed as a function of the price in market Y (P_y) over time:

$$P_{x,t} = \alpha_{xy,t} + \beta_{xy,t} P_{y,t} + \varepsilon_t \tag{1}$$

where α_{xy} captures the transactions and transportation costs between the two markets X and Y, $\beta_{xy,t}$ represents the strength of the price relationship across the markets considered and ε_t is a white noise or a random error term and is normally distributed such that $\varepsilon_t \sim N(0, \sigma^2)$. The state path governing the relationship between the prices across the two markets is be [$\alpha_{xy,t}$, $\beta_{xy,t}$]. Assuming the transportation costs to remain constant over time, the vector of the unobservable coefficient $\beta_{xy,t}$ which varies across the considered period should denote the strength of market integration through price relationship across the considered markets over time. So, when $\beta_{xy,t} = 0$, it implies that there is no relation between the market prices at any time t such that the markets are not integrated at all. Similarly, when $\beta_{xy,t} = 1$ at any time t suggest a full market integration. In this case, the law of once price holds meaning that the price differential is stationary with constant relative prices.

Now, following the constant transportation cost argument a transition equation (2) based upon a time-varying coefficient estimated using the Kalman Filter can be formulated. The intuitive appeal of equation (2) is that the values of β_t take into account the information of previous observations.

$$\beta_{xy,t} = \beta_{xy,t-1} + \theta_t \tag{2}$$

where θ_t is also a white noise process or a random error term and is normally distributed such that $\theta_t \sim N(0, \sigma^2)$. From equations (1) and (2), it can be deduced that if the markets (X and Y) are integrated (and competitive), the price differential across the two markets should converge towards transportation costs in the long run such that $\beta_{xy,t}$ is expected to converge towards unity. Thus, if markets X and Y are fully integrated and competitive in the long run, we expect that $\{\lim_{t \to infinity} (P_x - P_y)\} = \alpha_{xy}$ while the final state of convergence shall be $\{\lim_{t \to infinity} \beta_{xy}\} = 1$.

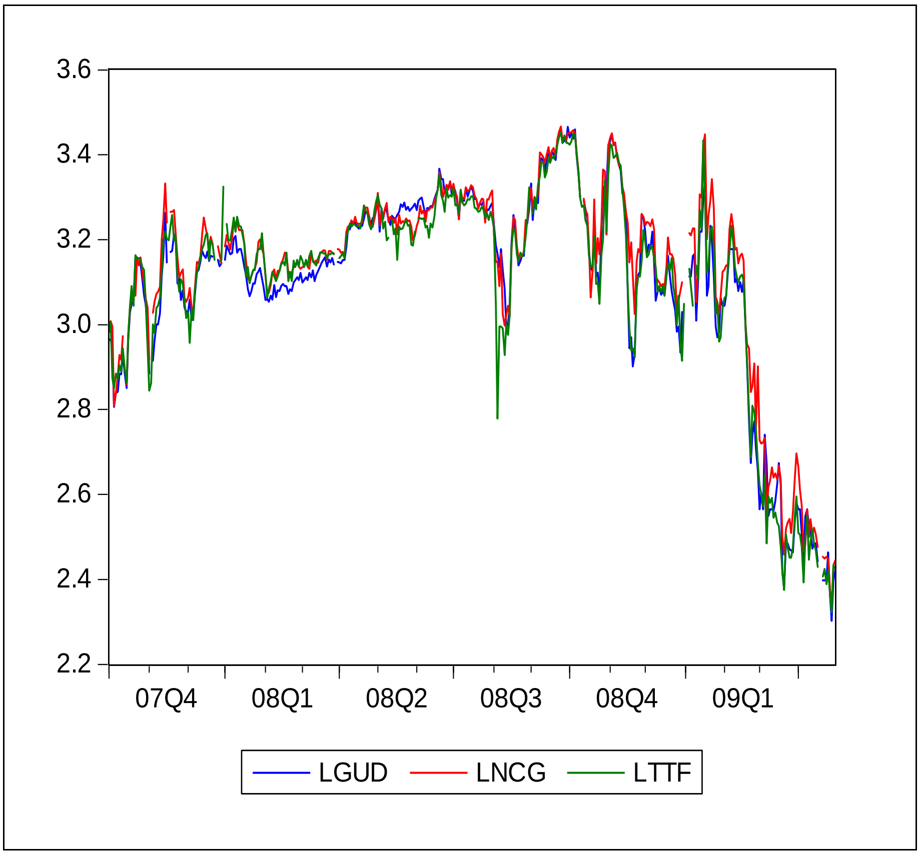
So, using the Kalman filter technique to the whole price sample (P_x and P_y) will enable us to obtain detailed information on the trends contained within the prices over time. It provides information on the value of state variables ($\alpha_{xy,t}$ and $\beta_{xy,t}$) for each point in time for both price series. The Kalman filter processes the whole data on both price series in two consecutive steps. It first estimates $\beta_{xy,t}$ by using available information till the period t-1. As a second step, the estimates of $\beta_{xy,t}$ are updated by incorporating prediction errors from the first step as information at time t is realized.

The Kalman filter as a result produces linear minimum mean error estimates of $\beta_{xy,\,t}$ using observed and available data through time t. Thus, the Kalman filter which is based on a specific optimization recursive algorithm allows for the updating of the model estimations using newly available information (see Hamilton, 1994). The filter approach thus ensures that the corrections made in $\beta_{xy,\,t}$ beyond t (say t+k) follow a time-varying moving average process of order k-1. As the error terms are assumed to be normally distributed, the parameters ($\beta_{xy,t}$) can be estimated using the maximum likelihood method (Harvey, 1987).It implies that the results obtained from Johansen cointegration technique should eventually complement the results obtained from the Kalman filter estimations. This is because the Johansen cointegration procedure is based on a maximum likelihood method. Hence, using the standard Johansen procedure of cointegration based upon the maximum likelihood tests, we show that the results from Kalman filter also supports the result obtained through cointegration by observing the long run normalized 'β' coefficient.

5. Data and descriptive statistics

The aim of this paper is to test for market integration via price convergence between the major two entry-exit zones in Germany namely GUD and NCG. Additionally we check for price relations with respect to the Dutch trading hub TTF which has well established trade connections with Germany and is also a major gas producer. For the German trading hubs, we have used the day-ahead spot market settlement price for natural gas as publicly obtained from the European Energy Exchange while for TTF the data has been obtained from Energate. The day-ahead data price is preferred to using weekly or monthly price data so as to portray the current institutional and infrastructural conditions in the markets being studied. Taylor (2001) argues that using lower frequency data (such as monthly or yearly) to study the price adjustment process can lead to temporal aggregation problems. So, the use of high frequency recent data should capture the reactions to ongoing regulatory and market reforms, thereby facilitating in the study to examine market integration. The timeframe for the data used in this study dates from 1st of October, 2007 when the mandatory introduction of the entry-exit system came into operation to the 30th of April, 2009. The prices have been transformed into logarithmic form as the spot market prices for natural gas tend to be highly volatile and may be potentially heteroscedastic in nature. The prices series can be observed in Figure one.

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



It can be seen from figure one that the day-ahead prices for natural gas were volatile throughout the considered time period for all market areas. The prices became more volatile during the last quarter of 2007 while the volatility moderated from the first quarter of 2008 till the second half of the third quarter of 2008. The prices then peaked across both market areas with immense volatility while the first quarter of 2009 also witnessed a steep decline in the prices for natural gas. We believe the decline in the natural gas prices is due to the falling prices for crude oil as the gas prices in mainland Europe are index-linked to that of crude oil with a six-month time lag. The descriptive statistics (see Table 1) governing these price series further provide a clear picture regarding the true nature of the above price series.

Table 1: Descriptive statistics for respective price series (values in logs)

€/MWh	GUD	NCG	TTF
Mean	3.10	3.13	3.09
Median	3.15	3.18	3.16
Maximum	3.47	3.47	3.45
Minimum	2.30	2.34	2.32
Standard Deviation	0.25	0.23	0.25
Skewness	-1.39	-1.55	-1.50
Kurtosis	4.50	5.02	4.65
Observation	394	394	394

The standard deviation generated from 394 observations for each price observation shows that the spot prices at the GUD and TTF hubs remained more volatile and unpredictable in general as compared to NCG. The maximum and minimum price limit albeit stays similar across all three market areas while skewness and kurtosis suggest that both price series remained normally distributed in general. Interestingly, GUD and TTF share similar descriptive statistics indicating that the prices across these trading hubs are closely related with each other. The marginal differences in the day ahead prices across the descriptive statistics between GUD and TTF might be attributed to the differences in the regulatory environment in Germany and the Netherlands respectively. In the next section, estimations and results based on the data described above are discussed.

6: Results Estimations and Discussions

Before applying the Johansen test of cointegration and the Kalman filter approach it is necessary to examine the economic properties of the data used. So, we proceed with the unit roots testing as discussed below.

6.1: Testing for Unit Roots

To assess the qualitative and quantitative aspects of the data used, unit roots testing is basically carried out as a pre-test for any time series analysis. The absence of a unit root in a price series implies the time series to be stationary[6] where the statistical properties of the series as a stochastic process do depend on time t. As a first step towards unit roots testing, we apply the widely used Augmented Dickey Fuller (Dickey and Fuller, 1979) test for non-stationarity. However, due to the low power associated with Augmented Dickey Fuller (ADF) in detecting the unit roots we applied the stationarity test suggested by Kwiatkowski, Phillips,

[6] Please note that a time series may be stationary in terms of mean but not variance.

Schmidt, and Shin (1992). A significant test statistic under ADF indicates a stationary time series while for Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) a significant test statistic means a non-stationary series. Table 2 presents the unit roots testing for the price series used in this study. The lag lengths for ADF testing was automatically selected using the Schwarz Information Criterion (SIC) while bandwidth selection under KPSS was automatically based on Newey-West.

Table 2: ADF and KPSS Unit Roots Testing

ADF		KPSS	
H_o: X_t has a unit root H_1: X_t does not have a unit root		Ho: Y_t is stationary H1: Y_t is non-stationary	
X_t	Probability (p-value)	Y_t	Probability (p-value)
GUD	0.39	GUD	0.00
NCG	0.38	NCG	0.00
TTF	0.42	TTF	0.00

The results from both ADF and KPSS unit roots testing suggest that all considered price series are non-stationary and follow a random walk at 1% level of significance. The results mean that the day ahead spot prices at both market areas considered experience unit root behaviour in their prices. Such presence of unit root can be explained by the fact that in contrast to electricity, natural gas is economically storable so it can be allocated between different periods when required. Hence, today's gas prices can also serve as a near or good estimate for tomorrow's gas prices as suggested by the unit roots hypothesis.

The existence of a unit root according to both ADF and KPSS tests also confirms that the price series are non-stationary in levels but stationary in first differences. This means that all the price series are integrated of order one which is a required characteristic prior to testing for meaningful cointegration. The next section discusses the results obtained from cointegration.

6.2: Cointegration

As mentioned above, we consider the Dutch TTF as a liquid reference market for our cointegration analysis. Based on this assumption we treat both German market areas as endogenous variables while testing for cointegration. The Johansen method of cointegration is applied to test for the presence or absence of cointegration for the price series considered in this study. The Johansen cointegration method treats both variables endogenously unlike

Engle and Granger (1987) approach where we are obliged to specify a variable as dependent and independent as the variables are treated asymmetrically. A lag length of 2 is chosen for an independent and identical distribution of the error terms. The critical values for the cointegration test are based on the estimations by MacKinnon, Haug and Michelis (1999) (MHM). Furthermore, in terms of the deterministic trends in the model, the constants are restricted while no trend is assumed in the cointegrating relations. This is done as to not affect the power of the test. Table 3 presents the results from the cointegration test where the test for cointegration is made for each market area against the others considered in our dataset.

Table 3: Cointegration test between GUD and NCG with TTF day-ahead spot prices

Variables	**Null hypothesis (H_0)**	**Alternative hypothesis (H_1)**	**Maximum eigen-value statistics (λ_{max})**	**Critical value (5%)**	**Probability (p-value)**	**Trace statistics (λ_{trace})**	**Critical value (5%)**	**Probability (p-value)**
GUD	**r = 0**	**r = 1**	**34.46**	**14.26**	**0.000**	**35.58**	**15.49**	**0.000**
TTF	**r ≤ 1**	**r = 2**	**1.13**	**3.84**	**0.2888**	**1.13**	**3.84**	**0.2888**
NCG	**r = 0**	**r = 1**	**41.86**	**14.26**	**0.000**	**42.85**	**15.49**	**0.000**
TTF	**r ≤ 1**	**r = 2**	**0.99**	**3.84**	**0.319**	**0.99**	**3.84**	**0.319**

The results from cointegration suggest that at 5% level of significance the null hypothesis of no cointegration or none cointegrating vector (r = 0) is rejected while the null hypothesis of at most one (**r ≤ 1**) cointegrating vector cannot be rejected. Thus, the results show that these price series have one cointegrating vector between them. Also, these findings do not change even though we change the reference market. This indicates that the day-ahead prices for natural gas in these two market areas move proportionally with each other such that the relative price difference remains constant in the long run. In other words, we have an evidence of long term equilibrium price formation where the constant difference between the price series can be mainly attributed to the differences in the transaction and transportation costs across the two entry-exit zones.

Similarly, the normalized long run coefficients (β) for the error correction obtained from the cointegration are indicative of a strong price convergence and hence market integration among the considered entry-exit zones. Table 4 reports the results.

Table 4: Normalized long run coefficients

Variables	β
GUD **TTF**	**1.000**
NCG **TTF**	**0.957**

The β value being equal to unity implies that the day ahead prices at the GUD and TTF virtual trading points is in full convergence and the two markets are perfectly integrated. Likewise, β being statistically close to unity between NCG and TTF implies that the prices in these two areas are still converging and market is moving towards greater integration. Nonetheless, these price series share a common stochastic trend and hence will not drift apart largely in the long run. So, evidence of strong market integration between the German hubs (GUD and NCG) and TTF is clearly established from our results. Furthermore, the unity of the β coefficient also suggests that the GUD and TTF day-ahead spot prices for natural gas are economically identical.

In order to confirm our results, we tested for Granger causality (Granger, 1969). Table A (see appendix) supports our claim that a bi-directional causality exist between GUD and TTF day-ahead prices. This is because in fully integrated and well-connected markets, the prices across both markets should be driven by the same factors. Also important to understand is that the TTF virtual trading point is attached to the GTS (Gas Transport Services) entry-exit system which is a wholly-owned subsidy of the Dutch gas transport company Gasunie. Hence, the fact that both GUD and TTF trading hubs are well inter-connected across the same networks owned by Gasunie, the two trading hubs serve as a single market with very similar day-ahead prices across both the hubs. So, both markets might be identified as liquid and competitive. On the other hand, the TTF day ahead prices leads the NCG day ahead prices in the price discovery process implying that the TTF hub is relatively more liquid than the NCG market area.

Likewise, we also tested for the Granger causality[7] test between the GUD and the NCG day-ahead prices to analyse the exact nature of price development among the trading hubs in Germany after the implementation of the entry-exit system. The test as illustrated in Table 5 shows that the GUD day ahead prices drive the NCG day ahead prices in the Granger sense.

Table 5: Granger causality tests at 5% level of significance

Null hypothesis (H_0)	Probability (p-value)
NCG does not Granger cause GUD	**0.526**
GUD does not Granger cause NCG	**0.000**

Results from vector error correction (see appendix) further support the findings from the Granger causality test. In the process of dynamic price adjustments towards price convergence, around 10% of downwards price adjustment is made by changes in the day ahead prices at GUD from one period to another while around 21% of upwards price adjustment is made from one period to another by changes in the day ahead spot prices at NCG. Given the insignificance of the error correction coefficient at GUD while the error correction coefficient for NCG prices being significant and positive[8]; the GUD market area corrects the error from one period to another at a greater speed than the NCG market area. Also, looking the impulse response functions from Figure A (see appendix) it becomes obvious that for every considered time period, the response to price shocks from all the explanatory variables in the dynamic price adjustment process is higher at the NCG market area than the GUD market area One reason for the GUD day-ahead prices leading in the price discovery process could be because the common market operation at the GUD hub started earlier than the NCG hub. Also, the interconnection of the GUD hub with the TTF hub as the first independent transmission system operator (TSO) of natural gas in continental Europe contributes to the explanation behind GUD day-ahead prices leading the NCG day-ahead prices: with a TSO interconnected to other systems, it can happen that one network is used as a transit system to move gas across one system for eventual delivery to customers connected to other networks. Furthermore, the prices for balancing energy at TTF are also linked to GUD but not to NCG. Hence, the integration of GUD with TTF makes GUD relatively more liquid than NCG while also driving the NCG prices in Granger sense.

[7] Likewise, a Grager causality test was carried out among all three prices series to assess the impact of gas trade flows between the hubs for summer and winter quarters. Our results (though not shown here but can be provided upon request) suggest no influence of gas flows in explaning the results obtained from Granger causality.

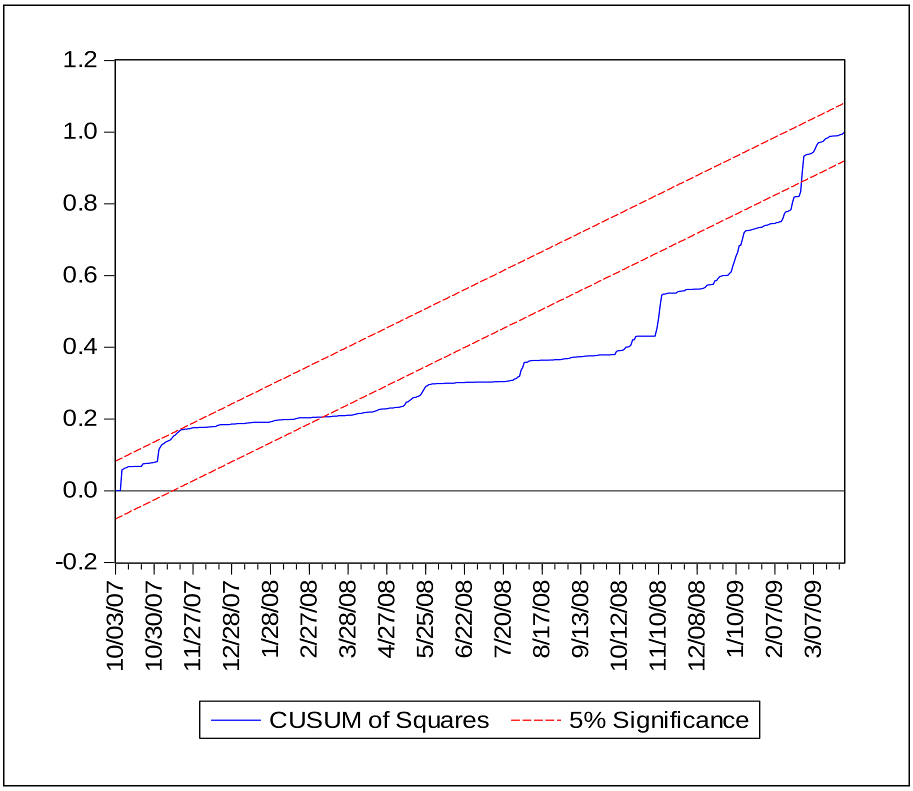
[8] Please refer to Schwarz and Szarkmy (1994) on the interpretation of the statistical outcome from vector error correction.

Similarly, running the Johansen cointegration test between GUD and NCG suggests that the markets are integrated as the prices are fairly converging with a normalized β coefficient of 0.96. As can be seen in the appendix, the prices in these market areas are cointegrated with one cointegrating vector.

To sum up, the econometric results from cointegration causality provide ample evidence of market integration through price convergence across the two German market areas considered in this study. But, one has to interpret these results with prudent optimism. The presence of cointegration does not necessarily imply the stability of the estimated β parameter. The long run β coefficient may not stay constant over time as several structural changes may occur in the energy markets (in particular gas) over time: Changes in market rules and regulations can affect the development of the β parameter over time. Hence, it is essential to test for the stability of the estimated parameter for the time period considered in this study. We have applied the cumulative sum of squares (CUSUM) test (Brown, Durbin and Evans, 1975) to detect for the occurrence of structural breaks.[9] The CUSUM test approximates the sum of recursive residuals and plots its value against the upper and lower bounds of the 95% confidence interval at each point. If the values of the cumulated sum cross the confidence interval, the parameter is considered to be not stable. Figure 2 shows the results from the CUSUM test applied to our price series.

Figure 2: CUSUM test for NCG and GUD day-ahead prices

[9] As the power of the CUSUM test can decrease and even go to zero as the magnitude of the change increases, we have also applied the Chow Breakpoint test to test for the presence of structural breaks. Please refer to Table D in the appendix. Also, for a detailed application of CUSUM test on cointergating regression, please refer to (Xiao and Phillips, 2002)



As the CUSUM plot lies outside of the stipulated region for most of the time period, structural breaks have been present. A series of events that might have unfolded after mid-February in the form of mergers and takeovers of market areas caused the structural breaks in the prices series under considerations. In fact, NCG was founded on the 1st of October 2008 as a result of the merger between Bayernets and E.ON Gas transport (EGT) entry-exit zones. The common market area NCG hence started from October 2008, having been announced in early 2008. Likewise as of 1st of July 2008, the gas transport segment of BEB was taken over by GUD. Taking these structural changes into account, it is of particular interest to study the effect of their effect on the price convergence and market integration by studying the development of the time-varying paths of β coefficient over time. The next sub section discusses the results based on recursive β coefficients obtained from Kalman filter estimation.

6.3: Kalman Filter Estimations

The Kalman filter estimations based on a recursive algorithm should allow us to analyse the convergence path of the prices series over time taking into account the possible structural changes mentioned above. Hence, it should also support and confirm the results obtained from cointegration analysis on the way towards long run price convergence. Figure 3 demonstrates the time varying path of β for the day ahead prices across the German trading points (GUD and NCG) within the stipulated (+ 2 and -2) mean square errors.

Figure 3: Time varying path of the integration coefficient (β)

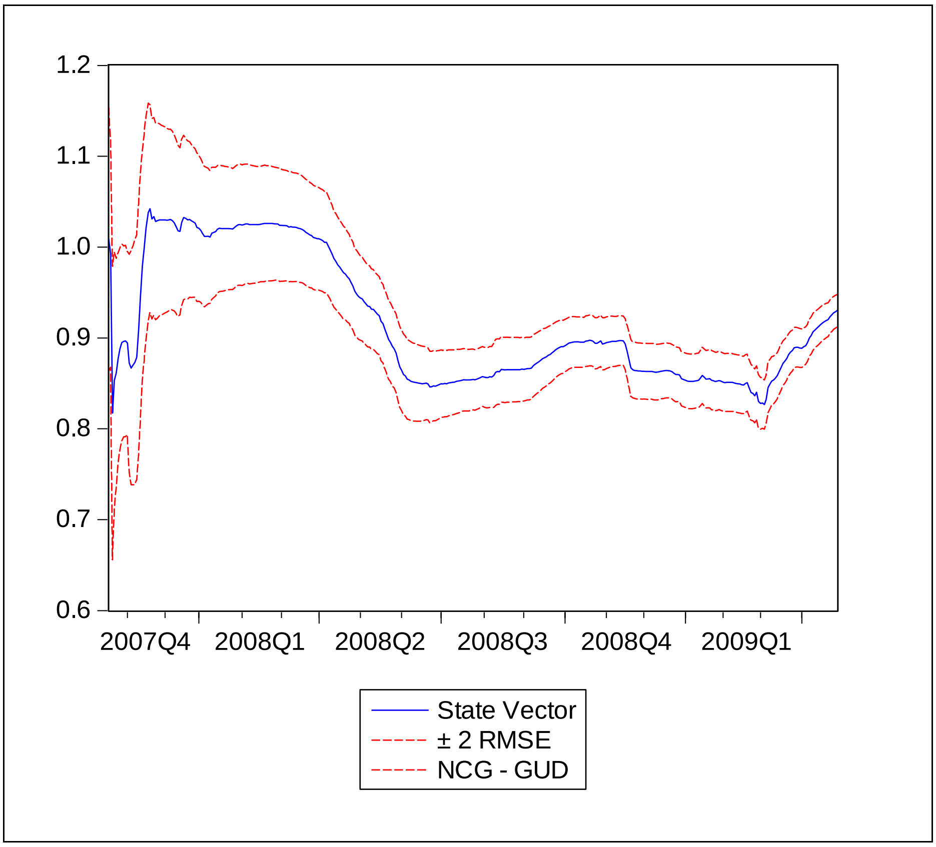


Figure 3 shows that the structural breaks that occurred in the NCG and GUD market areas led to instability of the integration coefficient over time. The announcement of a common market area between Bayernets and E.ON during early 2008 caused a plunge of the β coefficient from unity around mid-March towards 0.85 around the end of May. This suggests that the day ahead price differences were considerably high among both markets in this time period. On the other hand, the takeover of BEB by GUD around 1st of July 2008 had a reducing effect on the price differences as can be seen from the upward movement of the β coefficient. However, the common market area operation between EGT and Bayernets from October 2008 again created instability in the market widening the price gaps across the NCG and GUD market areas. Nonetheless, it can be seen from Figure 3 that from January 2009, the day ahead prices across NCG and GUD have started converging and a positive effect of the entry-exit system might be seen in the from of increasing market integration: the integration coefficient is moving towards unity and has reached around 0.96 at the end of April suggesting the development of a competitive market in Germany. This also confirms the result obtained from cointegration test (see Table C in appendix).

Now, Figures 4 and 5 illustrate the nature of market integration over time between the German and Dutch hubs. Prices across GUD and TTF have converged and hence market integration started as early as March 2008. However, the takeover of BEB by GUD in July, 2008 led to a downward surge in the integration coefficient though for a very brief period. Starting mid-July 2008 the prices have again begun converging while the two markets have reached full integration by the end of April, 2009. This can be taken from the integration coefficient statistically being equal to unity and thus confirming the results from the Johansen cointegration test. Similarly, Figure 5 shows that the prices across NCG and TTF market areas started converging after the announcement of common market operation between EGT and Bayernets. However, prices at NCG and TTF diverged for a short period after the takeover of BEB by GUD. Eventually, the prices started converging and market started moving towards greater integration (as still is) from January 2009. The integration coefficient between NCG and TTF stands around 0.96 at the end of April, 2009 and thereby confirms the results obtained from the cointegration test. Also, the similar behaviour of the integration coefficient in studying the relationship between NCG day ahead prices with respect to GUD and TTF suggest the existence of a single market and full market integration between GUD and TTF.

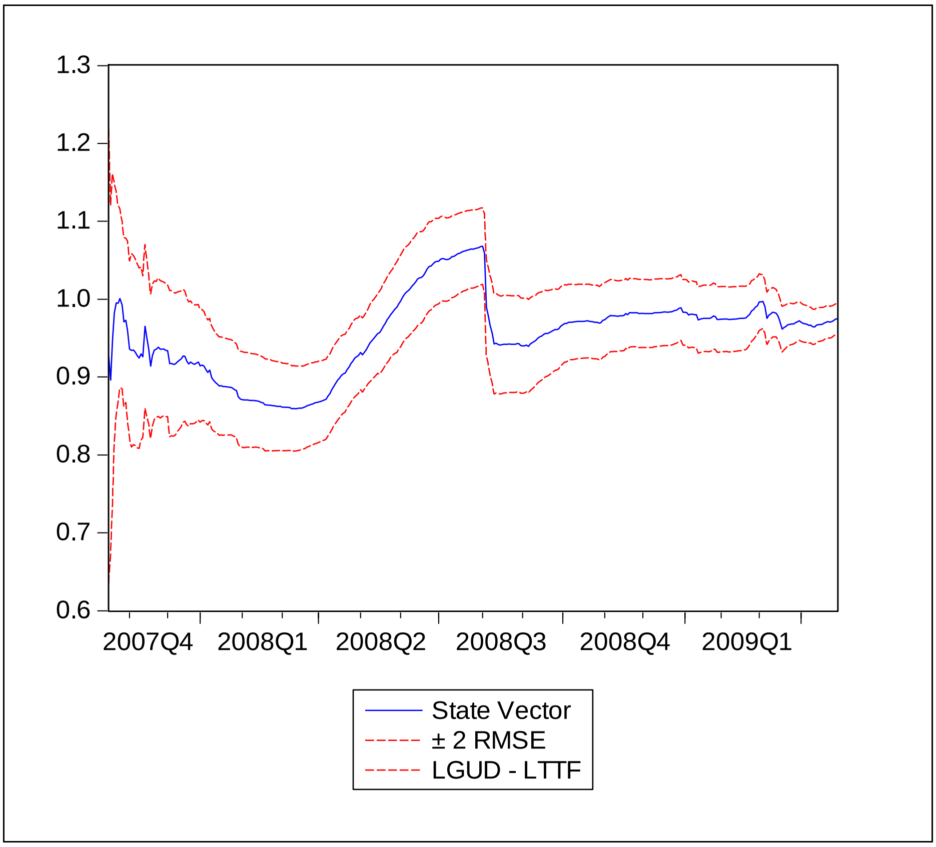


Figure 4: Time varying path of the integration coefficient (β)

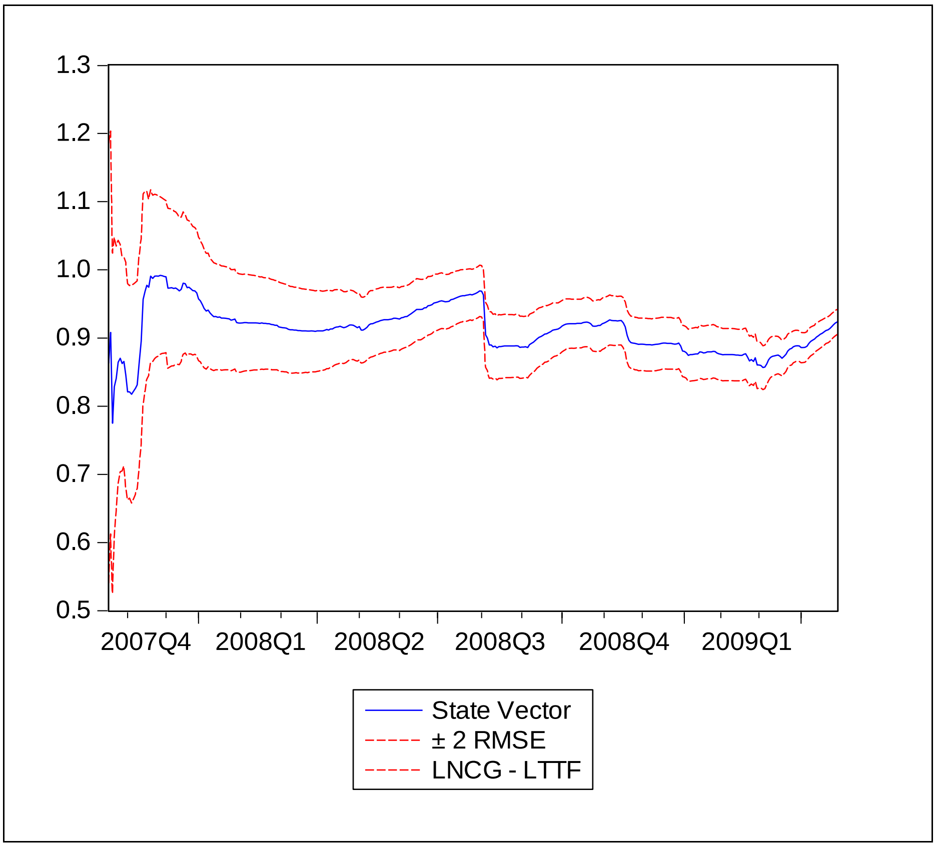


Figure 5: Time varying path of the integration coefficient (β)

7. Conclusions

The aim of this paper was to study the development of market integration after the introduction of the entry-exit network pricing regime in the natural gas markets in Germany. Therefore, we applied the Johansson cointegration test and Kalman filter estimation to test for price convergence. The results suggest the existence of full price convergence between two big market areas in Germany meaning that the markets have already and are still moving towards a greater level of integration. Our Results also show that the market integration of GUD with TTF makes GUD a relatively competitive trading hub than NCG. So, the German regulatory quest of achieving full market integration by developing a single large entry-exit zone covering all gas networks seems to be achievable also with the existence of two German hubs. The final effect of such full market integration could be a robust and competitive market for natural gas.

However, these results should not be interpreted as a first best economic situation. This is because our study only analyses the prices at the two major trading hubs while the German gas market is still heavily fragmented. Hence, gas networks have to be regulated and market rules have to be set. Thus, implementing incentive regulation in the natural gas transmission from the beginning of 2009 as well as a further development towards a competitive gas storage market should help in creating a competitive wholesale market for natural gas. Also, establishing effective and transparent rules concerning entitlements to open network access for third parties is and stays necessary in order to benefit from a fully liberalized market in Germany.

References:

Asche, F., Osmunden, P. and Tveteras, R. (2001). Market Integration for Natural Gas in Europe, *International Journal of Global Energy Issues*, Vol. 16, No. 4, pp. 300-312.

Brown, R.L., Durbin, J. and Evans, J.M. (1975). Techniques for Testing the Constancy of Regression Relationships over Time, *Journal of the Royal Statistical Society*, No. 37, pp. 149-192.

Caporale, MG, and Pittis, N. (1993). Common Stochastic Trends and Inflation Convergence in the EMS, *Weltwirtschaftliches Archiv*, Vol. 129, No. 2, pp. 207-215.

Dickey, D. and Fuller, W. (1979). Distribution of the estimators for autoregressive time series with a unit root, *Journal of the American Statistical Association,* Vol. 74, pp. 427-431.

EC, 1998. European Commission: *Directive 98/30/EC of the European Parliament and of the Council of 22 June 1998 concerning common rules for the internal market in natural gas*, Brussels, 1998.

EC, 2003. European Commission: *Directive 2003/55/EC of the European Parliament and the Council of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive*, Brussels, 2003.

Engle, R. and Granger, C. (1987). 'Cointegration and error correction: representation, estimation and testing', *Econometrica,* Vol. 55, pp. 251-276.

Granger, C.W.J. (1969). Investigating Causal Relation by Econometric and Cross-sectional Method, *Econometrica*, Vol. 37, pp. 424–438.

Hamilton, J. (1994). *Time Series Analysis*, Princeton, Princeton University Press, New Jersey, USA.

Harvey, A.C. (1987). Applications of the Kalman Filter. In: Truman F. Bewley, (ed.): *Advances in Econometrics*. Fifth World Congress, Vol. 1, pp. 285-313.

Hasbrouck, J. (1995). One security, Many markets, Determining the Contributions to Price Discovery, *The Journal of Finance*, Vol. 50, pp. 1175-1199.

Johansen, S. (1988). Statistical Analysis of Cointegration Vectors, *Journal of Economic Dynamics and Control*, Vol. 12, pp. 231-254.

Johansen, S. and Juselius, K. (1990). Maximum Likelihood Estimation and Inference on Cointegration - With Applications to the Demand for Money, *Oxford Bulletin of Economics and Statistics*, Vol. 52, No. 2, pp. 169-210.

Kalman, R.E. (1960). A New Approach to Linear Filtering and Prediction Problems, Transactions of the American Society of Mechanical Engineers, *Journal of Basic Engineering*, Series D, Vol. 82, No. 1, pp. 35-45.

King, M. and Cuc, M. (1996). Price Convergence in North American Natural Gas Spot Markets, *The Energy Journal*, Vol. 17, Issue 2, pp. 47-62.

Kleit, A.N. (2001). Are Regional Oil Markets Growing Closer Together? An Arbitrage Cost Approach, *The Energy Journal*, Vol. 22, No. 1, pp. 1-15.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P. and Shin, Y. (1992). Testing the Null Hypothesis of Stationary against the Alternative of a Unit Root, *Journal of Econometrics*, Vol. 54, pp. 159–178.

Li, R. (2008). International Steam Coal Market Integration, *Working Paper*, Department of Economics, Macquarie University, pp. 1-30.

MacKinnon, J.G., Haug, A.A. and Michelis, L. (1999). Numerical distribution Functions of Likelihood Ratio Tests for Cointegration, *Journal of Applied Econometrics*, Vol. 11, pp. 601-618.

Neumann, A., Silverstovs, B. and Hirschhausen, C. (2005). Convergence of European Spot Market Prices for Natural Gas? A real- Time Analysis of Market Integration using the Kalman Filter, *Working Paper*, Chair of Energy Economics and Public Sector Management, Technical University of Dresden, pp. 1-12.

Neumann, A. (2008). Linking Natural Gas Markets – Is LNG Doing its Job? *Working Paper*, German Institute for Economic Research, DIW, Berlin, September, pp. 1-15.

Ripple, R. D. (2001) US West Coast Petroleum Industry in the 1990s: Isolated or Globally Integrated, *Oil, Gas and Energy Quarterly*, Vol. 50, pp. 105-139.

Scheib, P., Kalisch, F. and Graeber, B. (2006). Analysis of a Liberalised German Gas Market, *Working Paper*, Center for Network Industries and Infrastructure, Berlin University of Technology, pp. 1-15.

Schwarz, T. and Szarkmy, A. (1994). Price discovery in Petroleum Markets: Arbitrage, Cointegration, and the Time Interval of Analysis, *Journal of Futures Markets*, Vol. 14, pp. 147-167.

Taylor, A.M. (2001). Potential Pitfall for the for the Purchasing Power Parity Puzzle? Sampling and Specification Biases in Mean-Reversion Tests of the Law of Once Price, *Econometrica*, Vol. 69, pp. 473-498.

Walls, W.D. (1994). Price Convergence across Natural Gas Fields and City Markets, *The Energy Journal*, Vol. 15, Issue 4, pp. 37-48.

Wood, D. (2008). *Spanish Gas Hub Workshop*, European Federation of Energy Traders, EFET, 23 July, Madrid.

Xiao, Z. and Phillips, C.B. (2002). A CUSUM test for Cointegration Using Regression Residuals, *Journal of Econometrics*, Vol. 108, Issue 1, pp. 46-31.

Zachmann, G. (2005). Convergence of Electricity Wholesale Prices in Europe? A Kalman Filter Approach, *Discussion Paper*, German Institute for Economic Research, pp. 1-26.

Appendix:

Table A: Granger causality test at 5% level of significance

Null hypothesis (H_0)	Probability (p-value)
GUD does not Granger cause TTF	0.000
TF does not Granger cause GUD	0.000
NCG does not Granger cause TTF	0.1150
TTF does not Granger cause NCG	0.000

Table B: A vector error correction model (VECM)

Error correction	D(GUD)	D(NCG)
Cointegration Equation	-0.1058 (0.0726) [-1.4565]	0.2140 (0.0795) [2.6902]

(standard errors) and [t- statistics]

Table C: Cointegration test between GUD and NCG day ahead spot prices

Variables	Null hypothesis (H_0)	Alternative hypothesis (H_1)	Maximum eigen-value statistics (λ_{max})	Critical value (5%)	Probability (p-value)	Trace statistics (λ_{trace})	Critical value (5%)	Probability (p-value)
NCG GUD	r = 0	r = 1	34.56	14.26	0.000	35.29	15.49	0.000
	r ≤ 1	r = 2	0.74	3.84	0.391	0.74	3.84	0.391
Normalized long run 'β' coefficient = 0.96								

Table D: Chow breakpoint test fixed to varying GUD coefficient

Chow Breakpoint Test: 07/01/2008, 10/01/2008			
F-statistic	15.82	Probability	0.000
Log likelihood ratio	60.00	Probability	0.000

Figure A: Impulse response functions based on vector auto regression