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CROSS-BORDER INFRASTRUCTURE CONSTRAINTS, REGULATORY MEASURES AND ECONOMIC INTEGRATION OF THE DUTCH - GERMAN GAS MARKET

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

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Abstract

We estimate to which extent regulatory measures in the Dutch market have reduced the vulnerability of this market to constraints in the cross-border infrastructure with Germany, which is the largest Dutch neighbouring market. We measure this vulnerability by the degree the markets are integrated, i.e. to which extent the gas prices differ between the Dutch market (Title Transfer Facility or TTF) and the German market (NetConnectGermany or NCG). The constraints are measured through the utilisation of the cross-border infrastructure. We find evidence that the introduction of a market-based balancing regime together with the obligation to deliver all gas on the TTF on 1 April 2011 reduced the impact of the utilisation the Dutch-German cross-border infrastructure on the differences in prices between these countries.

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

JEL-codes: Q41, L95, L51, C22

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1. Introduction

After the start of the liberalisation of gas markets in Europe in the 1990s, reducing infrastructure barriers and enhancing access to the infrastructure have been major challenges in the development of competitive gas markets. Initially, access to the infrastructure for both transport and storage was limited as access rights had been granted to the incumbents on the basis of non-market mechanisms. In these allocation mechanisms, such as FCFS and pro-rata[1], the price for capacity was related to infrastructure costs and not to the marginal willingness-to-pay of infrastructure users. As a result, cross-border capacity was inefficiently used (EC, 2007; NMa, 2007; LECQ, 2011). In addition to these inefficient allocations of existing capacity, the level of capacity also frequently formed a constraint for international trade (Neumann, Rosellón and Weigt, 2011).

Over the past year, however, the availability of cross-border gas infrastructure for market players increased as a result of extensions in pipeline capacities, both physically and virtually. Physical extension of (i.e. investments in) cross-border capacity has been realised, for instance, between the Netherlands and the United Kingdom (Balgzand-Bacton Line, or BBL) and on the Belgian-Dutch border through the creation of physical backhaul (GTS, 2012). Virtual capacity extension has been realised through the introduction of interruptible reverse (backhaul) flow services, making it possible to book gas in the reverse direction, for instance on the BBL (GTS, 2012). These measures reduced cross-border barriers which together with other measures as harmonisation of tariff systems and booking procedures are meant to result in stronger economic integration of national gas markets (Growitsch, Stronzik and Nepal, 2012).

Nevertheless, full integration is not yet realised as infrastructure barriers are still constraining arbitrage opportunities. On the Dutch border, it appears that most of the

[1] FCFS stands for “first come first served”; ‘pro rata’ is an allocation on the basis of relative demand.

technical capacity is contracted on long-term basis, leaving fewer options for other parties to benefit from price differences. A reason for the high level of contracting is that firms need to be able to adapt supply to changes in demand levels, which is in particular relevant for exporters supplying flexibility services (GTS, 2012). In order to further improve the functioning of European gas markets, the EC and the European regulators are considering additional measures (CEER, 2011). Measures considered are the introduction of secondary markets for capacity, changing the rules for primary allocation in the direction of more market-based schemes (i.e. auctioning) and the application of UIOLI mechanisms.[2] In addition, investments in network extension are viewed to be necessary to enhance international trade.

Besides the regulatory measures directed at the cross-border infrastructure, a number of domestic regulatory measures have been taken to increase the liquidity of the market. Key regulatory measure in the Dutch market were the abolishment of the obligation of market parties to book quality-conversion capacity, the implementation of a market-based balancing regime, the obligation on gas traders to deliver all gas on the virtual market place in the high-pressure network (Title Transfer Facility or TTF) and the implementation of backhaul on the BBL. If these measures increase the liquidity of the gas market, one might expect that they also reduce the vulnerability of that market to constraints in a specific part of the infrastructure. If this appears to be the case, these measures can be seen as contributing to the economic integration of neighbouring markets.

In this paper we estimate to what extent the impact of infrastructure barriers on the Dutch borders[3] on cross-border price differences have changed under influence of the above regulatory measures in the Dutch market. We focus on the Dutch market, as here a significant

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[2] UIOLI stands for "use it or lose it".

[3] Note that within countries also barriers might exist (see Growitsch, et al. 2012), but these do hardly play a role in the Dutch market.

domestic supply and demand coincides with a high degree of connection with its neighbouring countries (Germany, Belgium and United Kingdom), while a number of regulatory measures have been implemented in the recent past. Within the Dutch market, we focus on the Dutch-German border, as most of the Dutch imports and exports pass this border. In particular, the analysis is directed at the NetConnectGermany (NCG) network in Germany because for this network complete time series of gas prices are available.

By analysing the evolvement of price differences, we measure the development of economic integration of markets. 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. As a result price differences between countries do not exceed the actual costs of transportation, including transaction costs. We analyse how price differences were affected by the degree of utilisation of the cross-border transport infrastructure and to which extent this relationship changed because of the implementation of regulatory measures within the Dutch gas market.

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 analyse the integration of regional gas markets. The contribution of our paper is that we use high-frequency (hourly) data on the utilisation of infrastructure and on prices in the neighbouring markets in order to estimate the impact of regulatory measures on market integration. This approach enables us to determine to which extent remaining price differences can be contributed to the degree the infrastructure for transport have constituted a barrier for arbitrage and to which extent this relationship is affected by regulatory changes. The data on the utilisation of the infrastructure are derived from the Transmission System Operator or TSO (GTS, 2012), while data on prices are obtained from Bloomberg.

This paper proceeds as follows. Section 2 describes the theoretical relationship between cross-border infrastructure constraints and prices on both sides of the constraints. Before presenting our empirical model in Section 4, the interconnection between the Dutch and the German gas market over the past years is briefly described in Section 3. Section 5 gives the results of the econometric analysis and Section 6 concludes.

2. Infrastructure constraints, liquidity of gas markets and gas prices

Economic integration of gas markets might generate several benefits. Stronger economic integration reduces the impact of supply constraints, resulting in less scarcity rents and lower prices for gas users in otherwise constrained regions. In addition, stronger integration might also reduce, ceteris paribus, the market shares of players, reducing the market power of incumbents and, hence, decreasing the mark-ups because of more intensive competition. As the demand for gas is inelastic (Bernstein and Madlener, 2011), the above two types of benefits are mainly distributional effects from producers to consumers. In addition, stronger integration might result in an efficiency effect if it shifts the supply curve to the right as fields with relatively low marginal costs are becoming more available. We focus, however, on the impact of integration on price differences.

In a non-constrained, fully integrated market the Law of One Price (LOOP) holds, implying that prices in all regions of that market are equal (i.e. absolute LOOP) or that they move in the same direction (i.e. relative LOOP). If transport of goods is not costless, price differences between regions may exist in such a market, but they do not exceed the costs of transportation and other transaction costs:

$$P_i - P_j \leq TC_{ji} ; P_i - P_i \leq TC_{ij} \quad (1)$$

where the difference in price (P) between market i and market j does not exceed the costs of transportation from j to i, and vice versa. In such a market prices move in the same direction, driven by the same common factors (Siliverstovs et al., 2005). If, however, barriers (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). Indirect relationships might of course still occur if the regional markets are connected to common third markets or if there are common drivers, such as weather conditions.

The impact of the existence of barriers on prices in regional markets fundamentally differs from the impact of costs of transportation. The latter refer to actual costs, while a barrier does not directly refer to costs but to the impossibility to realise arbitrage benefits. Note that 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 based on the costs of the network operator while also being subject to regulatory overview. These costs of transportation might also include costs of quality conversion. On top of these costs, traders may have to make some transaction costs, making full price harmonisation not efficient. As these costs can be considered to be fairly constant over time, we may ignore them in our analysis.

We are interested in the impact on prices of constraints in the cross-border flows because of a fully utilised infrastructure. In that case, price convergence through cross-border flows is hindered. So, if $P_i - P_j > TC_{ji}$ and if the infrastructure to import from country j to country i is fully utilised, this price difference will not 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 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 implies that one has to control for possible endogeneity effects 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 integration between 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. Compared to Europe, 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 GASPOOL) 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. Hence, these authors conclude that capacity constraints between these markets still hinder the realisation of perfect arbitrage, in particular between the two German hubs. For the relation between the German and the Dutch markets, the authors conclude that they 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 the impact of regulatory measures to increase the liquidity of the domestic market on the impact of the cross-border constraints on price differences. By increasing the liquidity of a gas market, these measures also reduce the vulnerability of that market to constraints in a specific part of the infrastructure as in a liquid market traders are better able to quickly respond to changes in market circumstances (Cuddington and Wang, 2006; LECG, 2011). Neuman and Siliverstovs (2005), for instance, find differences in prices between unconstrained markets which might be due to illiquidity of one those markets. Consequently, if the above regulatory measures increase liquidity of the gas market, they indirectly contribute to the economic integration of the neighbouring markets.

In the recent years, a number of regulatory measures have been taken to increase the liquidity of the Dutch gas market (Table 1). A key regulatory measure in the Dutch market was the abolishment of the obligation of market parties to book quality-conversion capacity as of July 1, 2009. In the past, a shortage in conversion capacity hampered the integration of the high-calorific natural gas (H-gas) and the low-calorific natural gas (L-gas) market (NMa, 2007). Another measure which is perceived to improve the liquidity of the wholesale market is the implementation of a market-based balancing regime since April 1, 2011. In the same period, several institutional changes occurred in the German market. After the introduction of an entry-exit system in October 2007, several networks pooled which resulted in two network areas for H-gas and only one for L-gas. The two German H-gas networks are NCG and GASPOOL; the former covers the southern part of Germany and the latter the northern part.

Table 1. Institutional changes in the Dutch and German gas market, 2006-2011

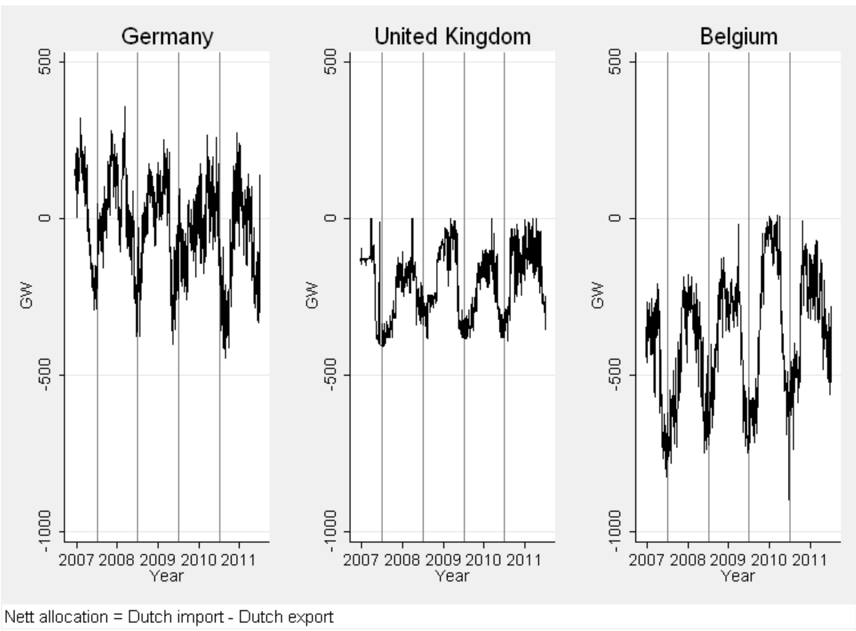
Date of implementation	Dutch market	German market
1 December 2006	Connection with the UK market (BBL)	
1 October 2007		Entry-exit system between 19 zones in Germany
1 July 2008	The Dutch TSO (Gasunie) acquires the GUD network in Germany	
1 October 2008		NetConnect Germany (NCG) results from pooling of areas of E.ON and Bayernets
1 July 2009	Abolishment of the obligation to book quality-conversion capacity	
1 October 2009		NCG network is extended with GRTgaz Deutschland, ENI and GVS
1 October 2010	Backhaul on BBL	
1 April 2011	New balancing regime; Obligation to deliver gas on the TTF instead of GOS	NCG network is extended with Thyssengas

We expect that the introduction of these measures influenced the liquidity of the gas markets and, hence, how vulnerable these markets are to cross-border bottlenecks. The abolishment of the obligation to book quality-conversion capacity implies that, for instance, constraints in the H-gas infrastructure not only affect the H-gas market, but also the L-gas market. In other words, a consequence of this measure is that shocks in demand or supply are diffused over a larger market which reduces its impact. In addition, the introduction of the market-based balancing regime as well as the obligation to deliver all gas on the TTF also make the gas market more liquid, as the volume and number of trades are raised, resulting in a lower vulnerability to cross-border constraints. The implementation of backhaul on the BBL, however, has a different effect as this measure makes the Dutch market more closely connected to a different market, i.e. the UK gas market. As a result, this measure raises the interdependence of Dutch and British gas prices, which in turn might result in greater differences between the Dutch and German prices.

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

A characteristic phenomenon of the Dutch market is the presence of the largest swing field in Northwest Europe (the "Groningen field") and a number of small fields, both onshore and offshore. Because of the Groningen field, the Dutch gas industry is able to export flexibility 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 and export, while the other two connections are only used for export (Figure 1).

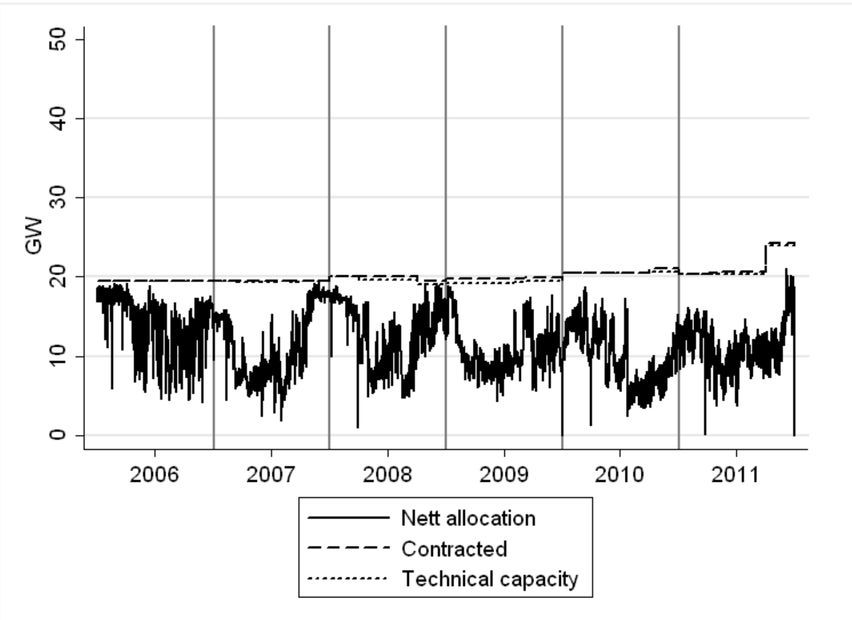
Figure 1. Net flows between the Dutch market and the markets in Germany, the United Kingdom and Belgium, 2007-2001



The net flows to Germany, defined as Dutch export minus Dutch imports, have a seasonal pattern. During winter time, exports exceed imports, while during summer time imports exceed exports, which results from the fact that mainly the export is strongly seasonally driven.

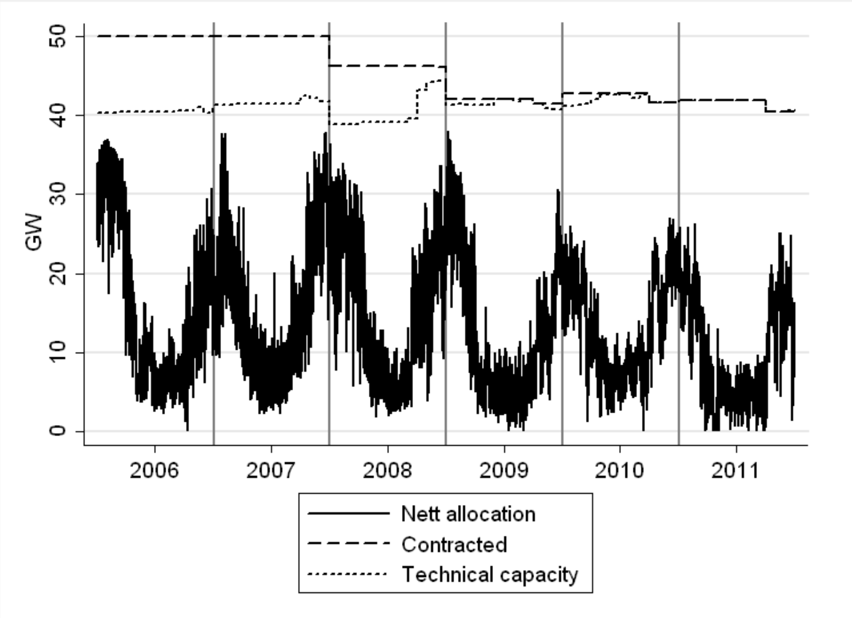
Import of gas consists only of H-gas from the Gasunie Deutschland (GUD) network. This gas is partly used by industrial consumers, including electricity companies, while the other part is re-exported. The latter implies that the Dutch network is also used as a transit network, needed to bring gas from for instance Russia to the United Kingdom. These transit flows are less temperature related than the domestic demand by residential users. Export flows of in particular of L-gas show a strong seasonal pattern (Figures 2 and 3). Import flows are more flat during a year.

Figure 2. Utilisation of the Dutch export infrastructure for H-gas to the NCG network in Germany, 2006-2011



Source: GTS

Figure 3. Utilisation of the Dutch export infrastructure for L-gas to the NCG network in Germany, 2006-2011

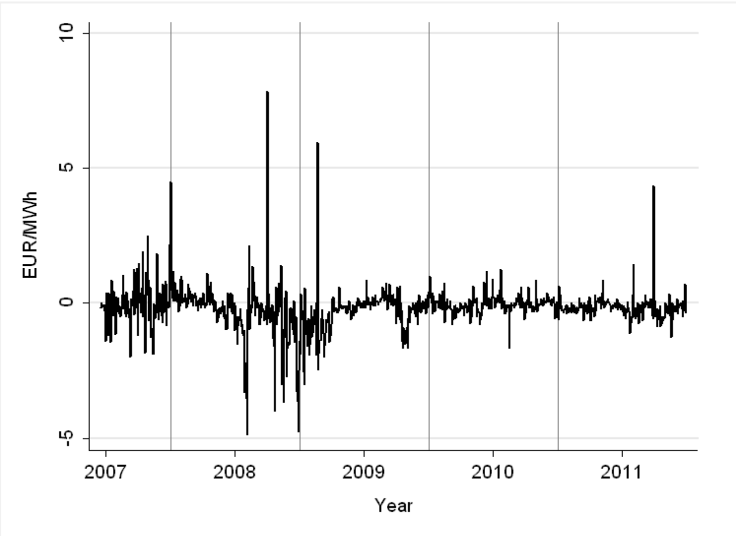


Source: GTS

In quantitative terms, the Dutch-German border is far more important than the Dutch-Belgian border and the Dutch-UK border. 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 import in 2011 was about 30 GW, while through the Dutch-Belgian border no more than 5 GW per hour was exported.

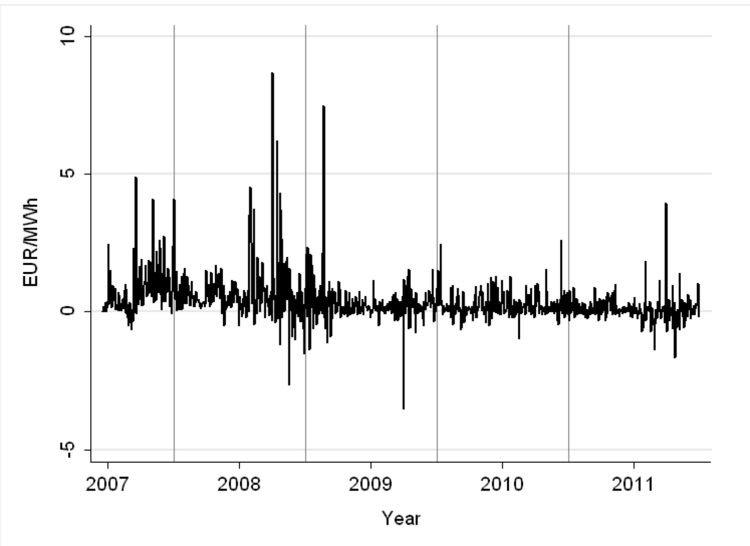
The capacity to import from Germany has significantly increased over the past years: in 2006 the capacity was 30 GW and in 2011 it reached the level of more than 70 GW. The import entirely comes through the GUD network in the north. This increase in physical capacity did not coincide with higher levels of import: these levels remained within the range of 15 to 30 GW. The capacity to export to Germany stayed fairly stable, both for H-gas and for L-gas (Figures 2 and 3). For both the import and the export infrastructure holds that the available capacity was almost fully booked, in particular in most recent years.

Figure 4. Difference in gas prices in the Dutch market (TTF) and the German market (NCG), 2007-2011



Source: Bloomberg

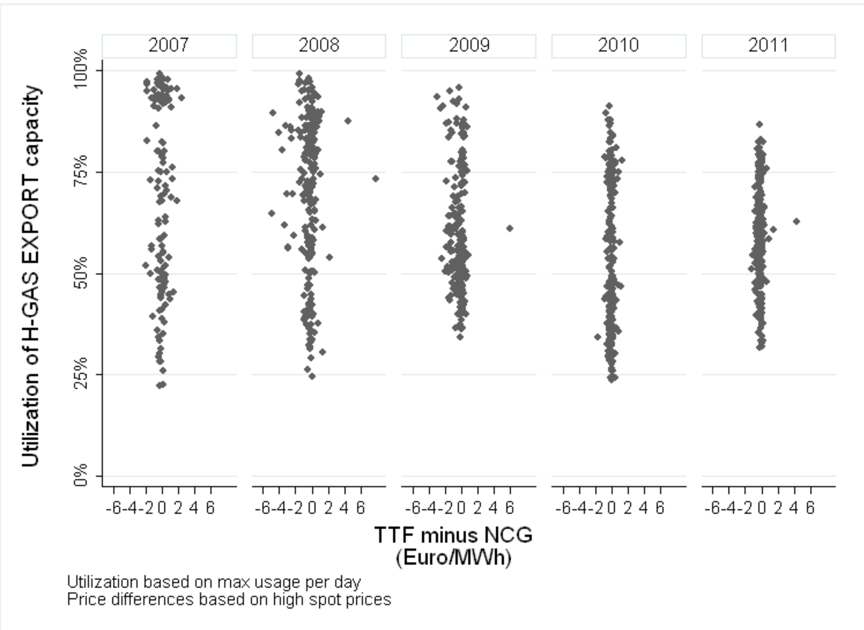
Figure 5. Difference in the spread between high and low gas prices in the Dutch market (TTF) and the German market (NCG), 2007-2011



Source: Bloomberg

Looking at the price differences between the Dutch market (TTF) and the German market (NCG), it seems that both markets have become more integrated because of the decline in these differences over the past years. In 2006 significant differences in prices existed, but gradually these differences have become smaller. This holds both for the differences between the high-prices on TTF and NCG (Figure 4) and the spreads between the high and low prices on both networks (Figure 5).

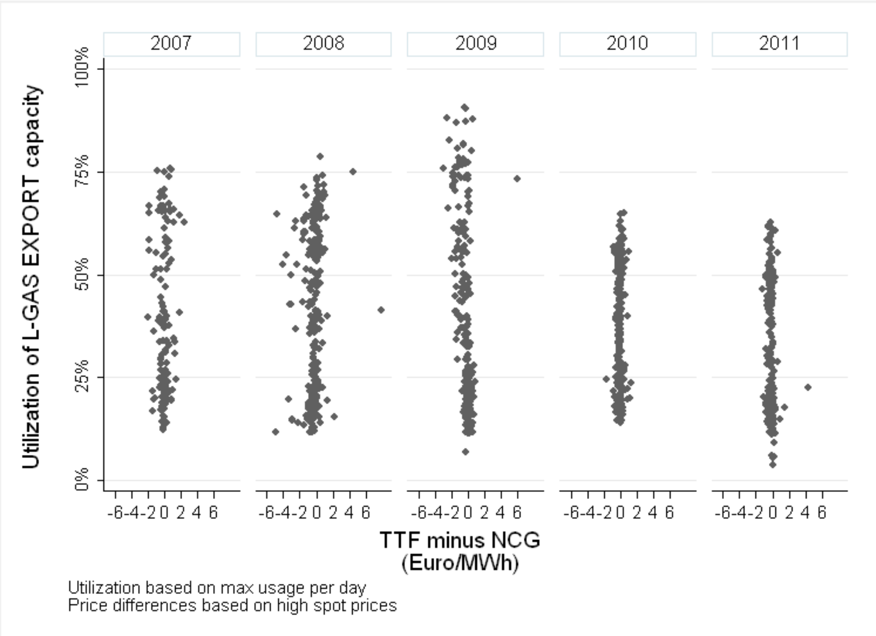
Figure 6. Utilisation of Dutch export infrastructure for H-gas to the NCG network and differences in prices on TTF and NCG, 2007-2011



Source: GTS/Bloomberg

It also appears that the cross-border infrastructure is increasingly efficiently used: in 2011 there were less hours showing price differences while the infrastructure is not fully used compared to a number of years ago (Figures 6 and 7). During those hours, traders apparently face restrictions in using the infrastructure in order to benefit from arbitrage opportunities. Nevertheless, in 2011 price differences still frequently occurred which might be caused by remaining bottlenecks in using the infrastructure.

Figure 7. Utilisation of Dutch export infrastructure for L-gas to the NCG network and differences in prices on TTF and NCG, 2007-2011



Source: GTS/Bloomberg

4. Empirical model and data

We estimate GARCH models to estimate the influence of infrastructure constraints on price differences.[4] We estimate two different models. In the first model the dependent variable is the difference in maximum daily spot price on the Dutch market (TTF) and on the German market (NCG). In the second model the dependent variable is the difference in the spread (i.e. the highest daily price minus the lowest daily price) between both markets. For both models we use the same set of explanatory variables.

The infrastructure constraint is included by the maximum daily capacity utilisation. We define the utilisation of infrastructure (*U*) as the ratio (in %) between the total allocated capacity and total available capacity on the borders with the neighbouring countries:

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

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

where *t* is the suffix for days.[5] 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.[6] For unidirectional clusters, 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 data on cluster level.[7]

We include the utilisation of the cross-border infrastructure between TTF and NCG for export of L-gas and H-gas (U^{EX}).[8] 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. 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. Note that these variables are lagged one period to avoid possible biases due to reverse causation.[9] In addition we include dummies for months (M_i) to capture seasonal patterns. Moreover, we make a distinction between capacity

[5] Note that 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

[6] 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.

[7] 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.

[8] Note that here is no imports of gas from NCG.

[9] 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.

utilization of L-gas and H-gas connections. What we have described above is the base model for price differences (in euro/MWh) and differences in the spread of gas prices (in euro/MWh) between TTF and NCG, which is formulated as:

$$P_t^{ttf-ncg} = \alpha_1 + \beta_1 U_{t-1}^{EX-H} + \chi_1 U_{t-1}^{EX-L} + \delta_1^G NX_{t-1}^{GER} + \delta_1^U NX_{t-1}^{UK} + \delta_1^B NX_{t-1}^{BEL} + \varepsilon_t \qquad (3)$$

Finally, we do not include transportation costs since these costs are rather stable within a year as is explained in Section 2.[10] The base model for the difference in the spread replaces the price difference $P^{ttf-ncg}$ with the difference in the spread $S^{ttf-ncg}$.

For both versions of the base model we introduce alternative models to analyse the effect of the regulatory changes on the impact of cross-border constraints on price differences as well as differences in the spread between TTF and NCG prices. In these alternative models, we include dummies (D_i) and interaction terms with all explanatory variables in order to measure the effect of the regulatory measures. The regulatory measures considered are (see also Table 1):

1. As from July 1, 2009 the obligation to book quality-conversion capacity is abolished (dummy D_2).
2. On October 1, 2010 interruptible reverse (backhaul) flow service is introduced (dummy D_3).
3. O April 1, 2011 a market-based balancing regime is introduced as well as the obligation to deliver all gas on the TTF (dummy D_4).

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

[10] Transportation costs refer to the fees charged by the network operators for the several cross-border points. These fees consist of both entry and exit fees.

$$P_t^{ttf-ncg} = \alpha_1 + \sum_{i=2}^{4}\alpha_i D_i + \beta_1 U_{t-1}^{EX-H} + \sum_{i=2}^{4}\beta_i D_i U_{t-1}^{EX-H} + \chi_1 U_{t-1}^{EX-L} + \sum_{i=2}^{4}\chi_i D_i U_{t-1}^{EX-L}$$
$$+ \delta_1^G NX_{t-1}^{GER} + \sum_{i=2}^{4}\delta_i^G D_i NX_{t-1}^{GER} + \delta_1^U NX_{t-1}^{UK} + \sum_{i=2}^{4}\delta_i^U D_i NX_{t-1}^{UK} \quad (4)$$
$$+ \delta_1^B NX_{t-1}^{BEL} + \sum_{i=2}^{4}\delta_i^B D_i NX_{t-1}^{BEL} + \sum_{i=1}^{11} M_i + \varepsilon_t$$

Again, for the second model we replace the maximum price difference with the difference in the price spread, denoted as $S^{ttf\text{-}ncg}$.

In the base models and in the alternative models the variance equation is a GARCH(1,1) model, and we assume that the residuals do not have 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. The hypotheses are that the regulatory measures led to reduced differences in both the highest daily prices and the spread (i.e. highest minus lowest price) between the Dutch gas market and the German gas market. These hypotheses can be tested from parameters β_2, β_3 and β_4 and χ_2, χ_3 and χ_4.

Table 2. Differences in maximum daily gas prices (TTF minus NCG), summary statistics for various samples based on policy changes

	Jun 2007 – Jun 30, 2009	Jul 1, 2009 – Sep 31, 2010	Oct 1, 2010 – Mar 31, 2011	Apr 1 2010 – Dec 31, 2011
Mean	-0.268	-0.076	-0.101	-0.159
Median	-0.150	-0.050	-0.100	-0.150
Standard Deviation	0.963	0.398	0.226	0.448
Skewness	1.096	-0.906	0.966	5.564
Kurtosis	18.525	6.899	5.881	57.032
Observations	508	314	125	188

Table 2 shows that, on average, NCG prices exceed TTF prices. The biggest difference of -0.268 euro/MWh is reported in the first sample (June, 2007 - June 30, 2009) before the first policy came into effect. Over time the price difference steadily decreases to -0.159 euro/MWh after April 1, 2010. 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 since April, 2010, and the distribution of the price difference is peaked relative to the normal distribution (kurtosis coefficient > 3) for all periods. The average spread of the gas prices between the Dutch and the German market steadily decreases from 0.618 euro/MWh before July 1, 2009 to 0.091 euro/MWh after April 1, 2010 as Table 3 indicates. The distribution of the spread is positively skewed and is relatively peaked in most of the sample.

Table 3. Differences in daily spread (TTF minus NCG), summary statistics for various samples based on policy changes

	Jun 2007 – Jun 30, 2009	Jul 1, 2009 – Sep 31, 2010	Oct 1, 2010 – Mar 31, 2011	Apr 1 2010 – Dec 31, 2011
Mean	0.618	0.227	0.191	0.091
Median	0.450	0.150	0.100	0.050
Standard Deviation	0.941	0.447	0.373	0.472
Skewness	3.273	-0.975	2.834	2.950
Kurtosis	23.260	19.828	16.786	27.709
Observations	508	314	125	188

Autocorrelations of the maximum price differences suggest dependence in the mean, and the autocorrelations of the squared price differences reveal dependence in volatility (see Table 4). 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. Table 5 indicates that there is also dependence in the mean and volatility for the difference in the price spread between the Dutch gas market and the German gas market.

Table 4. Autocorrelations of the differences in maximum daily gas prices (TTF - NCG) and squared differences in maximum daily gas prices, sample period: June 2007 – December 2011 (1135 observations)

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 5. Autocorrelations of the differences in spreads (TTF - NCG) and squared differences in spreads, sample period: June 2007 – December 2011 (1135 observations)

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).

5. Results

We apply GARCH 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 dummies, lagged net gas flows, lagged maximum daily utilization rates for exports of L-gas and H-gas, policy dummies with interaction terms, and an AR(1)–term as is suggested by the autocorrelations in Table 4 and 5 above. Using lagged variables ensures that the explanatory variables are predetermined, so we do not have to worry about the endogeneity bias.

5.1 Testing

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 1% significance levels), whereas the null in the price spread model is rejected for 8 lags and higher. So, we apply GARCH models instead of ordinary least squares.

We assume that the residuals do not follow a normal distribution. 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 480 in all four models). With *t*-distributed errors the log likelihood (ln *L*) for all models is higher than assuming that the errors follow a generalized error distribution.[11] So, we estimate the models assuming that the errors are *t*-distributed.[12] The parameter for the *t*-distribution is about 3.3 for the price difference model and even lower for the spread difference model. These estimates which are shown in the tables in the next section suggest that the error distribution is fat tailed.[13]

Testing reveals that the models are not covariance stationary, so we estimate Integrated GARCH(1,1) models. The results will be presented in the next section. 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.

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[11] 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).

[12] The estimates in case the errors follow a generalized distribution are in Tables B3 and B4 in Appendix B.

[13] Note that the *t*-distribution approaches the normal if the tail parameter gets infinitely large.

5.2 Estimation results

The sample period is June 2007- December 2011. The results are presented in Table 6 for the model for price differences and Table 7 for the model with the differences between the spread. Before we discuss the effect of the regulatory measures introduced in the sample period, we note that in the model with policy dummies, higher flows of gas between the Netherlands and Germany lowers the maximum price difference between TTF and NCG prices the next day. Trade between the Netherlands and the United Kingdom and Belgium increases the price difference between TTF and NCG prices. In the models with policy dummies, trade between the Netherlands and Germany also has a negative effect on the difference in the TTF spread and the NCG spread.[14] The difference between the spreads is not affected by trade between the Netherlands and the United Kingdom and Belgium. Seasonal patterns are observed in all specifications.

The focus in this paper is on the effects of the various regulatory measures implemented in the sample period by introducing 0-1 dummies and interaction terms (see Section 4 above). The effects of these measures 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. It should be noted that the regulatory measures remain in affect also after a new measure has been implemented. So, a new policy does not replace old policies. This implies that, for instance, the value of D_2 is zero before July 1, 2009 and 1 on July 1, 2009 until the end of the sample. In October 1, 2010 another policy is implemented. So D_3 becomes 1 on October 1, 2010 until the end of the sample. In this period also D_2 equals 1. The implication is that the coefficients for the interaction terms measure the impact of the regulatory measures on the impact of cross-border constraints on both price differences (Table 6) and differences in the spread (Table 7).

[14] These estimation results are reported in Tables B1 and B2 in Appendix B.

Table 6. Results for the maximum hourly difference between TTF and NCG prices with *t*-distributed errors, sample period: 2007-2011 (month dummies and net trade coefficients are not reported)

	AR(1)-IGARCH(1,1)		AR(1)-IGARCH(1,1)	
	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
Mean equation				
Constant	-0.075	0.084	-0.452***	0.127
D_2 (=1 since July 1, 2009)			0.457***	0.126
D_3 (=1 since October 1, 2010)			0.550***	0.151
D_4 (=1 since April 1, 2011)			-0.497***	0.158
Max Cap Util EX H-gas(-1)	0.227***	0.076	0.255	0.192
$D_2 \times$ Max Cap Util EX H-gas(-1)			0.015	0.219
$D_3 \times$ Max Cap Util EX H-gas(-1)			-0.397*	0.220
$D_4 \times$ Max Cap Util EX H-gas(-1)			-0.135	0.241
Max Cap Util EX L-gas(-1)	0.321***	0.114	-0.084	0.230
$D_2 \times$ Max Cap Util EX L-gas(-1)			-0.052	0.325
$D_3 \times$ Max Cap Util EX L-gas(-1)			0.843***	0.290
$D_4 \times$ Max Cap Util EX L-gas(-1)			-0.747**	0.310
AR(1)	0.348***	0.022	0.280***	0.023
Variance equation				
α_1, ARCH(1)	0.129***	0.010	0.131***	0.010
λ_1, GARCH(1)	0.871***	0.010	0.869***	0.010
Tail parameter *t*	3.377***	0.171	3.320***	0.163
Observations	1133		1133	
Log likelihood	-521.704		-481.121	

*** significant at 1%

** significant at 5%

* significant at 10%

Table 7. Results for the difference in the spread between TTF and NCG prices with *t*-distributed errors, sample period: 2007-2011 (month dummies and net trade coefficients are not reported)

	AR(1)-IGARCH(1,1)		AR(1)-IGARCH(1,1)	
	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
Mean equation				
Constant	-0.352***	0.100	0.139	0.158
D_2 (=1 since July 1, 2009)			0.379**	0.147
D_3 (=1 since October 1, 2010)			0.013	0.207
D_4 (=1 since April 1, 2011)			0.029	0.221
Max Cap Util EX H-gas(-1)	0.318***	0.080	0.684***	0.222
$D_2 \times$ Max Cap Util EX H-gas(-1)			-0.612**	0.242
$D_3 \times$ Max Cap Util EX H-gas(-1)			0.053	0.299
$D_4 \times$ Max Cap Util EX H-gas(-1)			-0.311	0.342
Max Cap Util EX L-gas(-1)	0.245*	0.143	0.540*	0.315
$D_2 \times$ Max Cap Util EX L-gas(-1)			-1.115***	0.418
$D_3 \times$ Max Cap Util EX L-gas(-1)			-0.013	0.399
$D_4 \times$ Max Cap Util EX L-gas(-1)			-0.529	0.426
AR(1)	0.183***	0.022	0.104***	0.022
Variance equation				
α_1, ARCH(1)	0.069***	0.007	0.056***	0.006
λ_1, GARCH(1)	0.931***	0.007	0.944***	0.006
Tail parameter *t*	3.000***	0.113	2.834***	0.092
Observations	1133		1133	
Log likelihood	-731.334		-675.335	

*** significant at 1%

** significant at 5%

* significant at 10%

The results lead to the following conclusions about how the regulatory measures change the impact of a 1%-point increase in export capacity utilization (for H-gas and L-gas separately) on maximum gas price differences (Table 6) and on differences in the spread between the Netherlands (TTF) and Germany (NCG) (Table 7):

- The direct impact of infrastructure capacity utilization on the maximum hourly price difference between the Dutch and the German gas market is absent once we include the policy dummies and the interaction terms with infrastructure capacity utilization. Without these policy dummies and interaction terms (the base model) an increase in the maximum capacity utilization export infrastructure increase the price difference reduced by 0.227 euro/MWh for H-gas and 0.321 euro/MWh for L-gas. Looking at the difference in the spreads, the direct impact of infrastructure capacity utilization is positive (note that the results between the base model and the alternative model with dummies and interaction terms are not statistically significant).
- After the obligation to book quality-conversion capacity is abolished on July 1, 2009 (dummy D_2=1), the impact of a rise in the maximum capacity utilisation of exports of H-gas and L-gas to Germany (NCG) on the difference between TTF and NCG prices has not changed. The effect of a higher maximum capacity utilisation of exports of H-gas and L-gas on the difference in the spread in this period, however, is strong: -0.612 euro/MWh for H-gas and -1.115 euro/MWh for L-gas.
- After the introduction of interruptible reverse (backhaul) flow services on BBL on October 1, 2010, a higher level of maximum capacity utilisation of exports of H-gas has lowered the price difference between TTF and NCG for H-gas by 0.397 euro/MWh (only significant at 10%). For L-gas, however, this regulatory measure raised the price difference by 0.843 euro/MWh. Possible, the increased linkage to the UK market has

reduced the integration with the German market. Looking at the differences in spreads, however, we do not find an effect of this regulatory measure.

- The joined introduction of regulatory measures regarding the gas balancing regime and the obligation to sell all gas on the TTF had no significant effect on the price difference resulting from a higher infrastructure capacity utilization for H-gas. For the L-gas infrastructure, however, we find a relatively strong negative effect. After the implementation of these measures, the impact of an increase in the maximum capacity utilization of L-gas export infrastructure price difference reduced by -0.747 euro/MWh (significant at 5%). Looking at the spreads, we do not find statistically significant effects.

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. The difference between the maximum daily gas prices initially drops over time, but after October, 2010 it tends to increase again. However, at the end of 2011 the price difference of -0.159 euro/MWh is lower than it was in June 2007 (-0.268 euro/MWh). Comparing the difference in the spread (high-low prices), we observe a steady drop from 0.618 euro/MWh to 0.091 euro/MWh in 2011. .

In order to integrate the national gas market into regional European markets, a number of regulatory measures have been taken. These measures are not only directed at the cross-border infrastructure, but also at the functioning of the domestic wholesale markets. In this paper we analyse to which extent a number of regulatory measures in the Dutch gas market have contributed to the integration with the German market.

Using daily data on cross-border infrastructure utilisation and prices, we find some evidence that 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 obligation to deliver all gas on the TTF on 1 April 2011 have contributed to making the Dutch market less vulnerable 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. Regarding the implementation of backhaul on the BBL, we conclude that this measure has reduced the integration of the Dutch and German, apparently because the Dutch market became more closely related to the UK market.

If we control for policy measures, by incorporating dummies and interaction terms, the direct impact of infrastructure capacity utilization on the maximum hourly price difference between the Dutch and the German gas market is absent. This implies that the degree of capacity utilization has no influence anymore on price differences as a result of the implemented regulated measures. This observation does, however, not hold true for the impact of infrastructure capacity utilization on the difference in the spread between the Dutch and the German gas prices. Even with the policy measures included, an increase in infrastructure capacity utilization increases the difference in the spreads. This latter result suggests that infrastructure constraints still influence prices despite the increase in liquidity of the markets in both countries. Consequently, the economic integration of the Dutch and German market can still be improved by either reducing cross-border constraints or by further raising the liquidity of the market places.

We stress the fact that our analysis of the effects of the regulatory measures 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 could 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 Belgium and the UK could further enhance the understanding of the impact of the regulator measures on 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 ($\sigma_{t\ i}^2$, i=1,…, q) as well as by p lags of the unconditional variance terms ($\varepsilon_{t\ i}^2$, 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. 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. 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.

APPENDIX B: Additional estimation results

Table B1. Results for the control variables in the model for maximum hourly difference between TTF and NCG prices with *t*-distributed errors, sample period: 2007-2011

	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
M_1	-0.086	0.056	0.009	0.057
M_2	-0.100**	0.042	-0.047	0.052
M_3	-0.118***	0.042	-0.122**	0.056
M_4	-0.169***	0.052	-0.072	0.063
M_5	-0.221***	0.065	-0.066	0.078
M_6	-0.184***	0.063	-0.029	0.076
M_7	-0.171***	0.066	-0.135*	0.077
M_8	-0.071	0.066	-0.063	0.077
M_9	-0.118*	0.067	-0.040	0.075
M_{10}	-0.200***	0.067	-0.456***	0.073
M_{11}	-0.074	0.048	-0.144***	0.046
Net EX GER(-1)	-0.001***	8.9E-05	-4.3E-04**	1.8E-04
$D_2 \times$ Net EX GER(-1)			3.4E-05	2.3E-04
$D_3 \times$ Net EX GER(-1)			-0.001**	2.3E-04
$D_4 \times$ Net EX GER(-1)			0.001***	2.2E-04
Net EX UK(-1)	1.2E-04	1.2E-04	0.001**	2.9E-04
$D_2 \times$ Net EX UK(-1)			-0.001***	3.3E-04
$D_3 \times$ Net EX UK(-1)			-7.5E-06	3.0E-04
$D_4 \times$ Net EX UK(-1)			0.001**	2.7E-04
Net EX BEL(-1)	1.5E-05	9.1E-05	0.001***	2.0E-04
$D_2 \times$ Net EX BEL(-1)			-3.5E-04	2.3E-04
$D_3 \times$ Net EX BEL(-1)			-0.001***	2.2E-04
$D_4 \times$ Net EX BEL(-1)			3.0E-04	2.5E-04

*** significant at 1%

** significant at 5%

* significant at 10%

Table B2. Results for the control variables in the model for the difference in the spread between TTF and NCG prices with *t*-distributed errors, sample period: 2007-2011

	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
M_1	-0.023	0.074	-0.118	0.076
M_2	-0.085	0.060	-0.258***	0.069
M_3	-0.047	0.057	-0.329***	0.070
M_4	0.084	0.066	-0.275***	0.081
M_5	0.153*	0.080	-0.294***	0.098
M_6	0.141*	0.079	-0.330***	0.099
M_7	0.144*	0.079	-0.314***	0.098
M_8	0.175**	0.081	-0.287***	0.097
M_9	0.199**	0.084	-0.226**	0.099
M_{10}	0.179**	0.078	-0.088	0.088
M_{11}	-0.019	0.070	-0.184***	0.066
Net EX GER(-1)	-1.5E-04	1.1E-04	-0.001**	2.5E-04
$D_2 \times$ Net EX GER(-1)			0.001***	2.9E-04
$D_3 \times$ Net EX GER(-1)			-2.6E-04	3.2E-04
$D_4 \times$ Net EX GER(-1)			3.2E-04	3.2E-04
Net EX UK(-1)	0.001***	1.4E-04	4.3E-04	3.7E-04
$D_2 \times$ Net EX UK(-1)			-0.001	4.2E-04
$D_3 \times$ Net EX UK(-1)			4.0E-04	3.9E-04
$D_4 \times$ Net EX UK(-1)			-7.3E-05	3.8E-04
Net EX BEL(-1)	2.9E-04***	1.0E-04	-7.0E-05	2.2E-04
$D_2 \times$ Net EX BEL(-1)			1.3E-04	2.4E-04
$D_3 \times$ Net EX BEL(-1)			-1.4E-04	2.7E-04
$D_4 \times$ Net EX BEL(-1)			2.6E-04	3.2E-04

*** significant at 1%

** significant at 5%

* significant at 10%

Table B3. Results for the maximum hourly difference between TTF and NCG prices with generalized distributed errors, sample period: 2007-2011 (month dummies and net trade coefficients are not reported)

	AR(1)-IGARCH(1,1)		AR(1)-IGARCH(1,1)	
	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
Mean equation				
Constant	-0.061	0.058	-0.453***	0.076
D_2 (=1 since July 1, 2009)			0.441***	0.087
D_3 (=1 since October 1, 2010)			0.529***	0.090
D_4 (=1 since April 1, 2011)			-0.394***	0.092
Max Cap Util EX H-gas(-1)	0.171***	0.054	0.344***	0.127
$D_2 \times$ Max Cap Util EX H-gas(-1)			-0.006	0.148
$D_3 \times$ Max Cap Util EX H-gas(-1)			-0.436***	0.127
$D_4 \times$ Max Cap Util EX H-gas(-1)			-0.334**	0.154
Max Cap Util EX L-gas(-1)	0.310***	0.088	-0.149	0.162
$D_2 \times$ Max Cap Util EX L-gas(-1)			-0.084	0.213
$D_3 \times$ Max Cap Util EX L-gas(-1)			0.998***	0.177
$D_4 \times$ Max Cap Util EX L-gas(-1)			-0.611***	0.234
AR(1)	0.386***	0.016	0.300***	0.015
Variance equation				
α_1, ARCH(1)	0.100***	0.009	0.095***	0.008
λ_1, GARCH(1)	0.900***	0.009	0.905***	0.008
GED parameter	0.794***	0.022	0.764***	0.021
Observations	1133		1133	
Log likelihood	-539.022		-489.978	

*** significant at 1%

** significant at 5%

* significant at 10%

Table B4. Results for the difference in the spread between TTF and NCG prices with generalized distributed errors, sample period: 2007-2011 (month dummies and net trade coefficients are not reported)

	AR(1)-GARCH(1,1)		AR(1)-GARCH(1,1)	
	Base model		Alternative model	
	Coefficient	Std. Error	Coefficient	Std. Error
Mean equation				
Constant	-0.441***	0.035	0.073	0.079
D_2 (=1 since July 1, 2009)			0.480***	0.079
D_3 (=1 since October 1, 2010)			-0.022	0.123
D_4 (=1 since April 1, 2011)			-0.112	0.137
Max Cap Util EX H-gas(-1)	0.351***	0.055	0.663***	0.110
$D_2 \times$ Max Cap Util EX H-gas(-1)			-0.734***	0.134
$D_3 \times$ Max Cap Util EX H-gas(-1)			0.331	0.208
$D_4 \times$ Max Cap Util EX H-gas(-1)			-0.376	0.235
Max Cap Util EX L-gas(-1)	0.300***	0.091	0.716***	0.178
$D_2 \times$ Max Cap Util EX L-gas(-1)			-1.386***	0.238
$D_3 \times$ Max Cap Util EX L-gas(-1)			0.373	0.237
$D_4 \times$ Max Cap Util EX L-gas(-1)			-0.506*	0.279
AR(1)	0.171***	0.011	0.141***	0.014
Variance equation				
α_0, Constant	0.010***	0.003	0.006***	0.002
α_1, ARCH(1)	0.082***	0.020	0.067***	0.017
λ_1, GARCH(1)	0.891***	0.020	0.913***	0.017
GED parameter	0.746***	0.026	0.713***	0.026
Observations	1133		1133	
Log likelihood	-731.426		-670.845	

*** significant at 1%

** significant at 5%

* significant at 10%

List of research reports

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