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Kuper, G.H.; Mulder, Machiel

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Gerard Kuper
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Visiting address:
Nettelbosje 2
9747 AE Groningen
The Netherlands

Postal address:
P.O. Box 800
9700 AV   Groningen
The Netherlands

T +31 50 363 7068/3815

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Cross-border constraints, institutional changes and integration of the Dutch – German gas market

Gerard Kuper
University of Groningen
g.h.kuper@rug.nl

Machiel Mulder
The Netherlands Authority for Consumers and Markets (ACM) and University of Groningen

CROSS-BORDER CONSTRAINTS, INSTITUTIONAL CHANGES AND INTEGRATION OF THE DUTCH - GERMAN GAS MARKET

GERARD KUPER[**] and MACHIEL MULDER[***]

April 2013

Abstract

We estimate the contribution of institutional changes in the Dutch and German gas markets to the integration of these markets. We measure this contribution through the impact of bottlenecks in the cross-border infrastructure on cross-border price differences. In the period 2007-2011, the differences in both price levels and price volatility between these two markets decreased. We find evidence that institutional changes in the Dutch market, in particular the abolishment of the obligation to book quality-conversion capacity, have reduced the impact of cross-border infrastructure bottlenecks on regional price differences. The integration of German regional networks into larger systems, however, appear to have had a negative effect on the integration with the Dutch market.

Keywords: gas market, regulation, infrastructure, time-series analysis

JEL-codes: Q41, L95, L51, C22

[**] University of Groningen, Department of Economics, Econometrics and Finance, e-mail: g.h.kuper@rug.nl.
[***] The Netherlands Authority for Consumers and Markets (ACM) and University of Groningen, Department of Economics, Econometrics and Finance, e-mail: machiel.mulder@acm.nl.

1. Introduction

Since the liberalisation of European gas markets in the 1990s market places in various European countries have been developed, such as the National Balancing Point (NBP) in the United Kingdom, the Title Transfer Facility (TTF) in the Netherlands and NetConnectGermany (NCG) in Germany. The liquidity of in particular NBP and TTF has grown significantly over the past years (Heather, 2012). For the creation of a European gas market, the national market places need to be mutually connected, enabling traders to engage in international price arbitrage. The level of the installed transport capacity, however, frequently formed a constraint for international trade (Neumann, Rosellón and Weigt, 2011). In addition, access to the transport infrastructure was limited as long-term access rights were granted to the existing firms on the basis of non-market mechanisms as FCFS and pro-rata[1], resulting in an inefficient use of cross-border capacity (EC, 2007; NMa, 2007; LECG, 2011).

We estimate the impact of cross-border infrastructure barriers on cross-border price differences and we analyse to which extent this impact changed under the influence of institutional changes affecting the liquidity of separate market places. Our paper is related to papers like Siliverstovs, L'Hégaret, Neumann and von Hirschhausen (2005), Cuddington and Wang (2006), Marmer, Shapiro and MacAvoy (2007) and Growitsch, Stronzik and Nepal (2012) who also analyse the integration of regional gas markets. The contribution of our paper is that we not only use data on prices, but also data on the utilisation of infrastructure. Unlike earlier literature, we make a distinction between low calorific gas (L-gas) and high calorific gas (H-gas) for which there are different supply grids in the Netherlands, Belgium, Northern France and Northern Germany. H-gas is mainly used by industrial consumers. Furthermore, we assess the contribution of institutional changes in national market places to the integration of markets, comparable to the analysis of Kleit (1998) who analyses the effect

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[1] FCFS stands for "first come first served"; 'pro rata' is an allocation on the basis of relative demand.

of deregulation on integration of US gas markets. Finally, we not only look at cross-border price differences but also at cross-border differences between within-day price ranges.

We focus on the Dutch market, as here a large domestic supply and demand coincides with a high degree of connection with its neighbouring countries (Germany, Belgium and United Kingdom), while a number of institutional changes occurred in the recent past.[2] In the period 2007-2011, three major changes in the Dutch gas market occurred affecting the liquidity of the TTF (Heather, 2012). In 2009, the obligation of market parties to book quality-conversion capacity was abolished, actually removing the distinction between H-gas and L-gas in gas trade. In April 2011, two other changes were implemented: the introduction of a market-based balancing regime and the new policy of GasTerra, the Dutch incumbent gas trader, to supply all gas for the domestic market on the TTF instead of factory gates or city gates.

We further focus on the connection with Germany as most of the Dutch imports and exports pass this border.[3] Although Germany has two major gas market areas (NetConnect Germany (NCG)) and GASPOOL Balancing Services (GPL), we analyse in particular the connection with NCG as this hub was more a trading hub than GPL which was until recently primarily used for balancing purposes (Heather, 2012). Moreover, in the NCG market a number of merging activities took place during the period of analysis. Note that Growitsch et al. (2012) found that the NCG and GPL markets were reasonably well economically integrated, although capacity constraints hindered perfect arbitrage from time to time.

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[2] Within countries also barriers might exist, but these do hardly play a role in the Dutch market.

[3] The highest export flow of L-gas to Germany in 2011 was approximately 40 GW, which was about twice as big as the highest export flow to Belgium. For H-gas the respective amounts are 30 (Germany) and 15 (Belgium) GW, while the export of H-gas to the United Kingdom peaked at 15 GW in 2011. For the import of H-gas, the Dutch-German is even more important: the highest hourly import in 2011 was about 30 GW, while through the Dutch-Belgian border no more than 5 GW was imported.

Our analysis is directed at the influence of the above institutional changes on the integration of the TTF and the NCG market. All these changes were supposed to make the gas markets more liquid. As an increase in liquidity enlarges the flexibility of a market to respond to exogenous shocks, we expect that these measures also have reduced the impact of cross-border constraints on price differences between the Dutch and German market.

We apply GARCH (1,1) models to the differences in daily gas prices on the TTF and NCG over the period June 2007 – December 2011. We use a mean equation in which the key explanatory variables are the daily utilization rates of the L- and H-gas export infrastructure and dummies for the institutional changes with interaction terms. We control for the influence of time patterns, outside temperature and the Ukraine gas crisis.

We analyse market integration in two ways. The difference in the highest daily day-ahead prices between TTF and NCG is our measure of integration of price levels.[4] In addition, we look at the range between the highest and the lowest day-ahead prices at TTF and NCG. The high-low price range of day-ahead prices is interpreted as an indicator of volatility. In an integrated market, not only price levels converge, but also price volatility as in integrated markets all prices show similar movements (Stigler and Sherwin, 1985) reducing the difference between the high-low ranges of day-ahead prices at TTF and NCG. We use day-ahead prices because daily changes in cross-border utilisation in particular affect short term prices.

The utilisation rates are used as a measure of the cross-border constraints, using daily data on transport flows and capacity (GTS, 2012). We measure the constraint as a continuous variable because traders can be expected to face more difficulties in acquiring additional capacity if the level of transport flows approaches the capacity levels. This general

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[4] The price data are obtained from Bloomberg. These data are to a large extent similar to the data from ICIS Heren, although some small differences exists.

relationship holds even more in the gas industry where most of the capacity is booked in advance through long-term contracts, leading to situations in which some traders face capacity restrictions where others still have unused capacity (CEER, 2011). This means that utilisation rates (far) below 100% may indicate constraints for international price arbitrage.

This paper proceeds as follows. Section 2 gives the theoretical background, Section 3 describes the Dutch gas market and its connection with the German market. This section also introduces various institutional changes in the Dutch and German gas market. Section 4 presents the empirical model, Section 5 gives the results of the econometric analysis and Section 6 concludes.

2. Infrastructure constraints and gas prices

We measure the integration of gas markets by the evolvement of price differences. This analysis is based on the idea that in a fully integrated market, price differences quickly disappear as a result of traders using arbitrage opportunities (Stigler and Sherwin, 1985). In such a market, price differences between countries do not exceed the actual costs of transportation, including transaction costs. If, however, constraints between regional markets do exist, prices in these markets are not directly related to each other anymore and, as a result, they may show diverging patterns for a period of time (Marmer et al., 2007). Hence, in case of transaction costs as well as cross-border constraints, the Law of one Price (LOOP) can be formulated as follows (Barrett, 2001):

$$p^0 \begin{array}{ll} \leq p^1 + t^{1,0} & \text{if} \quad q^{1,0} = 0 \\ = p^1 + t^{1,0} & \text{if} \quad q^{1,0} \in (0, Q^{1,0}) \\ \geq p^1 + t^{1,0} & \text{if} \quad q^{1,0} = Q^{1,0} \end{array} \tag{1}$$

where the p^0 and p^1 are the prices in the markets 0 and 1, respectively, $t^{1,0}$ is the transaction costs of exporting the good from market 1 to market 0, $q^{1,0}$ is the actual flow of the good from market 1 to market 0 and $Q^{1,0}$ is the cross-border transport capacity from market 1 to market 0. As far as the constraint is not reached by the actual flows, the price difference equals the transaction costs.

The impact of infrastructure constraints on prices fundamentally differs from the impact of costs of transportation. The latter is related to actual costs, while a barrier is not directly related to costs but to the impossibility to realise arbitrage benefits. Furthermore, costs of transportation reflect cross-border price differences if transportation is allocated through an auction mechanism. Even in such cases, transport costs need not be fully equal to cross-border differences if cross-border trade is hampered by imperfect information, as is shown for European electricity markets by Gebhardt and Höffler (2013). In the gas market, however, the prices for cross-border capacity are subject to regulatory supervision resulting in constant costs on annual basis. Note, that transaction costs might also include other transaction costs, for instance costs related to finance and insurance (Barrett, 2001).

We are interested in the impact on prices of constraints in the cross-border flows resulting from a high level of utilisation of the infrastructure. If $p^1 - p^0 > t^{1,0}$ and if the infrastructure to import from country 1 to country 0 is fully utilised, this price difference cannot be reduced through arbitrage. Note that the causality between regional price differences and utilisation of infrastructure is bidirectional: the more benefits can be realised (i.e. the larger the regional price differences), the sooner a connecting infrastructure is fully utilised. If differences in prices between regions increase, for instance due to a supply shock in one region, the utilisation of the infrastructure increases as a result of traders searching for arbitrage profits. This should be taken into account in the econometric analysis.

We elaborate on previous papers analysing the degree of integration of gas markets on the basis of price differences between countries or hubs. Several authors have found evidence for economic integration of markets. Siliverstovs et al. (2005) find, on the basis of a cointegration analysis on data from the early 1990s to 2004, that the European and Japanese gas markets were integrated in the long term, because of the presence of similar long-term contract structures and oil-price indexation. Although cointegrated, short-term price differences did exist as a result of fluctuations in transportation costs as well as the use of different types of reference oils applied in the oil-price indexation contracts. Regarding the relationship between the European markets and the US gas markets, the authors find that these markets were not integrated as arbitrage was hardly possible between these regions, while there were neither common drivers behind the gas prices. In the US, gas prices were already more determined in competitive gas markets, while in Europe gas prices were more linked to the oil price. Marmer et al. (2007), however, argue that the US gas market consists of three relatively isolated regional markets: the Northeast, Midwest and California. Demand shocks in one of these regional markets appeared not to result in sufficient price adjustments in other regions. Cuddington and Wang (2006) also find different regional markets within the US.

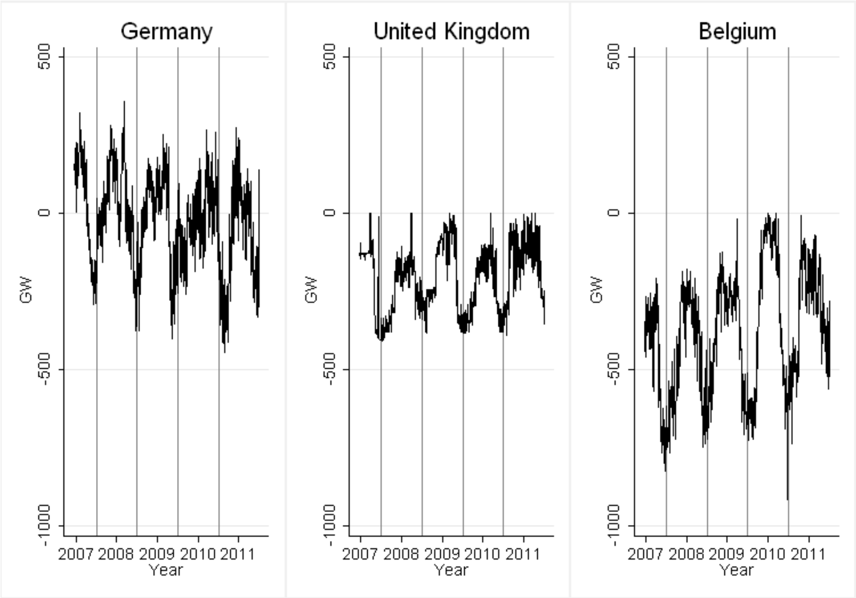
For the German gas market, Growitsch et al. (2012), using a cointegration and a time-varying coefficient approach, find that the two major trading hubs (NCG and GPL) and the Dutch TTF market are reasonably well integrated. Nevertheless price differences do occur which cannot be explained by transportation costs, i.e. the exit and entry charges imposed in the entry-exit system of the gas networks. The authors conclude that capacity constraints between the two German markets still hinder the realisation of perfect arbitrage. In addition, they conclude that the German NCG market and the Dutch TTF are increasingly integrated: prices between NCG and TTF appear to adjust within one trading day.

Our analysis differs from the above studies as we focus on how institutional changes affects the impact of cross-border constraints on price differences. If an institutional change raises the liquidity of a gas market, it indirectly reduces the sensitivity of prices in that market to constraints in a specific part of the infrastructure. Neumann and Siliverstovs (2005), for instance, find differences in prices between unconstrained markets which might be due to illiquidity of one of those markets. Hence, in liquid markets, traders are better able to quickly respond to changes in market circumstances (Cuddington and Wang, 2006; LECG, 2011).

3. The Dutch gas market and its cross-border connections

A characteristic phenomenon of the Dutch market is the presence of a huge swing field (Groningen), i.e. a field with a high well-head pressure enabling the operator to quickly change the level of production, and a number of small fields, both onshore and offshore. Because of the Groningen field, the Dutch gas industry is able to export gas with a high seasonal profile to the neighbouring countries. The Dutch gas network is connected to the networks in Germany, Belgium and the United Kingdom. The connection with German is used both for import (mainly H-gas) and export (mainly L-gas), while the other two connections are only used for export. The UK-NL interconnector is bi-directional since October 2010. This is one of the institutional changes we discuss at the end of this section. The net flows to Germany, defined as Dutch import minus Dutch export, as well as the exports to Belgium and the United Kingdom have a strong seasonal pattern (Figure 1). During winter time, exports exceed imports, while during summer time imports exceed exports, which is related to the abovementioned swing characteristic of the Groningen field. In our analysis we will include Heating Degree Days to capture the effect of cold weather.

Figure 1. Net flows between the Dutch market and the markets in Germany, the United Kingdom and Belgium, 2007-2011



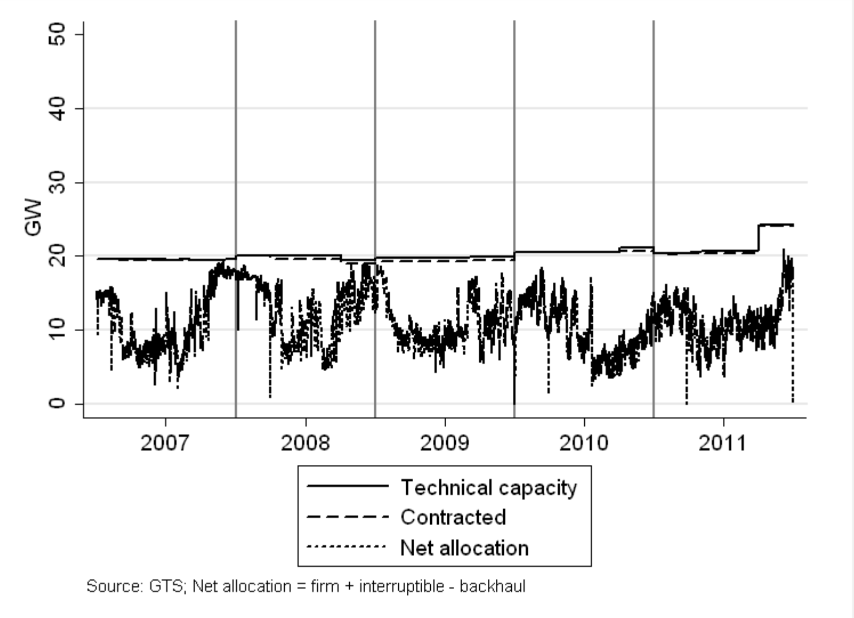
Source: GTS; Net flow = Dutch import - Dutch export

Import of gas consists only of H-gas from the Gasunie Deutschland (GUD) network, which is a part of GASPOOL. This gas, coming from Norway and Russia, is partly used by industrial consumers, including electricity companies, while the other part is re-exported. The latter implies that the Dutch network is also used as a transit network, needed to bring gas from for instance Russia to the United Kingdom. These transit flows are less temperature related than the domestic demand by residential users. The data show that import flows are fairly flat during a year.

As explained in Section 1, we focus on the NCG network. The capacity to export to the NCG network stayed fairly stable, both for H-gas and for L-gas (Figures 2 and 3). This capacity was almost permanently fully booked on a long-term basis. One reason for the high level of contracting is that firms need to be able to adapt supply to changes in demand levels, which is particularly relevant for exporters supplying flexibility services (GTS, 2012). Hence, they book capacity on a firm basis which means that are assured the capacity will be available. If not 100% certainty is needed, shippers can also book interruptible capacity which is capacity facing the risk of not being available in case of a high level of utilisation.

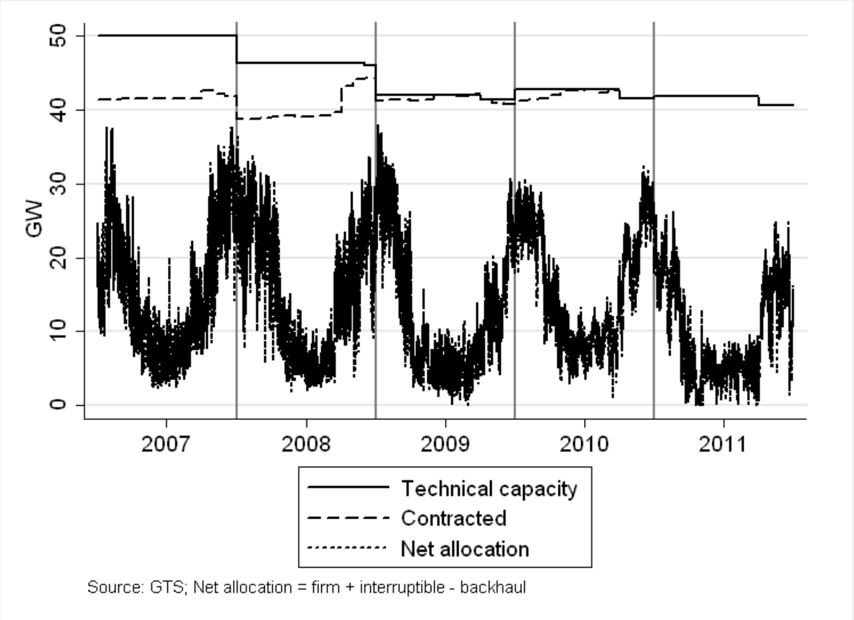
The tariffs for booking transport capacity are subject to regulatory supervision: on annual basis, the tariffs should be such that the aggregated revenues (given a certain expected level of volume) do not exceed the level of so-called efficient costs of the TSO including a fair return on capital (NMa, 2011). The Dutch TSO sets tariffs for all entry and exit points, both on the borders and domestically. In 2011, there were specific tariffs for 19 entry border points and 25 exit border points. For each point, different tariffs exist for different periods for which capacity is needed. The reference tariff is the tariff for one year. The (unweighted) average annual tariff for all cross-border exit points were 1.55 Euro/MWh/h/year in 2007 and 2008, 1.62 Euro/MWh/h/year in 2009, 1.68 Euro/MWh/h/year in 2010 and 2011. These tariffs were constant during a year.

Figure 2. Utilisation of the Dutch export infrastructure for H-gas to the NCG network in Germany, 2007-2011



Source: GTS; Net allocation = firm + interruptible - backhaul

Figure 3. Utilisation of the Dutch export infrastructure for L-gas to the NCG network in Germany, 2007-2011



Source: GTS; Net allocation = firm + interruptible - backhaul

The liquidity of the TTF has grown substantially. The share of the TTF in the Dutch gas market increased from 5% in 2007 to 40% in 2011 (Figure 4). Although the churn ratio between nominated volumes and volumes actually delivered on the TTF remained fairly stable at the level of about 4, the actual churn ratio exceeded 15 as an increasing number of trades occurs in the period before traders have to nominate their gas flows.[5] A churn ratio above 10 indicates that the TTF is a mature market (GTS, 2012; Heather, 2012). The churn of the NCG, however, hardly exceeded 1, implying that the trade in this market is relatively strongly related to physical delivery and that this market is much less liquid than TTF and NBP.

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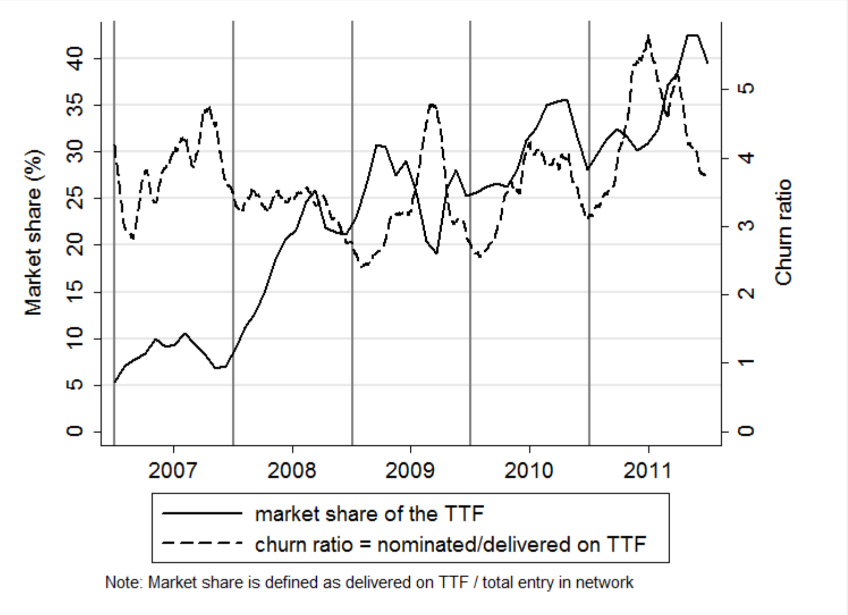
[5] Traders have to nominate their gas flows within a year before the gas is going to flow. During this year the gas can still be exchanged, resulting in new (re)nominations. When the gas is actually going to flow, the last nomination of a gas flow is translated into an allocation of a gas flow, which is related to the actual delivery. The churn ratio presented in Figure 4 is based on the aggregate nominations versus the aggregate allocations.

Figure 4. Churn ratio and market share of TTF, 2007 – 2011 (per day)



The day-ahead price on the TTF during the period 2007-2011 is depicted in Figure 5. Besides the volatility from day to day, we also see significant changes from year to year. The day-ahead price on the NCG correlates strongly with the day-ahead price on the TTF (correlation coefficient is 0.993). From Figure 6, we see that the difference between the highest and lowest day-ahead price on the TTF fluctuates strongly, resulting in large spikes from time to time. The correlation between highest and lowest day-ahead prices on the TTF and NCG has increased from 0.430 in the first half of the sample (before October 2009) to 0.687 since October 2009.

The price difference between TTF and NCG does not reveal a seasonal pattern, but it has clearly declined over the past years (Figure 7). In 2007, substantial differences in prices existed, but gradually these differences have become smaller. This holds both for the differences between the highest daily prices on TTF on the one hand and NCG on the other (Figure 7) and for the differences in the volatility, measured by the range between the highest daily price and the lowest daily price (Figure 8).

Figure 5. Day-ahead gas price in the Dutch market (TTF), 2007-2011 (highest per day)

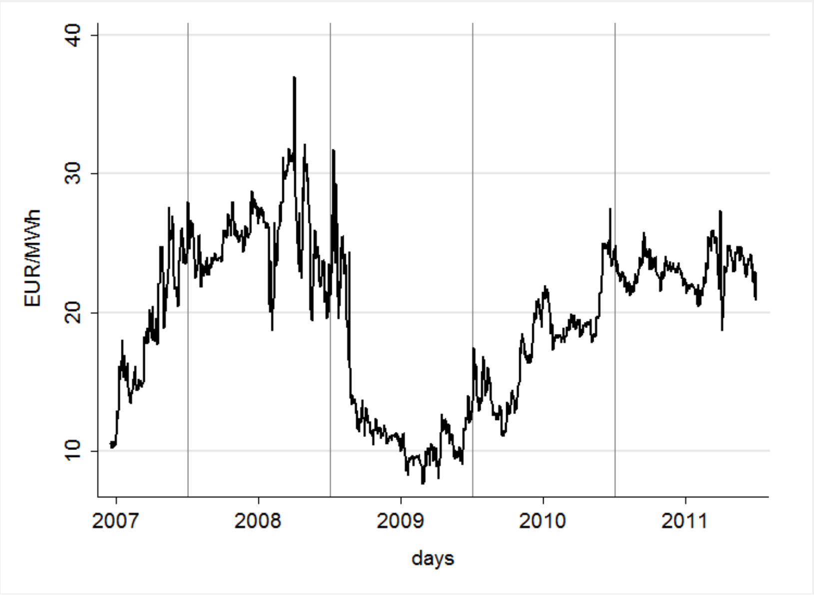


Figure 6. Range between highest and lowest day-ahead gas price in the Dutch market (TTF), 2007-2011 (per day)

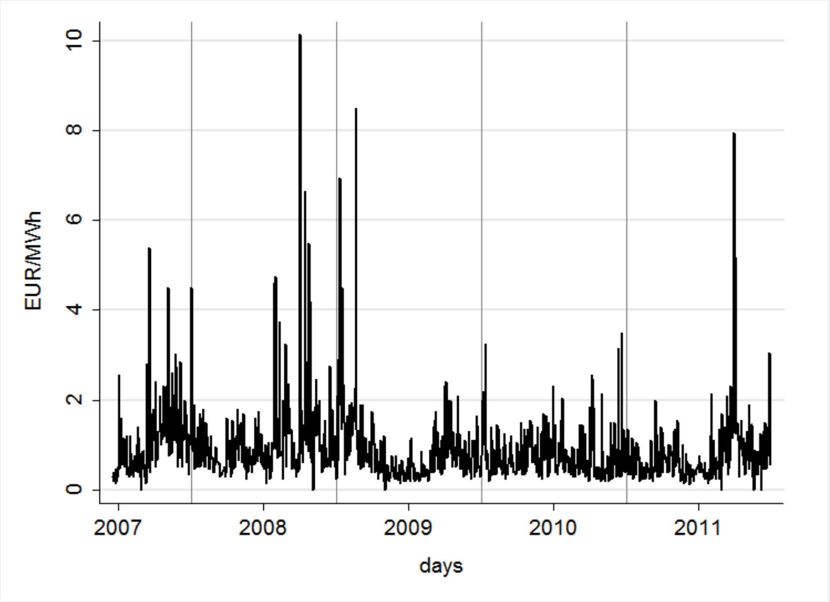
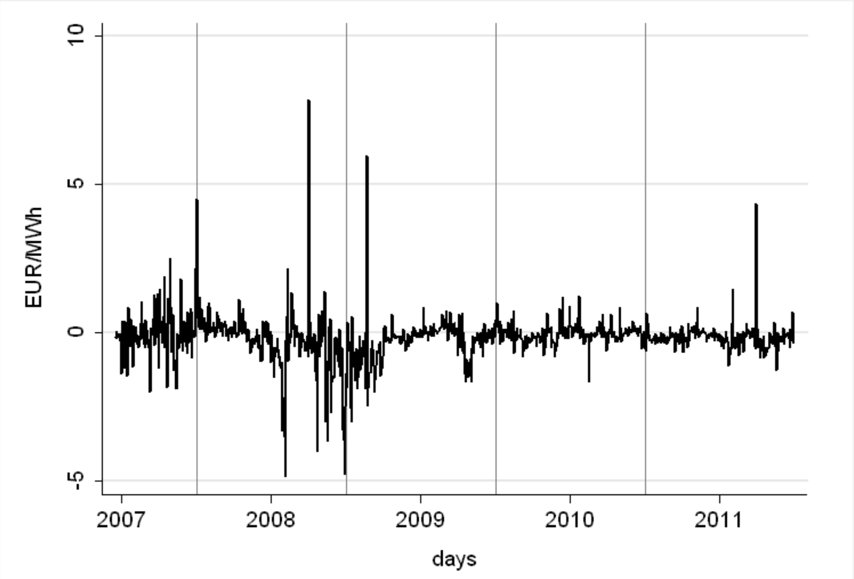
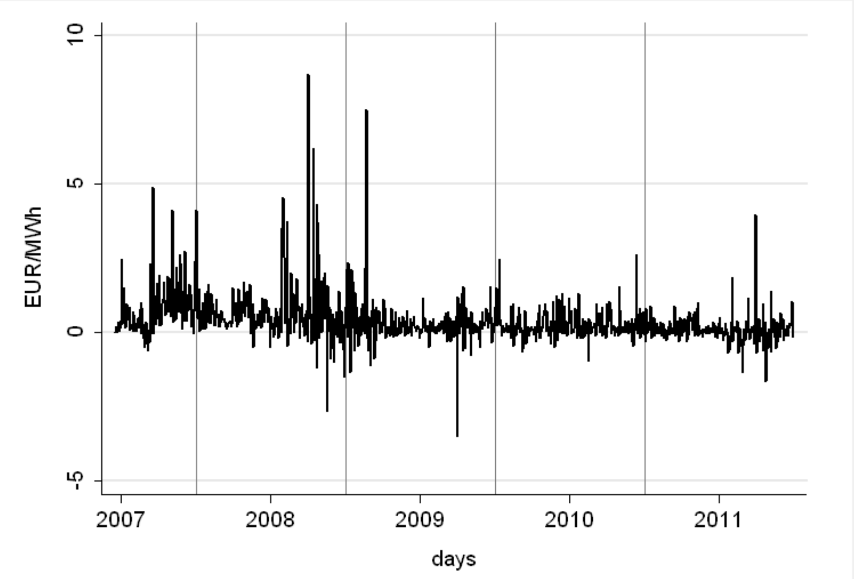


Figure 7. Difference in the day-ahead gas price in the Dutch market (TTF) and the German market (NCG), 2007-2011 (per day)



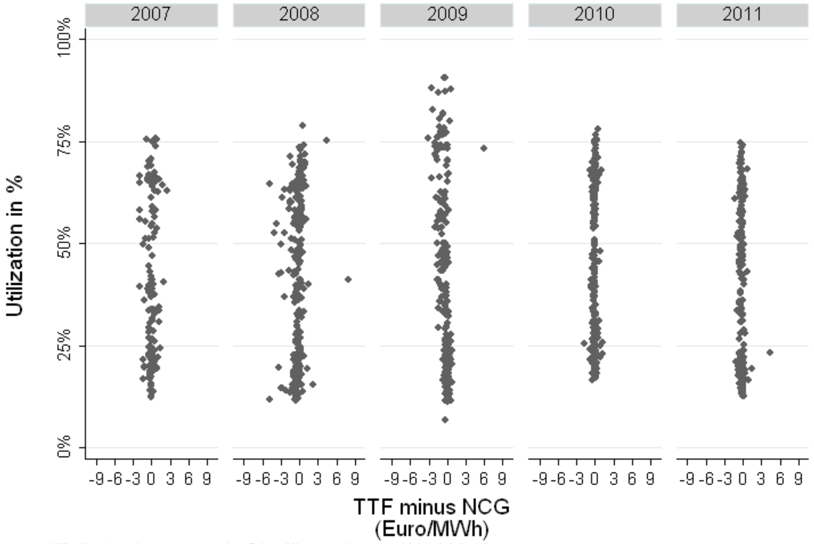
Source: Bloomberg

Figure 8. Difference in the range between the highest and the lowest day-ahead gas price in the Dutch market (TTF) and the German market (NCG), 2007-2011 (per day)



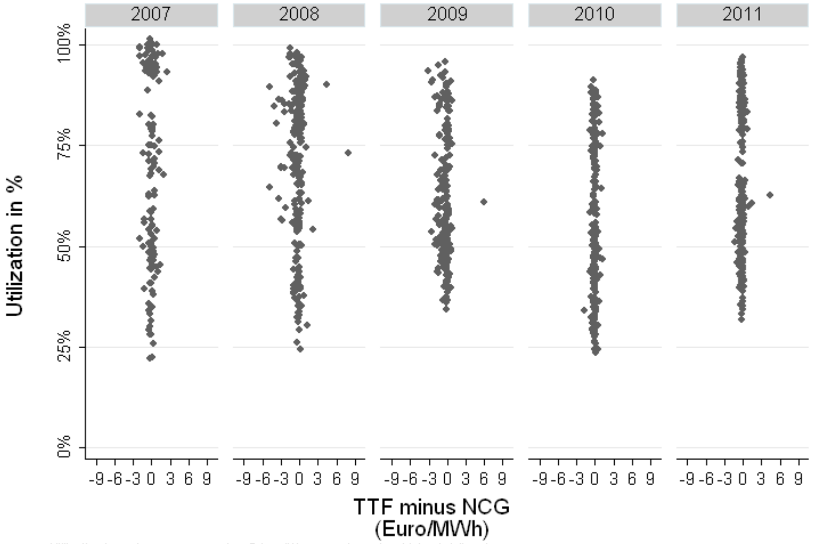
Source: Bloomberg

Figure 9. Utilisation of infrastructure for the export of L-gas to Germany (NCG) and differences in prices on TTF and NCG, 2007-2011



Utilization based on usage per day; Price differences based on highest daily price
Source: GTS/Bloomberg

Figure 10. Utilisation of infrastructure for the export of H-gas to Germany (NCG) and differences in prices on TTF and NCG, 2007-2011



Utilization based on usage per day; Price differences based on highest daily price
Source: GTS/Bloomberg

The cross-border infrastructure is increasingly efficiently used: in 2011 less hours showed price differences while the infrastructure was not fully used compared to a number of years ago (Figures 9 and 10). In these hours, traders apparently face restrictions in using the infrastructure to benefit from arbitrage opportunities. Nevertheless, in 2011 price differences still frequently occurred which might be caused by remaining bottlenecks in using the infrastructure.

Table 1. Institutional changes in the Dutch and German gas market, 2007-2011

Dummy variable	Date of implementation	Dutch market	German market
D_1	1 October 2007		Introduction of entry-exit system between 19 zones in Germany
D_2	1 July 2008	The Dutch TSO (Gasunie) acquires the GUD network in Germany	
D_3	1 October 2008		NetConnect Germany (NCG) results from pooling of areas of E.ON and Bayernets
D_4	1 July 2009	Abolishment of the obligation to book quality-conversion capacity	
D_5	1 October 2009		NCG network is extended with GRTgaz Deutschland, ENI and GVS
D_6	1 October 2010	Introduction of backhaul on BBL	
D_7	1 April 2011	New balancing regime; Obligation to deliver gas on the TTF	NCG network is extended with Thyssengas

The dummy variable takes the value of one from the start of the institutional change. The institutional changes remain in affect also after a new measure has been implemented. This implies that, for instance, the value of D_4 is zero before July 1, 2009 and one on July 1, 2009 until the end of the sample. In October 1, 2010 another policy is implemented. So D_5 becomes one on October 1, 2009 until the end of the sample, while D_4 remains one.

In this paper, we analyse the impact of a number of institutional changes in both the Dutch and the German market (Table 1). In the models discussed in the next section, these institutional changes are modelled using dummy variables defined in Table 1.

A key institutional change in the Dutch market was the abolishment of the obligation of market parties to book quality-conversion capacity as of July 1, 2009. The connection with the UK market was raised through the introduction of interruptible reverse (backhaul) flow services on the BBL (Balgzand-Bacton Line), making it possible to book gas in the reverse direction (GTS, 2012).

Other measures to improve the liquidity of the Dutch wholesale market were the implementation of a market-based balancing regime on April 1, 2011 and the policy of GasTerrra, the Dutch incumbent gas supplier, to deliver all gas for the domestic market on TTF instead of factory or city gates (Heather, 2012).

In the German market also several institutional changes occurred. After the introduction of an entry-exit system in October 2007, several networks pooled resulting in two network areas for H-gas and only one for L-gas. The two German H-gas networks are NCG and GPL; the former covers the southern part of Germany and the latter the northern part.

4. Empirical model and data

4.1 Dependent variables

We measure the economic integration of the Dutch and German gas market through differences in the day-ahead prices. We use the day-ahead price instead of longer-forward prices as the former prices are more sensitive to short-term changes in availability of cross-border capacity. As day-ahead prices refer to gas flows on the next business day, we relocate the prices in the database accordingly, taking into account the effect of weekends and bank holidays.

Data on the prices were obtained from the Bloomberg database. This database gives the highest price realised on a day, the lowest prices and the last price. We use this data to estimate two different models. In the first model the dependent variable is the difference in highest daily day-ahead price on the Dutch market (TTF) and on the German market (NCG). In the second model the dependent variable is the difference in the daily price range (i.e. the highest daily price minus the lowest daily price) between both markets. The daily price range can be seen as measure for the daily volatility. For both models we use the same set of explanatory variables.

Table 2. Summary statistics of differences in maximum daily gas price (TTF minus NCG), for various samples based on institutional changes

	Oct 2007-Jun 2008	**Jul 2008-Sep 2008**	**Oct 2008-Jun 2009**	**Jul 2009-Sep 2009**	**Oct 2009-Sep 2010**	**Oct 2010-Mar 2011**	**Apr 2011-Dec 2011**
Mean	0.081	-0.490	-0.633	0.135	-0.131	-0.101	-0.159
Median	0.100	-0.450	-0.450	0.050	-0.100	-0.100	-0.150
Std. Dev.	0.681	0.839	1.202	0.228	0.415	0.226	0.448
Skewness	1.376	-0.738	2.087	1.090	-0.813	0.966	5.564
Kurtosis	13.167	6.793	20.556	4.102	6.538	5.881	57.032
nObs.	186	62	185	65	249	125	188

Data source: Bloomberg

Table 3. Summary statistics of differences in daily price range (TTF minus NCG), for various samples based on institutional changes

	Oct 2007-Jun 2008	**Jul 2008-Sep 2008**	**Oct 2008-Jun 2009**	**Jul 2009-Sep 2009**	**Oct 2009-Sep 2010**	**Oct 2010-Mar 2011**	**Apr 2011-Dec 2011**
Mean	0.778	0.669	0.501	0.193	0.236	0.191	0.091
Median	0.625	0.475	0.250	0.150	0.200	0.100	0.050
Std. Dev.	0.637	0.936	1.207	0.252	0.485	0.373	0.472
Skewness	2.004	2.324	3.519	0.656	-1.026	2.834	2.950
Kurtosis	10.064	8.891	21.937	5.624	18.009	16.786	27.709
Obs.	186	62	185	65	249	125	188

Data source: Bloomberg

Tables 2 and 3 report descriptive statistics for various subsamples that reflect important institutional changes reported in Table 1. Table 2 shows that, on average, NCG prices exceed TTF prices. The biggest difference of -0.633 euro/MWh is reported in the period October 1, 2008 – June 30, 2009 before the obligation of market parties to book quality-conversion capacity was abolished in the Netherlands. Over time the price difference steadily decreases to -0.159 euro/MWh after April 1, 2011. A similar pattern is observed for the median price difference. The standard deviation reaches its lowest value in the period between Oct 1, 2010 and Mar 31, 2011. The gas price difference shows a long right tail (positive skewness) especially towards the end of the sample, and the distribution of the price difference is peaked relative to the normal distribution (kurtosis coefficient > 3) for all periods. The average difference in the range of the daily gas prices between the Dutch and the German market steadily decreases from 0.778 euro/MWh before July 1, 2008 to 0.091 euro/MWh after April 1, 2011 as Table 3 indicates. The distribution of the difference in the daily range is positively skewed and is relatively peaked in most of the sample.

Autocorrelations of the maximum price differences suggest dependence in the mean, and the autocorrelations of the squared price differences reveal dependence in volatility (see Appendix B). The former observation leads us to assume an AR(1) process in the mean equation, while the latter observation justifies the use of GARCH models.[6] Table B2 in Appendix B indicates that there is also dependence in the mean and volatility for the difference in the price range (measured as the difference between the high and low gas prices within a day) between the Dutch gas market and the German gas market.

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[6] See Appendix A for the specification of GARCH models.

4.2 Base model

The base model consists of a set of explanatory variables measuring the utilisation of infrastructure and controlling for a number of other influences on price differences.

The infrastructure constraint is included by the (first lag of the) maximum daily capacity utilisation (U), defined as the ratio (in %) between the total daily allocated capacity and total maximum available capacity on the borders with the NCG network:

$$U_t = \frac{FN_t + IN_t - BN_t}{FC_t}, \tag{2}$$

where t is the suffix for days.[7] The total available capacity is based on firm capacity (FC), which is the capacity allocated to market parties under firm conditions (GTS, 2012). Total allocated capacity consists of both firm (FN) and interruptible (IN) nominations.[8] For unidirectional clusters[9], we net the interruptible forward with the backhaul nominations (BN). After all, backhaul results in lower net flows. For bidirectional clusters, this is not needed as here no backhaul takes place. Since we want to analyse the relationship between gas prices on network level, we measure the utilisation of the cross-border infrastructure on network level as well, aggregating the cluster-level data. In addition, we take the maximum daily value of the utilisation rates as these better reflect cross-border constraints than for instance the

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[7] Gas prices are only available on working days, as exchanges and OTC trading places are closed on weekends and bank holidays. Therefore, we estimate the infrastructure utilisation also per day. Since we want to know whether an infrastructure is congested, we use the maximum hourly value per day

[8] These data are measured at the level of clusters, which might combine several entry and/or exit points. Note that the maximum capacity of a cluster might be lower than the aggregate capacity of the related entry/exit points.

[9] The Dutch gas network is connected to the neighbouring networks through a number of entry and exit points. These points are grouped together in about 10 clusters. As the network is distinguished in a L-gas and a H-gas part, there are also separate clusters for L-gas and H-gas and also for Groningen-gas or G-gas and G+-gas. See GTS (2012) for more details.

average daily value. Moreover, as separate infrastructures exist for H- and L-gas, we include the utilisation rates for both export of H-gas ($U^{EX\text{-}H}$) and export of L-gas ($U^{EX\text{-}L}$).[10]

Tables 4 and 5 show the summary statistics of these two variables for various samples which are related to the institutional changes (see Table 1). It appears that the (maximum daily) utilisation rate is fairly constant over the various samples, both in terms of average value (mean and median) and in terms of volatility (standard deviation). Moreover, the time series are hardly skew distributed and they neither show a peak relative to the normal distribution (kurtosis < 3). Only the last period (April 2011 – December 2011) shows a somewhat deviating pattern.

Table 4. Summary statistics of the utilisation rate of the H-gas export infrastructure to NCG, for various samples related to the duration of institutional changes

	Oct 2007-Dec 2011	**Jul 2008-Dec 2011**	**Oct 2008-Dec 2011**	**Jul 2009-Dec 2011**	**Oct 2009–Dec 2011**	**Oct 2010-Dec 2011**	**Apr 2011-Dec 2011**
Mean	0.650	0.624	0.627	0.617	0.617	0.631	0.586
Median	0.623	0.597	0.597	0.596	0.598	0.587	0.565
Std. Dev.	0.196	0.186	0.187	0.184	0.188	0.178	0.138
Skewness	0.011	0.112	0.132	0.083	0.068	0.373	0.465
Kurtosis	1.797	1.918	1.876	1.933	1.914	1.833	2.524
nObs.	1060	874	812	627	562	313	188

We take the first lag of the utilisation rate while the price data were placed one day into the future (see Section 4.1). Consequently, we control for the fact that traders may know the utilisation rate when they make their trade decisions on the day-ahead market, while we do not encounter causality problems as the utilisation rate on a specific day cannot be influenced by trade decisions on that same day (which result in flows the next day).

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[10] There is no import of gas from NCG.

Table 5. Summary statistics of the utilisation rate of the L-gas export infrastructure to NCG, for various samples related to the duration of institutional changes

	Oct 2007- Dec 2011	Jul 2008- Dec 2011	Oct 2008- Dec 2011	Jul 2009- Dec 2011	Oct 2009– Dec 2011	Oct 2010- Dec 2011	Apr 2011- Dec 2011
Mean	0.413	0.393	0.406	0.385	0.407	0.418	0.308
Median	0.396	0.356	0.380	0.336	0.390	0.450	0.214
Std. Dev.	0.203	0.203	0.202	0.191	0.189	0.202	0.175
Skewness	0.215	0.384	0.309	0.380	0.220	0.0004	0.969
Kurtosis	1.656	1.811	1.756	1.692	1.624	1.487	2.533
Obs.	1060	874	812	627	562	313	188

We also include the net cross-border flow of gas (L-gas + H-gas in GW) to and from Germany, the United Kingdom and Belgium as exogenous variables (*NX*). The latter variables are included to control for the effects of trade in gas between all Dutch trading partners on the price of gas in the Netherlands. We expect that these flows negatively influence price differences. These variables are lagged one period to avoid possible biases due to reverse causation.[11]

We also control for the Ukraine gas crisis in January 2009, which strongly affected European gas markets, by including a dummy (*D_UKR*) for the period 7 January 2009 – 18 January 2009 (Kovacevic, 2009). Moreover, we control for the impact of cold weather periods on the gas market by including the Heating Degree Days (*HDD*), based on the average daily temperature in the Netherlands as measured by the Dutch Meteorological Institute (KNMI). In addition we include dummies for months (M_i) to capture seasonal patterns. We also include year dummies (Y_i) to control for annual changes in cross-border tariffs.

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[11] Including contemporaneous explanatory variables using IV yields similar results. However finding valid and relevant instruments has proven to be problematic, so here we present OLS results using lagged explanatory variables.

What we have described above is the base model for price differences (in euro/MWh) and differences in the daily range of gas prices ($P^{ttf\text{-}ncg}$, in euro/MWh) between TTF and NCG ($S^{ttf\text{-}ncg}$) which is formulated as:

$$P_t^{ttf-ncg} = \alpha_0 + \beta_0 U_{t-1}^{EX-H} + \chi_0 U_{t-1}^{EX-L} + \delta_0^G NX_{t-1}^{GER} + \delta_0^U NX_{t-1}^{UK} + \delta_0^B NX_{t-1}^{BEL} + Z_t \gamma + \varepsilon_t \,, \qquad (3)$$

where vector Z_t captures all other control variables. The coefficients of interest are β_0 and χ_0. These coefficients measure the impact of a one unit increase in the maximum daily capacity utilisation for exports of H-gas and L-gas respectively, on the difference in the daily prices.

4.3 Alternative models

With the alternative models, we analyse the impact of a number of institutional changes in both the Dutch and the German market (Table 1). We capture the effect of each of these institutional changes by dummy variables. These variables are included in the model both separately and in interaction with the variables measuring the degree of utilisation of the cross-border infrastructure. As the different sample periods are characterised by comparable levels of utilisation of the cross-border infrastructure (Tables 4 and 5), we may conclude that possible differences in estimation results for the various interaction terms cannot be the result of different levels of the utilisation rates, but must be the consequences of external factors, such as changing liquidity of the gas markets.

Concluding, the mean-equation model for the difference in maximum spot prices is as follows:

$$\begin{aligned}P_t^{ttf-ncg} &= \alpha_0 + \sum_{i=1}^{7}\alpha_i D_i + \beta_0 U_{t-1}^{EX-H} + \sum_{i=1}^{7}\beta_i D_i U_{t-1}^{EX-H} + \chi_0 U_{t-1}^{EX-L} + \sum_{i=1}^{7}\chi_i D_i U_{t-1}^{EX-L} \\ &+ \delta_0^G NX_{t-1}^{GER} + \sum_{i=1}^{7}\delta_i^G D_i NX_{t-1}^{GER} + \delta_0^U NX_{t-1}^{UK} + \sum_{i=1}^{7}\delta_i^U D_i NX_{t-1}^{UK} \\ &+ \delta_0^B NX_{t-1}^{BEL} + \sum_{i=1}^{7}\delta_i^B D_i NX_{t-1}^{BEL} + Z_t\gamma + \varepsilon_t\end{aligned} \qquad (4)$$

Because of the way the dummies are coded (one from the implementation date of the policy until the end of the sample), the coefficients for the interaction terms measure the impact of the change in the degree of capacity utilisation on the cross-border price difference of that policy. Again, for the second model we replace the maximum price difference with the difference in the price range, denoted as $S^{ttf\text{-}ncg}$.

The hypotheses are that the institutional changes led to reduced differences in both the highest daily prices and the price range (i.e. highest minus lowest price) between the Dutch gas market and the German gas market. These hypotheses can be tested from parameters $\beta_1,\ldots,\beta_7$ and $\chi_1,\ldots,\chi_7$.

5. Results

In this section we report the estimation results for Equations (3) and (4). In these equations, the coefficients for the maximum daily utilisation rates for exports of H-gas and L-gas are independent of their initial levels. Including power terms to allow for nonlinearities did not lead to different results, so we estimate the original equations. But before we estimate Equations (3) and (4) we show that the variables in these equations are stationary, so that the results reported here are not spurious. In the previous section we indicated that these equations cannot be estimated efficiently with Least Squares. Here, we test formally that we need to apply GARCH models (see Appendix A) in which Equations (3) and (4) are the mean equations.

5.1 Testing

Tests for stationarity using the Augmented Dickey-Fuller test of the maximum prices (both TTF and NCG) do not reject the null of a unit root at the 5% significance level. This is confirmed by the Kwiatkowski-Phillips-Schmidt-Shin test. The latter test does not reject the null of stationarity at the 5% significance. However, both test clearly indicate that the cross-border difference in maximum prices clearly is stationary. The same holds true for the difference between the within-day price range. Hence, the dependent variables in Equations (3) and (4) are stationary. Also the explanatory variables are stationary.

Applying the ARCH LM-test on ordinary least squares estimates shows that the null of no serial correlation of volatility is strongly rejected for lags up to order 10 and higher (at 5% significance levels), whereas the null in the price range model is rejected for 8 lags and higher. Testing reveals that the models are not covariance stationary, so we estimate Integrated GARCH(1,1) models implying that the volatility of the model is not mean-reverting as is often observe in financial time series. As a consequence external shocks leading to a change in volatility are permanent.[12]

We assume that the residuals do not follow a normal (Gaussian) distribution, because the error distribution is fat-tailed (a higher than normal probability of extreme events) as is often observed in finance and commodity markets. Applying the likelihood-ratio test to test the null of normally distributed errors against both the generalized error distribution and the *t*-distribution clearly rejects the null ($\chi^2(1)$ exceeds 558 in all four models). With *t*-distributed

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[12] Caporale, Pittis and Spagnolo (2003) and Mikosch and Stărică (2004) examine why volatility may not be mean reverting. They refer to nonstationarities and structural breaks.

errors the log likelihood (ln L) for all models is higher than assuming that the errors follow a generalized error distribution.[13] So, we estimate the models assuming that the errors are t-distributed.[14] The degrees of freedom (dof) for the t-distribution is about 3.3 for the price difference model and even lower for the price range model. These estimates which are shown in the tables in the next section suggest that the error distribution is fat tailed.[15]

The ARCH LM test indicates that there is no autoregressive conditional heteroskedasticity up to any order in the standardized residuals for the base models and the alternative models including policy dummies. This is confirmed by the Ljung–Box Q–statistic of the standardized squared residuals up to any lag. From these tests we conclude that the volatility model is adequate.

Concluding, we apply GARCH (1,1) models to the differences in daily gas prices in the Netherlands (TTF) and Germany (NCG) over the period June 2007 – December 2011. We use a mean equation (3) that includes a constant, month and year dummies, lagged net gas flows, lagged maximum daily utilization rates for exports of L-gas and H-gas, dummies for the institutional changes with interaction terms, the Ukraine dummy, heating degree days (HDD), and an AR(1)–term as is suggested by the autocorrelations in Appendix B.

5.2 Estimation results

From Table 6, showing the results for the base models, we conclude that the degree of utilization of the cross-border infrastructure is positively related to cross-border differences in price levels. This result confirms our expectation that the utilization rate affects the ability of

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[13] Obviously this is confirmed by Akaike's Information Criterium (AIC = $2k - 2 \ln L$, where k is the number of parameters which is the same for the generalized error distribution and the t-distribution).

[14] The estimates in case the errors follow a generalized distribution are in Appendix C.

[15] The t-distribution approaches the normal if the degrees of freedom gets infinitely large.

traders to make use of arbitrage opportunities. This positive relationship is found for both the H-gas and the L-gas network. Regarding differences in volatility (measured as the within-day price range), we find a positive relationship for the utilization of the H-network, but not for the L-network.

The differences in price levels appear to be negatively related to the size of cross-border flows between the Netherlands and Germany, which was also expected. The net cross-border flows between the Netherlands and the markets in Belgium and the UK had no effect on the price differences with Germany as we may expect. The outside temperature, measured by the Heating Degree Days, negatively affects price differences, which means that when the gas demand is relatively large due to low temperatures, markets have more difficulties to realize equal prices. From Table 6 we also learn that seasonal effects play a significant role explaining cross-border price differences, both regarding levels and volatility (price range). The Ukraine gas crisis had a positive effect on differences in price volatility, which likely resulted from the high level of uncertainty in European gas markets in those days.

The focus in this paper is on the effects of the various institutional changes. The effects of these changes are based on interpreting the coefficients of the interaction terms of the dummies and the export capacity utilization variables for H-gas and L-gas (Table 7). The dummy variables are related to the utilization of both the H-gas and the L-gas network. Because the utilization variables for H-gas and L-gas are strongly correlated we need to test the joint significance of the corresponding coefficients for H-gas and L-gas in order to assess the effect of a specific measure.

Table 6. Results for the base models with *t*-distributed errors, 2007-2011 (Obs = 1133)

	Difference in price levels		**Difference in price range**	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Mean equation				
constant	-0.162	0.124	0.614***	0.138
$U^{EX\text{-}H}$	0.373***	0.076	0.141*	0.080
$U^{EX\text{-}L}$	0.146	0.136	-0.314*	0.169
NX^{GER}	-0.001***	0.0001	0.000002	0.0001
NX^{UK}	-0.00004	0.0001	0.0002	0.0002
NX^{BEL}	0.00005	0.0001	-0.0001	0.0001
D_UKR	-0.627	0.439	1.228***	0.268
HDD	0.007***	0.003	0.002	0.004
$Month_1$	-0.118**	0.057	-0.011	0.067
$Month_2$	-0.139***	0.040	-0.137**	0.055
$Month_3$	-0.153***	0.045	-0.180***	0.055
$Month_4$	-0.209***	0.057	-0.174**	0.068
$Month_5$	-0.230***	0.075	-0.221**	0.086
$Month_6$	-0.167**	0.074	-0.238***	0.088
$Month_7$	-0.150**	0.075	-0.250***	0.088
$Month_8$	-0.058	0.077	-0.233**	0.091
$Month_9$	-0.130*	0.074	-0.162*	0.090
$Month_{10}$	-0.211***	0.070	-0.048	0.078
$Month_{11}$	-0.072	0.049	-0.121*	0.064
$Year_2$	0.061	0.058	0.067	0.049
$Year_3$	0.042	0.050	-0.225***	0.043
$Year_4$	0.121**	0.054	-0.288***	0.051
$Year_5$	-0.042	0.052	-0.367***	0.048
AR(1)	-0.329***	0.022	0.115***	0.022
Variance equation				
α_1, ARCH(1)	0.130***	0.010	0.062***	0.006
λ_1, GARCH(1)	0.870***	0.010	0.938***	0.006
t-dist dof	3.341***	0.166	2.862***	0.095
Log likelihood	-509.872		-679.675	

***, ** and * significant at 1%, 5% and 10%, respectively.

Table 7. Results for the alternative models with t-distributed errors, 2007-2011 (Obs = 1133). Results for M, Y and UKR dummies, HDD and net flows available on request

	Difference in price levels		**Difference in price range**	
	Coefficient	*Std. Error*	*Coefficient*	*Std. Error*
Mean equation				
constant	0.170	0.454	1.300***	0.478
D_1	-0.924*	0.488	-0.471**	0.501
D_2	1.482*	0.830	1.779	0.849
D_3	-1.516*	0.888	-1.278	0.949
D_4	0.652**	0.267	-0.175	0.360
D_5	-0.619***	0.215	0.082	0.258
D_6	0.493***	0.178	0.301	0.250
D_7	-0.471***	0.179	-0.605*	0.347
$U^{EX\text{-}H}$	0.795	0.546	0.359	0.555
$D_1 * U^{EX\text{-}H}$	-0.089	0.622	0.545	0.647
$D_2 * U^{EX\text{-}H}$	-1.584	1.000	-2.934***	0.957
$D_3 * U^{EX\text{-}H}$	2.107**	1.071	1.653	1.090
$D_4 * U^{EX\text{-}H}$	-1.188**	0.515	0.482	0.650
$D_5 * U^{EX\text{-}H}$	0.435**	0.220	0.161	0.255
$D_6 * U^{EX\text{-}H}$	-0.610***	0.233	-0.614	0.411
$D_7 * U^{EX\text{-}H}$	0.250	0.223	0.400	0.422
$U^{EX\text{-}L}$	-0.119	0.895	0.061	0.767
$D_1 * U^{EX\text{-}L}$	0.727	0.975	0.686	0.907
$D_2 * U^{EX\text{-}L}$	-0.017	1.261	-1.758	1.283
$D_3 * U^{EX\text{-}L}$	-0.678	1.253	1.349	1.348
$D_4 * U^{EX\text{-}L}$	-0.669	0.568	-1.694**	0.800
$D_5 * U^{EX\text{-}L}$	0.826*	0.492	0.961	0.601
$D_6 * U^{EX\text{-}L}$	0.601*	0.312	0.409	0.506
$D_7 * U^{EX\text{-}L}$	-0.935***	0.343	-0.503	0.554
AR(1)	0.135***	0.023	0.057***	0.022
Variance equation				
α_1, ARCH(1)	0.119***	0.010	0.058***	0.006
λ_1, GARCH(1)	0.881***	0.010	0.942***	0.006
t-dist dof	3.017***	0.118	2.766***	0.084
Log likelihood	-412.144		-631.151	

***, ** and * significant at 1%, 5% and 10%, respectively.

Table 8. Joint significance (a) and significance of the sum (b) of the coefficients of dummies for institutional changes with p-values in brackets

Dummy variable	C(1), Coefficient interaction term with $U^{EX\text{-}H}$	C(2), Coefficient interaction term with $U^{EX\text{-}L}$	(a) H_0: C(1)=0,C(2)=0 H_1: C(1)≠0 and/or C(2)≠0 F-Statistic (p-value)	(b) H_0: C(1)+C(2)=0 H_1: C(1)+C(2) ≠0 F-Statistic (p-value)
Differences in price level				
D_1	-0.089	0.727	0.383 (0.682)	0.227 (0.634)
D_2	-1.584	-0.017	1.901 (0.149)	0.628 (0.428)
D_3	2.107	-0.678	3.666 (0.026)	0.494 (0.482)
D_4	-1.188	-0.669	3.143 (0.044)	5.403 (0.020)
D_5	0.435	0.826	3.110 (0.045)	5.160 (0.023)
D_6	-0.610	0.601	5.160 (0.006)	0.001 (0.980)
D_7	0.250	-0.935	4.493 (0.011)	2.704 (0.100)
Differences in price range				
D_1	0.545	0.686	0.564 (0.569)	1.080 (0.299)
D_2	-2.934	-1.758	4.718 (0.009)	5.836 (0.016)
D_3	1.653	1.349	1.244 (0.289)	2.168 (0.141)
D_4	0.482	-1.694	2.601 (0.075)	1.323 (0.250)
D_5	0.161	0.961	1.467 (0.231)	2.932 (0.087)
D_6	-0.614	0.409	1.348 (0.263)	0.110 (0.740)
D_7	0.400	-0.503	0.791 (0.454)	0.024 (0.877)

Table 8 shows two tests based on the coefficients of the dummies interacted with the maximum daily utilization rates for exports of L-gas and H-gas. Test a) tests the null that both coefficients are zero against the alternative that at least one coefficient deviates from zero. From Table 8 we conclude that the dummies D_3-D_7 have a significant influence on the differences in price levels, while dummies D_2 and D_4 have an impact on differences in volatility (within-day price range). In particular the abolition of the obligation to book quality-conversion capacity in 2009 (D_4) has reduced cross-border differences in both price levels and price volatility. The measures implemented on the 1st of April in 2011 (D_7) also had a positive effect on market integration between the Dutch and the German market. The pooling of network areas in Germany into larger networks in 2008 and 2009 (D_3 and D_5), however, seem to have reduced the integration with the Dutch market. We do not find an effect of the introduction of an exit-entry system in Germany in 2007 (D_1) and the acquisition of the GUD network by the Dutch Gasunie (D_2). Regarding the implementation of backhaul on BBL (D_6) we do find a significant effect on differences in price levels, but the sign of this effect is not clear as the coefficients for the L-gas network and the H-gas network are of an equal size but with the opposite sign. This is confirmed in Test b) where the hypothesis is tested that the sum of coefficients deviates from zero. The abolition of the obligation to book quality-conversion capacity in 2009 (D_4) and the pooling of network areas in 2009 Germany (D_5) indicate a significant impact on differences in the price level, whereas the acquisition of the GUD network by the Dutch Gasunie (D_2) and D_5 show a significant impact on the difference in price volatility.

6. Conclusions

Comparing the daily gas prices between the Dutch market (TTF) and the German market (NCG), we find that these markets have become more integrated over the past years. At the end of 2011, the difference in price levels is -0.159 euro/MWh which is lower than it was in the period from mid-2008 to mid-2009. Comparing the difference in the price range (high-low prices), we observe a steady drop from 0.778 euro/MWh to 0.091 euro/MWh in 2011.

Using daily data on cross-border infrastructure utilisation and prices, we find that the degree of utilization of the cross-border infrastructure is positively related to price differences, but that this relationship weakens during the period of analysis. We find evidence that the several institutional changes within the Dutch market have contributed to this. The abolishment of the obligation to book quality-conversion capacity on 1 July 2009 as well as the introduction of a market-based balancing regime and the policy of the Dutch incumbent GasTerra to deliver all gas on the TTF as from 1 April 2011 have contributed to making the Dutch market less sensitive to cross-border constraints. Hence, these measures appear to have raised the ability of market players to respond more quickly to price differences between the Dutch and German market. The pooling on network areas in Germany in 2008 and 2009, however, seems to have reduced the integration with the Dutch market. This result might be related to the fact that the NCG market is still not a very liquid market, while the TTF market has become one of the most liquid gas markets in Europe.

We stress the fact that our analysis of the effects of the regulatory interventions on market integration is done by capturing these measures through dummy variables, implying that the results might be distorted because of the influence of other events occurring at the same time. Further research is needed to analyse to which extent such events really have taken place. In addition, extending our analysis by also paying attention to the utilisation of the cross-border infrastructure with the GUD network in Germany and the networks in Belgium and the UK could further enhance the understanding of the impact of the institutional changes on the integration of gas markets.

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APPENDIX A: Specification of ARCH models

ARCH models have been developed to correct for clustered volatility (see Engle, 1982; Bollerslev, Engle and Nelson, 1994, generalized to GARCH by Bollerslev, 1986). Neglecting the exact nature of the dependence of the variance of the error term conditional on past volatility results in loss of statistical efficiency.

Defining ε_t^2 as the variance of the error term ε_t in a generalized regression equation where the dependent variable y_t is determined by a set of regressors x_t,

$$y_t = x_t'\beta + \varepsilon_t, \tag{A.1}$$

GARCH models assume that the conditional variance σ_t^2 (the variance of ε_t conditional on information up to time t-1 changes over time) is affected by conditional variances q periods in the past (σ_{t-i}^2, i=1,…, q) as well as by p lags of the unconditional variance terms (ε_{t-i}^2, i=1,…, p):

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} \lambda_j \sigma_{t-j}^2, \tag{A.2}$$

where $\alpha_0 > 0, \alpha_i \geq 0, \lambda_j \geq 0.$ This model is referred to as a GARCH(p,q). Note that with p=0 the model is an ARCH(q) model. To test whether volatility is serially correlated over time up to some lag p, first estimate the mean equation (A.1), retrieve the residuals ε_t, and regress the squared residuals on lagged squared residuals up to lag p (this procedure is known as the ARCH LM test). If the usual assumption that standard errors ε_t are Gaussian is violated, quasi–maximum likelihood covariances and standard errors as described by Bollerslev and Wooldridge (1992) may be reported, or it may be assumed that errors follow an alternative distribution.

Well–defined conditional variances require that the parameters α_0, α_i, and λ_j are non–negative. The estimate $\sum \hat{\alpha}_i + \sum \hat{\lambda}_j$ is a measure of persistence: the average time for volatility to return to the mean is $1/\left(1 - \sum \hat{\alpha}_i + \sum \hat{\lambda}_j\right)$. If the estimate for $\sum \hat{\alpha}_i + \sum \hat{\lambda}_j$ is close to unity, the model is not covariance stationary (the process is an Integrated GARCH process). In that case the model can be used only to describe short–term volatility.

APPENDIX B Test on autocorrelations in dependent variables

Table B1. Autocorrelations of the differences and squared differences in maximum daily gas prices (TTF - NCG), sample period: June 2007 – December 2011

Lags	Price differences	Squared price differences
1	0.385*	0.165*
2	0.347*	0.117*
3	0.243*	0.078*
4	0.187*	0.038
5	0.179*	0.036
6	0.165*	0.033
7	0.165*	0.033
8	0.184*	0.026
9	0.223*	0.044
10	0.214*	0.044

* Significantly different from zero at approximately the 5% significance level if the autocorrelations exceed $2/\sqrt{N}$ (=0.059 with N=1135).

Table B2. Autocorrelations of the differences and squared differences in the price range (TTF - NCG), sample period: June 2007 – December 2011

Lags	Price differences	Squared price differences
1	0.224*	0.066*
2	0.184*	0.050
3	0.116*	0.009
4	0.152*	0.028
5	0.181*	0.025
6	0.109*	0.030
7	0.183*	0.067*
8	0.218*	0.262*
9	0.189*	0.045
10	0.095*	0.000

* Significantly different from zero at approximately the 5% significance level if the autocorrelations exceed $2/\sqrt{N}$ (=0.059 with N=1135).

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