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EWI Working Paper, No 05/12

ISSN: 1862-3808

Institute of Energy Economics at the University of Cologne (EWI)
www.ewi.uni-koeln.de

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Abstract

In 2007, Germany changed network access regulation in the natural gas sector and introduced a so-called entry-exit system. The re-regulation's spot market effects remain to be examined. We use cointegration analysis and a state space model with time-varying coefficients to study the development of natural gas spot prices in the two major trading hubs in Germany and the interlinked Dutch spot market. To analyse information efficiency in more detail, the state space model is extended to an error correction model. Overall, our results suggest a reasonable degree of price convergence between the corresponding hubs. However, allowing for time-variant adjustment processes, the remaining price differentials are only partly explained by transportation costs, indicating capacity constraints. Nonetheless, market efficiency in terms of information processing has increased considerably among Germany and The Netherlands.

Keywords: natural gas market, regulation, cointegration, price convergence, time-varying coefficient

JEL classification: C32, G14, L95

1. Introduction

The creation of an integrated competitive natural gas market throughout Europe is one of the European Union's priority objectives. The introduction of the European Gas Directive (98/30/EC) and the EU 'Acceleration Directive' (2003/55/EC) have brought fundamental changes in the natural gas sector across many European countries. As such, the natural gas industries have been transformed from vertically integrated monopolies to more competitive structures. While some countries, notably including the UK and the Netherlands, have been relatively progressive in the liberalisation process, others such as Germany have moved more cautiously. Germany did not effectively open its natural gas market until the EU Directive 2003/55/EC had been transposed into national law in 2005.

This implementation has led to a new institutional design called entry-exit system and aimed at facilitating market entry in the energy sector and at establishing competition in wholesale and retail energy markets. As a consequence, regional natural gas wholesale markets in the form of different virtual trading points (hubs) were established in Germany. At the two major German hubs, NetConnect Germany (NCG)

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We would like to thank Jörg Breitung, Felix Höffler, Reinhard Madlener, Sebastian Nick, Heike Wetzel and Georg Zachmann for helpful comments and discussions. Financial support from Bundesnetzagentur is gratefully acknowledged.

roughly covering the South of Germany and GASPOOL (GPL) covering Northern Germany, a liquid market for natural gas seems to have evolved. Whether these two sub-national markets are yet well functioning remains to be empirically tested.

In theory, well functioning connected markets should show equal prices for a certain good (law of one price). Such markets share a common long run equilibrium price and can be said to be economically integrated. Persistent price differences beyond transaction costs should not exist. Likewise, the market's response to external shocks and corresponding reversion to the competitive equilibrium should be fast, i.e. information should be processed efficiently (Fama, 1970).

To evaluate whether the German natural gas wholesale market is yet functioning, we study the price convergence in Germany and the development of market efficiency. However, analysing only the two major German hubs might be misleading, inasmuch as it neglects the possible importance of the directly connected large Dutch gas market. The Dutch Title Transfer Facility (TTF) hub can be considered to be one of the most liquid wholesale gas trading hubs in continental Europe. Given its proximity and the liquidity to Germany, it might serve as a (competitive) benchmark for the German natural gas spot markets.

To analyse whether the prices at the different hubs have a common long run equilibrium, we use cointegration analysis (Johansen, 1988, 1991). One implicit assumption of cointegration analysis is that the structural relation among the prices is fixed over the considered time period; however, due to the on-going changes of the regulatory framework in Europe and Germany and different mergers of Germany's gas TSOs, market integration could also be a gradual and on-going process. In a second step, we therefore examine the convergence path of the natural gas spot market prices and the degree of market integration estimating a state space model using a Kalman filter (Kalman, 1960). In contrast to cointegration analysis, this estimator allows time-varying coefficients and thus explicitly accounts for possible dynamic structural changes. Furthermore, introducing a constant into the estimation equation allows us to indirectly test for capacity constraints. Finally, the state space model is extended to an error correction model to analyse how efficiently markets respond to new information. The time-varying nature of this approach allows us to draw conclusions as to how market efficiency evolved over time, and whether changes of the regulatory framework have led to better market functioning.

We find a reasonable degree of price convergence between the corresponding hubs. However, persistent price differentials indicate capacity constraints. Nonetheless, information efficiency has increased considerably among Germany and The Netherlands.

Different international studies have been carried out on natural gas markets integration and price convergence as an aftermath of market liberalisation. However, the methodology to account for market integration and price convergence differs across studies. Using cointegration analysis, Walls (1994), De Vany and Walls (1993, 1996) as well as Serletis (1997) found that the opening of network access in the aftermath of FERC Order 436 in 1985 led to greater market integration as prices across different locations converged in the North American natural gas markets. Likewise, King and Cuc (1996) examined the degree of pairwise price convergence using a time-varying parameter approach in the North American natural gas spot markets confirming the results of the cointegration analyses. Serletis and Rangel-Ruiz (2004) showed that the main driver for North American natural gas prices is the price trend at the Henry Hub. Applying a vector error correction model (VECM), Cuddington and Wang (2006) found different degrees of market integration across regions.

While the East and Central regions are highly integrated, the Western market is only loosely connected to common price trends.

In the European context, Asche et al. (2002) applied cointegration techniques to test for the law of one price across the French, German and Belgian market using monthly natural gas import prices. Their results show an integrated gas market where prices across the regions considered follow a similar pattern over time. Using a Kalman filter, Neumann et al. (2006) study the price relation between the UK (National Balancing Point) and the Belgian spot market (Zeebrugge). They conclude that prices between these two markets are fully converged.

Further empirical studies have investigated price relations for natural gas either between different continents or between gas and other commodities in a certain region. Among the first group are e.g. Ripple (2001), Siliverstovs et al. (2005) and Neumann (2009). All studies find evidence for an increased price convergence across continents. The relationship of gas prices to other commodities has been analysed quite extensively, e.g. by Asche et al. (2006) and Panagiotidis and Rutledge (2007) for the UK, and by Hartley et al. (2008) and Brown and Yücel (2009) for the US.

Our paper differs from the existing literature on natural gas price convergence and market integration in three ways. First, we focus our analysis on the market effect of a new network access regime on a sub-national gas market level by looking at the dynamic price interactions between two major German gas spot markets. Moreover, these regional market developments are put into a European context by relating them to the Dutch spot market. Second, we apply both cointegration analysis and a time-varying coefficient approach. Extending the time-varying coefficient approach to an error correction model enables us to draw conclusions not only about price convergence, but also about how efficiently new information is absorbed by the market and how this information efficiency has evolved over time. Third, we explicitly control for transportation costs, which have been neglected to a certain extent in the previous literature.

The paper is structured as follows. Section two describes the institutional design of the German natural gas market. Section three discusses the previous literature on the international natural gas wholesale market development. The econometric methodology is laid out in section four. Data description follows in section five. Section six includes the estimation results and their interpretation. Finally, section seven concludes with potential policy recommendations.

2. Institutional Design and Recent Developments in Germany

In 2005, a new Energy Law (Energiewirtschaftsgesetz, EnWG) was enacted in Germany to transpose the European Directive 2003/55/EC into national law. Its major purpose is to develop and establish competition in the German energy sector. Concerning third party access to the natural gas networks, a system charging regime based on simple entry and exit charges (entry-exit system) was imposed. In October 2006, the transmission network operators and the regulator concluded an agreement about the institutional design of the new regime. Since October 1st 2007, the entry-exit system has become mandatory for all Transmission System Operators (TSOs). The agreement initially divided Germany into 19 entry-exit zones (also called market areas or transmission system zones). Meanwhile, due to several poolings effected by additional governmental intervention in form of an amendment of the German Energy Law (§ 20 Sec. 1b EnWG)

, the number of zones has decreased to three, one for L-gas and two for H-gas (as of April 2011).[1] The latter developed the following way. NetConnect Germany (NCG) initiated a major pooling which became operational on October 1st 2008 and combined the former areas of E.ON and Bayernets. In October 2009, GRTgaz Deutschland, ENI and GVS joined NCG. In April 2011, Thyssengas, the former RWE gas TSO, joined NCG as latest member. While NCG since then covers the South and West of Germany, GASPOOL (GPL) as the second major market zone is located in the northern part of Germany.[2] The core of this area had already been established in 2006 as a result of a cooperative arrangement between BEB,[3] StatoilHydro and DONG Energy. In July 2008, Gasunie, operating the Dutch transmission network, has taken over the transportation services of BEB. In October 2009, ONTRAS and Wingas Transport joined GPL.

The entry-exit system requires 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) are no longer based upon the distance between the entry and exit points (also known as the contractual path) as previously practiced in Germany. The abolition of such a 'path-based' charging system was meant to promote price transparency because 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. The entry-exit system should facilitate both domestic as well as cross-border transports for third parties thus encouraging market entry and eventually competition. Furthermore, the market redesign aims at increasing the flexibility and comfort in booking procedures inasmuch as no capacity reservation is required for the individual pipeline sections used to fulfill transport contracts. In sum, consumers and distributors were intended to benefit from increasing gas-to-gas competition as a result of the implementation of entry-exit after gas market liberalisation.

The reform's economic success faces certain uncertainties, however. The German antitrust commission complained about illiquidity of the natural gas wholesale market, congestion and grandfathered capacity rights held by the incumbents (Monopolkommission, 2009). Whether 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 remains an empirical question.

3. Econometric Methodology

In this section, we (1) deduce empirical criteria for measuring German natural gas market competitiveness and its development, and (2) present the corresponding econometric methodology. To be able to test the law of one price, we adjust the regional natural gas spot prices at GASPOOL (GPL), NetConnect Germany (NCG) and the Dutch Title Transfer Facility (TTF) hub for transmission charges. We employ cointegration analysis in order to test whether prices tend towards a common long-run equilibrium price. We use these

[1] H-gas is high caloric natural gas primarily delivered from Norway and Russia to Germany. L-gas is a low caloric natural gas and has a lesser energy content than H-gas. As low caloric gas plays only a minor role in Germany, our focus is solely on H-gas.

[2] GASPOOL has been severally renamed over the considered period. To avoid confusion we use the current name GASPOOL of this market zone throughout the paper.

[3] BEB, owned by Shell and ExxonMobil, was one of the frontrunners as they introduced an entry-exit system already in 2004.

results as a first indication as to whether markets are integrated or not. In a final step, we estimate a time-varying coefficient model using the Kalman filter to study price convergence over time. Here, we develop a time-varying error correction model to identify the development of information efficiency.

3.1. The Law of One Price and Transmission Charges

The starting point for our analysis is the spatial arbitrage condition for efficient markets, which says that prices of identical products traded at regionally distinct locations should differ only in transaction costs (law of one price). In natural gas markets, the most noteworthy transaction costs are the network fees that shippers have to pay for gas transmission. Accounting for these transmission costs, freedom from arbitrage for gas traded at different locations is assured if the price in the exporting region ($P_{i,t}$) plus the cost of transmission ($TC_{i->j,t}$) equals the price in the importing region ($P_{j,t}$). The spatial arbitrage condition can be generalised as follows:

$$(1) \quad P_{i,t} - P_{j,t} \leq TC_{i->j,t},$$

where equality holds only if trade between the two regions occurs. If the price differential is strictly less than the cost associated with gas transport, market participants have no incentive to trade. In an entry-exit regime, these costs in one direction consist of the exit fee for the exporting region and the entry fee for the importing region. As regards continental Europe, transmission charges are direction-specific, i.e. in general $TC_{i->j,t} \neq TC_{j->i,t}$. Due to this asymmetric characteristic, the arbitrage condition can be reformulated as:[4]

$$\begin{aligned}
(1a) \quad & P_{i,t} + d_{i->j,t} * TC_{i->j,t} = P_{j,t} + d_{j->i,t} * TC_{j->i,t}, \\
& d_{i->j,t} = 1 \text{ if } P_{i,t} + TC_{i->j,t} \leq P_{j,t} \text{ and } d_{i->j,t} = 0 \text{ otherwise;} \\
& d_{j->i,t} = 1 \text{ if } P_{j,t} + TC_{j->i,t} \leq P_{i,t} \text{ and } d_{j->i,t} = 0 \text{ otherwise;} \\
& \text{i,j} = \text{GPL, NCG, TTF.}
\end{aligned}$$

Physical gas flows are only possible in one direction at a time. As no information is publicly available about the actual flows between the considered regions, we include a set of dummy variables d mapping potential flows between the regions i and j. A dummy variable $d_{i->j,t}$ ($d_{j->i,t}$) is one if the price $P_{i,t}$ ($P_{j,t}$) plus the costs of transmission $TC_{i->j,t}$ ($TC_{j->i,t}$) are less than or equal to the price $P_{j,t}$ ($P_{i,t}$) and zero otherwise.

These dummies enable us to determine the relevant transmission costs as a function of the actual price differential. It should be noted that both dummies can be zero at the same time, but both dummies can never be unity at the same time. The former situation prevails if spot price differentials are too low to exceed the transmission charges, in which case trading gas between the two regions would be unprofitable.

[4] With this approach we modified a model suggested by Zachmann (2008) who analysed convergence of European electricity spot prices controlling for the outcome of capacity auctions.

With $P_{i,t}^{net} = P_{i,t} + d_{i->j,t} * TC_{i->j,t}$ ($P_{j,t}^{net} = P_{j,t} + d_{j->i,t} * TC_{j->i,t}$) and using log prices $p_{i,t}^{net} = log(P_{i,t}^{net})$ ($p_{j,t}^{net} = log(P_{j,t}^{net})$) , equation (1a) becomes

$$
\text{(1b)} \quad p_{i,t}^{net} = p_{j,t}^{net}, \quad i,j = GPL, NCG, TTF.
$$

If this condition is violated, markets are not economically integrated and not efficient. However, real world complexities in trading imply that several factors may exist leading to deviations from this condition. The hypothesis to be tested is that the establishment of an entry-exit system has removed some of the causes of inefficiency, and that prices converged as a result thereafter.

3.2. Cointegration Tests

A precondition for cointegration analysis is that the time series considered have a unit root. Therefore, we test for unit roots using the Augmented Dickey Fuller (ADF, Dickey and Fuller, 1979) and the Kwiatkowski Phillips Schmidt and Shin (KPSS, Kwiatkowski et al., 1992) tests. While ADF is based upon the null hypothesis of a unit root, the KPSS is based upon the null hypothesis of stationarity. Given that unit root tests sometimes face the problem of poor power properties, double testing mitigates the risk of a false conclusion.

Applying the Johansen cointegration test (Johansen, 1988, 1991) to natural gas spot price series of two regions, one expects exactly one cointegrating relationship if these regions have a long run equilibrium. The corresponding two dimensional Vector Error Correction (VEC) model is:

$$
\text{(2)} \quad \Delta p_t^{net} = \Pi p_{t-1}^{net} + \sum_{k=1}^{l-1} \Gamma_k \Delta p_{t-k}^{net} + \epsilon_t;
$$

where Δ is the first difference operator, p_t^{net} is the vector of the two spot prices, $\epsilon_t \backsim n.i.i.d.(0, \Sigma)$, Π is a (2x2) matrix of the form $\Pi = \alpha\beta'$, with β comprising the cointegrating vector and α representing the corresponding loadings. While β coefficients show the long-run equilibrium relationship between price levels, α coefficients measure the adjustment speed towards equilibrium. The closer β is to (minus) one, the better economically integrated the markets are. A high absolute value for α in turn indicates a high the speed of price adjustment and a more efficient market.

According to equation (1b), we expect $\beta = [1, -1]$. In order to control for transaction costs other than transmission fees, we allow for a constant in the cointegrating relationship; however, if the law of one price holds, this constant should be (close to) zero.

The Johansen approach assumes a constant cointegrating vector over time. As pointed out by several studies, e.g. King and Cuc (1996) and Kleit (2001), the cointegration relationship does not shed any light on the dynamics of possible price convergence or divergence. Against the background of the dynamic regulatory framework in Europe as pointed out earlier, the assumption of a fixed relationship between spot prices over time might be problematic. Following the line of argument of Barrett (1996), Baulch (1997a,b) as well as Barrett and Li (2002), we use results from cointegration only as a kind of pre-test as to whether markets are integrated or not.

3.3. Time-varying Coefficient Model

An approach with time-varying coefficients can overcome the drawbacks of cointegration analysis and can account for the dynamics of parallel price developments from regionally distinct markets. The introduction of a time-varying coefficient into the linear relationship of prices enables us to analyse the path of price convergence or divergence over time.

Recalling equation (1b) and introducing a constant c_{ij}, again reflecting costs associated with trades between the two regions and not already covered by transmission charges, we can formulate the following state space model:

$$\begin{aligned} (3) \quad & p_{i,t}^{net} = c_{ij} + \beta_t p_{j,t}^{net} + \epsilon_t, \\ & \beta_t = \beta_{t-1} + \nu_t \end{aligned}$$

where $\epsilon_t \backsim n.i.i.d.(0, \sigma_\epsilon^2)$ and $\nu_t \backsim n.i.i.d.(0, \sigma_\nu^2)$ are white noise processes and β_t is the vector of unobservable coefficients at time t.

β_t represents the strength of price convergence across regions. If $\beta_t = 0$, it implies that there is no relation between the natural gas spot prices, and that markets were completely decoupled. If price have converged and markets are perfectly integrated and competitive, β_t should be equal to one. Furthermore, as prices (p_t^{net}) are already adjusted for transportation costs, we expect c_{ij} to be negligible. If c_{ij} were substantial, it would tend to imply that significant other costs in addition to the transportation charges were present in the market preventing shippers from trading and, therefore, prices from converging. Economically, a constant gap between the price series considered might thus indicate permanent capacity constraints. Such constraints could be of *technical* nature as a result, for instance, of underinvestment. On the other hand, *contractual* capacity constraints might suggest hoarding of capacity rights by incumbents,[5] and might signal third party discrimination or even the abuse of market power.

The state space model is estimated using the Kalman filter (Kalman, 1960).[6] This technique processes the data in two consecutive steps. It first estimates β_t by using available information until period t-1. In a second step, the estimates of β_t are updated by incorporating prediction errors from the first step (to time t-1) to compute values for time t. Applying the Kalman filter provides information for c_{ij} and for β_t at each point in time, and thus enables us to obtain detailed information on the common development of prices.

In employing the Kalman filter, it is important to determine the initial variances for ϵ_t and ν_t as well as of the expected value of β_0.[7]

Calibrating $E(\beta_0) = 1 \approx \frac{p_{i,1}^{net}}{p_{j,1}^{net}}$, $\sigma_\epsilon^2 = 0.1 \approx Var(p_{i,t}^{net})$ and $\sigma_\nu^2 = \sigma_\epsilon^2/1,000$ provides suitable noise reduction and signal preservation.

[5] Transmission capacity is often booked very long in advance and has to be nominated when shippers actually want to use it. Hoarding of capacity rights means unused capacity which is not available to other market participants.

[6] For further details see Harvey (1987).

[7] Usually, the maximum likelihood function has several local maxima. Therefore, inadequately chosen starting points can lead to undesirable results. Exaggerated values of would lead to the inclusion of short-term behaviour making it difficult to distinguish random shocks from structural relationships. In contrast, setting the variance too low would ignore significant developments in the convergence process over time.

Finally, we use the framework of time-varying coefficients to formulate an error correction model in the following way:

$$(4)\quad \Delta p_{i,t}^{net} = c_{ij} + \alpha_t(p_{i,t-1}^{net} - p_{j,t-1}^{net}) + \epsilon_t$$
$$\alpha_t = \alpha_{t-1} + \nu_t$$

where α_t measures the time of it takes to bring the system back towards equilibrium after new information appears on the market. The larger the absolute value for α_t, the higher the speed of price adjustment and the more efficiently information is converted into price signals. Therefore, the time-varying framework enables us to draw conclusions not only on how efficiently prices adjusted to new information, but also how efficiency evolved over time. Since the entry-exit regime was introduced in order to ease gas transmission and foster gas-to-gas competition, we expect the absolute value of α_t to increase over time.

The error correction model specification needs a new calibration of the starting values for the Kalman filter:

$$E(\alpha_0) = 0 \approx \frac{\Delta p_{i,2}^{net}}{p_{i,1}^{net} - p_{j,1}^{net}}, \sigma_{\epsilon_t}^2 = 0.1 \approx Var(\Delta p_{i,t}^{net}) \text{ and } \sigma_{\nu_t}^2 = \sigma_{\epsilon_t}^2$$

Setting the expected value of α_0 to zero assumes inefficient information processing at the beginning of the observation period. This seems especially plausible, since market participants seem to need time to adopt to a new regulatory regime.[8]

4. Data

The aim of this paper is to test for market integration and price convergence between the major two entry-exit zones in Germany, namely GPL and NCG. Additionally, we analyse price relations with respect to the Dutch trading hub TTF, which is well connected with Germany and is a major European gas trading point. 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 (EEX),[9] while data for TTF has been obtained from Energate. Daily price data is preferred over weekly or monthly data because lower frequencies can lead to temporal aggregation problems if used to study the price adjustment process (Taylor, 2001). The use of high frequency data should better capture the markets' reactions to ongoing regulatory and market reforms, thereby facilitating the investigation of market integration. The observation period lasts from the 1st of October, 2007, when the mandatory introduction of the entry-exit system came into operation to the 31st of March, 2011. The prices have been transformed into logarithmic form because spot market prices for natural gas tend to be highly volatile which may bias our results.The aim of this paper is to test for market integration and price convergence between the major two entry-exit zones in Germany, namely GPL and NCG. Additionally, we analyse price relations with respect to the Dutch trading hub TTF, which is well connected with Germany and is a major European gas trading point. For the German trading hubs, we have

[8] Growitsch and Weber (2008) show the same in a paper on the re-design of the German balancing power market. Different starting values hardly influence the results, though.

[9] Although only 10% of the total volume is traded at EEX (90% is traded over-the-counter (OTC)), we have chosen EEX data as it is the only publicly available price series covering a longer time period without structural breaks.

used the day-ahead spot market settlement price for natural gas as publicly obtained from the European Energy Exchange (EEX), while data for TTF has been obtained from Energate. Daily price data is preferred over weekly or monthly data because lower frequencies can lead to temporal aggregation problems if used to study the price adjustment process (Taylor, 2001). The use of high frequency data should better capture the markets' reactions to ongoing regulatory and market reforms, thereby facilitating the investigation of market integration. The observation period lasts from the 1st of October, 2007, when the mandatory introduction of the entry-exit system came into operation to the 31st of March, 2011.[10] The prices have been transformed into logarithmic form because spot market prices for natural gas tend to be highly volatile which may bias our results.

It can be seen from Figure 1 that the day-ahead prices for natural gas were volatile throughout the time period considered for all market areas. The prices became more volatile during the last quarter of 2007, while the volatility declined from the first quarter of 2008 to the third quarter of 2008. From the first quarter of 2009, prices witnessed a steep decline. The development is likely - at least to some extent - to be explained by the falling prices for crude oil.[11] Since the third quarter of 2009, gas prices have started to rise again due to the on-going recovery of the economy after the crisis 2008/9. All in all, the price series show a rather similar development pattern over time[12] leading to the expectation of highly integrated markets, and thus values close to one for the coefficient in equations (2) and (3).

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

[10]Price data for both German market areas prior to October 2007 hardly exist and face the problem of low reliability. The considered time period covers three and a half so called "gas years", starting with the heating season in October and ending end of March. For each price series this results in 915 observations (trading days).

[11]Gas prices in mainland Europe are often index-linked to that of crude oil with some time lag While the price for Brent Crude Oil peaked on 3rd of July, 2008, GPL prices reached their maximum on 23rd of September 2008. NCG and TTF prices had their peak both on the 17th of September, 2008. This amounts to a lag of roughly two and a half months.

[12]This is confirmed by the descriptive statistics which are available from the authors upon request. E.g., the standard deviation as a proxy for volatility is around 0.40 e/MWh (in log terms) for all three regions.

Information on transmission charges were obtained from the websites of the relevant TSOs as well as in interviews of the shippers.[13] For each possible relation between the three considered markets, we chose a representative connecting point. To get consistent data, we converted the corresponding capacity-based entry and exit charges expressed in [€/(kWh/h)/a] into [€/MWh]. We assume that a transport of one MWh of natural gas corresponds to holding a capacity of one MW. The TSO have changed their fees at different points in time. The resulting development of transmission charges over time is summarised in Table 1. While the cost of transporting natural gas within Germany has decreased quite substantially (by about 25 %), fees for cross-border transmission have decreased to a lesser extent.

Table 1: Transmission Charges

Direction of Transport	**Connecting Point**	**Transmission Charges [€/MWh]**							
		10/07	*10/08*	*12/08*	*04/09*	*07/09*	*10/09*	*01/10*	*10/10*
GPL → NCG	Bunder Tief	0.619	0.582	0.565	0.534	0.534	0.483	0.483	0.453
NCG → GPL		0.557	0.523	0.512	0.497	0.497	0.434	0.434	0.417
GPL → TTF	Oude Statenzijl	0.420	0.420	0.420	0.410	0.400	0.366	0.361	0.361
TTF → GPL		0.409	0.409	0.409	0.394	0.408	0.338	0.334	0.334
NCG → TTF	Bocholtz	0.387	0.399	0.386	0.386	0.398	0.411	0.406	0.398
TTF → NCG		0.486	0.498	0.484	0.484	0.490	0.429	0.422	0.397

5. Results

To answer the question of whether the introduction of an entry-exit regime has led to more competitive market conditions, first we present the results of the cointegration analysis, and then the results of the time-varying coefficient approaches.

5.1. Cointegration Analysis

To check whether the price series fulfil the precondition for cointegration analysis, we test for unit roots. The results from both ADF and KPSS, displayed in Table 2, provide a clear picture. All time series have a unit root and are I(1) as first differences are stationary.

Table 2: Unit Root Tests

Natural Gas Spot Prices (log)				
	ADF		KPSS	
Region	Level	First difference	Level	First difference
GPL	-2.004	-28.966***	1.010***	0.072
NCG	-1.843	-32.422***	1.070***	0.087
TTF	-1.854	-31.108***	1.067***	0.118

Remarks: Tests include a constant but no time trend. For ADF, the lag length is selected according to Schwarz Information Criterion (SIC). For KPSS, bandwidth has been chosen according to Newey-West using the Bartlett Kernel. The provided numbers denote the t-ratios for ADF and the LM statistic for KPSS. *, **, *** indicate significance at the 10, 5 and 1 %-levels.

Next, we estimate Equation (2) applying the approach developed by Johansen (1988, 1991). Each pairwise price relation has exactly one cointegrating term indicating that long-run equilibria do exist.[14]

[13] Due to the ongoing reorganisation of the German TSOs and market zones, consistent historical data on transmission charges is not publicly available.

[14] Both unrestricted cointegration rank tests, Trace as well as Maximum Eigenvalue, lead to equivalent results.

Price series share a common stochastic trend and hence will not drift apart greatly in the long run. Table 3 shows the main results of the corresponding VEC models.

All β coefficients are very close to one. The likelihood ratio test in the next to last column of Table 3 tests for the restriction of the cointegrating vector being $\beta = [1, -1]$, meaning that a 1% price change in region i is accompanied by the same price change in region j. Only in the case of GPL and the Dutch TTF this indication of very strong market integration has to be rejected at a 10% level. The insignificant constant in the long-run cointegrating equation signals that no other significant transaction costs in addition to the already captured transmission charges and therefore no persistent price differential exist. Looking at the error correction coefficient we see significant bi-directional price adjustments for GPL-NCG and GPL-TTF. The relationship of natural gas spot prices between GPL and TTF is stronger since the level of significance and adjustment speed are a bit higher. While for GPL-NCG only around 10% of an external shock is absorbed within one period (i.e. one trading day), GPL prices adjust for 20% of an imbalance with TTF prices. The corresponding half-lives, defined as the time in which a marginal change in the stationary component becomes half of the initial jump and computed as $\ln(0.5)/\ln(1-\alpha)$, are 6.4 days and 3 days respectively. The stronger interrelation between GPL and TTF might be due to the fact that both networks are now run by the same TSO, Gasunie. The asymmetric price adjustment in the latter case, with GPL prices adjusting faster than TTF prices, indicates that the TTF as the larger and more liquid market is the leading market for GPL. The same argument holds for the NCG-TTF results, with only the NCG adjusting to deviations from equilibrium. A likelihood ratio test restricting α_{TTF} to zero confirms that TTF is weakly exogenous for NCG. These results support the hypothesis that the Dutch TTF can be considered as a kind of reference or leading market for both German market areas.

Table 3: Long-run Cointegrating Equations (ML Estimation)

Region	**Cointegrating Equation**				**LR Test**	
	β	α		Constant	$\beta = [1, -1]$	$\alpha = 0$
GPL-NCG	-0.988** (0.007)	GPL	-0.102** (0.066)	-0.013 (0.010)	2.562	4.255**
		NCG	0.184*** (0.067)			11.090***
GPL-TTF	-0.989** (0.008)	GPL	-0.206*** (0.063)	-0.017 (0.010)	2.829*	19.458***
		TTF	0.125*** (0.064)			3.672*
NCG-TTF	-1.004** (0.009)	NCG	-0.259*** (0.070)	-0.001 (0.013)	0.016	35.726***
		TTF	0.051 (0.068)			0.007

Notes: Lag length to map short-run dynamics selected according the Schwarz Criterion using an unrestricted VAR. Numbers in brackets report standard errors. Numbers for the LR test denote the χ^2-statistics.
*, **, *** indicate significance at the 10, 5 and 1 %-levels.

To sum up, results from cointegration analysis provide evidence of market integration across the two German market areas considered in this study; however, one has to interpret these results with care. The presence of cointegration does not necessarily imply the stability of the estimated β parameter. Also, the long-run β coefficient may not stay constant over time, as several structural changes have occurred in the natural gas markets within the period considered.

5.2. Time-varying Coefficient

The time-varying coefficient approach is particularly suitable for accounting for these structural changes. Table 4 presents the main results of the analysis of market integration through price convergence (Equation 3), as well as the outcomes of the error correction model (Equation 4) which gives insights into the development of information efficiency.

Table 4: Results of the Time-varying Coefficient Models

Region	**Price Convergence [Equation(3)]**		**Information Efficiency [Equation(4)]**	
	β	Constant	α	Constant
GPL-NCG	0.975*** (0.001)	0.034*** (0.005)	0.047 (0.267)	-0.0002 (0.0007)
GPL-TTF	0.969*** (0.002)	0.044*** (0.007)	-0.568* (0.266)	0.001* (0.0006)
NCG-TTF	0.983*** (0.002)	0.006*** (0.004)	-0.979*** (0.261)	0.002*** (0.0007)

Remarks: For the coefficients the final state is provided. Numbers in brackets report the root mean square error for the coefficients and standard errors for the constant.
*, **, *** indicate significance at the 10, 5 and 1 %-levels.

In the final state, NCG and TTF show the highest degree of price convergence (0.983), and a very high speed to adjust to changes. This means these highly integrated markets seem to be almost efficient. Comparing the results with the previous cointegration analysis, what is most striking is the significance of the constant in all three estimations of Equation (3). Allowing for a time-varying specification reveals a price differential that goes beyond transmission charges. The highest additional price gaps are associated with the GPL market zone. This gap might be interpreted as the price effect induced by capacity constraints. As one of the major complaints concerning the natural gas market - raised not only by market entrants but also by energy regulators - is the insufficient amount of transmission capacity available to market participants, the result of the state space approach is much more consistent with market observations than the one of cointegration analysis in the previous sub-section.[15] Due to the assumption of constant price relations over the considered period, the VECM failed to demonstrate this finding. In fact, the averaging characteristic of cointegration analysis may lead to overestimated degrees of price convergence.

Figure 2 shows the development of the β coefficients over time. All three pairs of market zones started with a rather high degree of price convergence (above 0.96)[16] that increased moderately after the introduction of the entry-exit regime in October 2007. The coefficients for GPL-NCG and GPL-TTF peaked around July 2008 which coincides with the takeover of BEB by Gasunie. A plunge of the β coefficient for both price relations can be observed right after the establishment of NCG as a merger of E.ON and Bayernets (October 2008). While prices between NCG and GPL started to converge again, the gap between GPL- and TTF-prices decreased only slightly. Concerning NCG and TTF, the price gap decreased more or less steadily

[15] The issue of available transmission capacity is raised in nearly every monitoring report on the German natural gas market. The paucity of well-functioning secondary markets for unused capacity rights amplifies this problem.
[16] The high value at the beginning is not sensitive to the assumption of $E(\beta_0) = 1$. Setting $E(\beta_0) = 0$ reveals similar results.

until the first quarter of 2009, but increased thereafter. While the β coefficient of GPL-NCG swung back above the initial level of price convergence by April 2011, the other two relations approximately reached their starting values again. All in all, the Dutch-German gas market seems to be well integrated.[17]

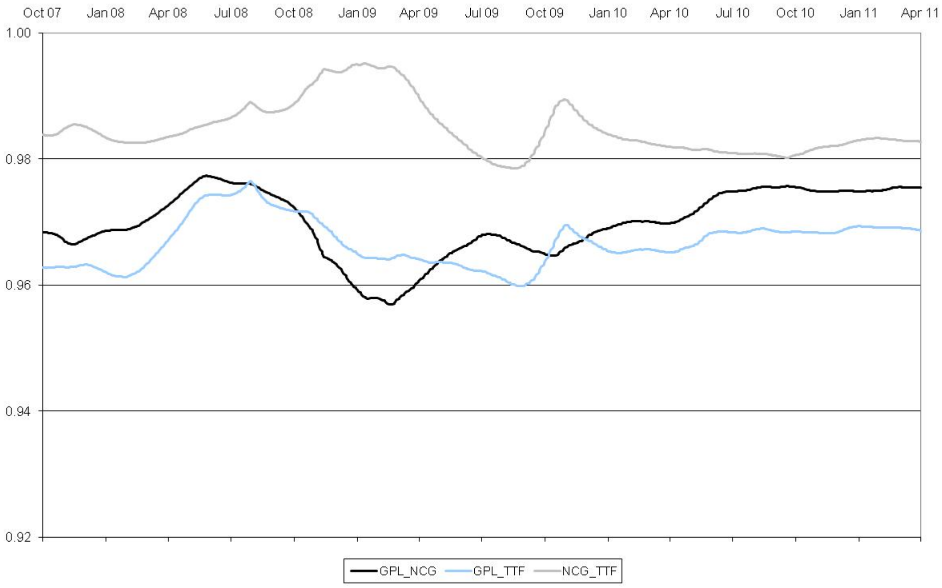

Figure 2: Price Convergence β

However, as pointed out above, market integration in terms of price convergence has to be distinguished from market efficiency. Therefore, the question remains whether the observed degree of price convergence is sufficient to allow efficient adjustment to new information. The development of information efficiency is depicted in Figure 3. The coefficient α of the error correction model of Equation (4) indicates how fast prices turn back to equilibrium once new information has appeared. The higher the absolute value of α, the faster prices adjust to new information and the more efficient markets are. The price relation between GPL and NCG shows the lowest efficiency over most of the time period considered. In the first year after the entry-exit system became mandatory, prices adjusted pairwise between NCG and GPL to around 10% of new information within one day, which is about half the speed of pairwise price adjustment between GPL and TTF (Figure REF). The information processing between NCG and TTF being the highest for nearly the entire observation period might be explained by considerably higher trading volumes at NCG compared to GPL.[18] The churn rate of NCG, e.g., measuring the ratio between traded and physically delivered volumes, has risen from 1.6 in September 2007 to 3.2 in September 2010, thus getting close to the churn rate of the

[17]One might argue that the formations of the β coefficients are mainly explained by the oil price movement as a common exogenous factor driving the gas prices. This argument seems to be implausible, since the decline of price convergence between NCG and TTF started later than in the other two cases. Furthermore, the oil price has increased already since beginning of 2009. Taking into account the time lag of roughly two and a half months months (see footnote 11), β should have envisaged an upswing in all three price relations during the second quarter of 2009.

[18]95% of natural gas trading volume at EEX is related to the market area of NCG, only 5% to GASPOOL.

Dutch TTF.[19] For GPL-TTF and NCG-TTF, a major increase in the speed of information processing can be observed during the fourth quarter of 2008, thus shortly after the creation of NCG.

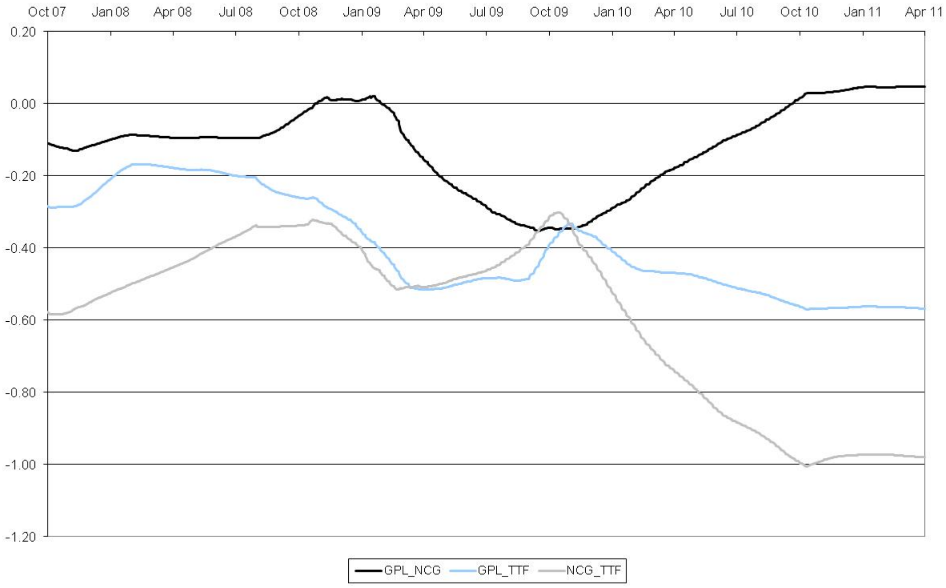

Figure 3: Information Efficiency (α)

The zero value of α between GPL and NCG around January 2009, which indicates that prices did not adjust to new information in any way, can be explained by the gas conflict between Russia and Ukraine. On the 1st of January, 2009, Russia stopped gas delivery to the Ukrainian transmission network completely. Russia accused the Ukraine of consuming gas illegally that had been designated for transit to Germany and other European countries. Since the EU imports around 25% of its gas from Russia, with the main transit route via the Ukraine, the suspension of delivery resulted in gas shortages in Central and Southeast Europe, which necessitated a rearrangement of gas flows. While cross-border gas transport just changed the direction, the rearrangement within Germany led temporarily to inefficient pricing behaviour. Nevertheless, after GRTgaz, ENI and GVS joined NCG in October 2009, the information processing between GPL and NCG dropped to zero again. In the same time, information efficiency between NCG and TTF increased considerably up to approx. 100%. Both developments indicate the relative importance of NCG over GPL.

To sum up, although price convergence did not really increase since the mandatory introduction of the entry-exit system, information efficiency with regard to cross-border trades has increased significantly over the 3.5 years. As Barrett and Li (2002) point out, market integration has to be distinguished from efficiency issues in spatial price analysis. Regarding the price relations between the two major German market zones for natural gas as well as the connection to the Dutch TTF, markets are sufficiently integrated to provide for an improved processing of new information. Prices between NCG and TTF adjust within one trading day.

[19] The number of 1.6 is related to the market zone of E.ON as a precursor of NCG. Compared to the British National Balancing Point (NBP) as the most liquid hub in Europe, churn rates in Continental Europe are still significantly lower. NBP has a churn rate of around 10.

6. Conclusions and Policy Implications

The aim of this paper was to study the development of market integration and efficiency in Germany after the mandatory introduction of an entry-exit network pricing regime in the natural gas market. We applied Johansen's cointegration analysis and a time-varying coefficient approach (Kalman filter) to test for price convergence. The state space model was extended to an error correction model to analyse how fast prices adjust to new information, i.e. how efficient the markets are.

Using price series for the two major German market areas, NetConnect Germany (NCG) and GASPOOL (GPL), as well as data from the Dutch Title Transfer Facility (TTF) hub as a competitive benchmark, we explicitly accounted for transportation costs in order to test the spatial arbitrage condition. Results of the Johansen approach show a level of price convergence close to one between all three locations with the Dutch TTF - as the more mature market - leading the pricing behaviour at both German hubs. The time-varying coefficient model reveals lower levels of convergence, which are nonetheless sufficient to provide for an improved processing of new information between the larger German hub NCG and TTF. Since the mandatory introduction of the entry-exit system, information efficiency has increased significantly, especially after the merger of the two market zones resulting in the foundation of NCG in October 2008 and an additional enlargement of the NCG consortium in October 2009. Prices adjust to new information within one trading day.

However, we found a persistent price differential between the markets not explained by transportation costs. These price differences indicate capacity constraints. They exist between any of the markets, but are six to seven times higher between GPL and either of the other markets. One important reason could be blocked or congested transportation capacity (contractual constraints through capacity hoarding). Thus, establishing effective and transparent rules concerning entitlements to open network access for third parties is and remains necessary in order to benefit from a fully liberalised market in Germany. Overall, major improvements have been especially achieved concerning the NCG market region.

Future research might extend the analysis to entire Europe. Moreover, it could be interesting to analyse different regulatory regime in terms of their effect on the functioning of the respective wholesale markets.

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