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Kuper, Gerard H.; Mulder, Machiel

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

Gerard H. Kuper^{a,*}, Machiel Mulder^{a,b}

^a University of Groningen, Department of Economics, Econometrics and Finance, P.O. Box 800, 9700 AV Groningen, The Netherlands

^b The Netherlands Authority for Consumers and Markets (ACM), P.O. Box 16326, 2500 BH The Hague, The Netherlands

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ABSTRACT

We evaluate the contribution of nine institutional changes to the integration of the Dutch and German gas markets. We analyse this contribution through the impact of bottlenecks in the cross-border infrastructure on the absolute value of cross-border price differences. In the period 2007–2013, the absolute value of the differences in price levels between the Dutch and the German NCG market decreased, indicating more integration. We find evidence that the improved connections within the German networks as well as between the Dutch and the German network contributed to this. The strengthening of the connections with the UK market and the Russian supply, however, had a negative effect on market integration between the Dutch and the German NCG market. The liquidity-enhancing changes within the Dutch market had a negligible effect.

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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 connected, enabling traders to engage in international price arbitrage. The available 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; LECC, 2011; NMa, 2007).

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 et al. (2007) and Growitsch et al. (2013) 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. Also, unlike earlier literature, we make a distinction between low calorific gas (L-gas) and high calorific gas (H-gas) for which different supply grids exist 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 of deregulation on integration of the US gas markets.

We focus on the Dutch market, as here a large domestic supply and demand coincide with a high degree of connection with its neighbouring countries (Germany, Belgium and the United Kingdom), while a number of institutional changes occurred in the recent past.² In the period 2007–2013, three major changes in the Dutch gas market affected the liquidity of the TTF (Heather, 2012). In 2009, the obligation of market parties to

* Corresponding author. Tel.: +31 50 3633756.

E-mail addresses: g.h.kuper@rug.nl (G.H. Kuper), machiel.mulder@acm.nl (M. Mulder).

¹ FCFS stands for First Come First Served; “pro rata” is an allocation on the basis of relative demand.

² Within countries also bottlenecks might exist, as was the case between the different German networks, but these do hardly play a role in the Dutch market which consists of one integrated network. Only barriers between the L-gas and the H-gas infrastructures occurred now and then until July 2009, when the obligation to book quality-conversion capacity was abolished.

Fig. 1. Net flows between the Dutch market and the markets in Germany, the United Kingdom and Belgium, 2007–2013 (Source: GTS; net flows = Dutch import–Dutch export).

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 the Dutch incumbent gas trader GasTerra to supply all gas for the domestic market on the TTF instead of factory gates or city gates. Moreover, the Dutch market became stronger connected to the UK market in 2010.

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). In the NCG market a number of merging activities took place during the period of analysis. Note that Growitsch et al. (2013) found that the NCG and GPL markets were reasonably well economically integrated, although capacity constraints hindered perfect arbitrage from time to time. In addition, the German network became directly connected to the Russian gas fields by completing the Nord Stream project in 2012. Finally, the Dutch and the German networks became more connected through the acquisition of the part of the German network by the Dutch TSO (Gasunie) in 2008 and the introduction of new mechanisms to allocate capacity on the Dutch–German border in 2013.

Our analysis is directed at the influence of the aforementioned 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 markets. In an integrated market, price levels converge

(Stigler and Sherwin, 1985). Because daily changes in cross-border utilisation in particular affect short term prices, we use day-ahead prices.

Since daily gas prices are very volatile, we apply GARCH (1,1) models to the absolute value of the differences in daily gas prices on the TTF and NCG over the period June 2007–December 2013.⁴ We use a mean equation in which the key explanatory variables are the daily utilisation rates of the L- and H-gas export infrastructure and dummies for the institutional changes with interaction terms. We control for the influence of annual and seasonal patterns, outside temperature and the Ukraine gas crisis in 2009.

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 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 below 100% may restrict international price arbitrage.

This paper proceeds as follows. Section 2 gives the theoretical background. Section 3 describes the Dutch gas market and its connection to the German market. This section also introduces various institutional changes in the Dutch and German gas markets. Section 4 presents the empirical model, while 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 how price differences evolve over time. 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. If, however, constraints between regional markets do

³ The highest hourly export flow of L-gas to Germany in 2013 was 39 GW, which was about twice as big as the highest export flow to Belgium (19 GW). For H-gas the respective amounts are 32 (Germany) and 26 (Belgium) GW, while the export of H-gas to the United Kingdom peaked at 20 GW in 2013. For the import of H-gas, the Dutch–German is even more important: the highest hourly import in 2013 was 40 GW, while through the Dutch–Belgium border no more than 9 GW was imported. Source: GTS.

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 exist.

Fig. 2. Utilisation of the Dutch export infrastructure for H-gas to the NCG network in Germany, 2007–2013 (Source: GTS; net allocation = firm + interruptible – backhaul).

exist, prices in these markets are not directly related anymore and, as a result, prices may diverge for a period of time (Marmer et al., 2007). Hence, in case of transportation costs as well as cross-border constraints, the Law of one price can be formulated as follows (Barrett, 2001):

$$\begin{aligned} p^A &< p^B + t^{B,A} & \text{if } q^{B,A} &= 0 \\ p^A &= p^B + t^{B,A} & \text{if } q^{B,A} &\in (0, Q^{B,A}) \\ p^A &> p^B + t^{B,A} & \text{if } q^{B,A} &= Q^{B,A} \end{aligned} \quad (1)$$

where p^A and p^B are the prices in the markets A and B , respectively, $t^{B,A}$ is the transportation costs of exporting the good from market B to market A , $q^{B,A}$ is the actual flow of the good from market B to market A and $Q^{B,A}$ is the cross-border transport capacity from market B to market A . As long as the constraint is not binding, the price difference equals the transportation 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, transportation costs need not to be equal to cross-border differences if cross-border trade is hampered by imperfect information, as is shown for the European electricity markets by Gebhardt and Höfler (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 transportation costs may also include other 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 $p^B - p^A > t^{B,A}$ and if the infrastructure to import from country B to country A 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 more 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. These bidirectional effects need to be taken into account in the econometric analysis.

Various papers analysed 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

Fig. 3. Utilisation of the Dutch export infrastructure for L-gas to the NCG network in Germany, 2007–2013 (Source: GTS; net allocation = firm + interruptible – backhaul).

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 no common drivers behind the gas prices. In the US, gas prices were already to a large extent determined in competitive gas markets, while in Europe gas prices were 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.

Using a cointegration and a time-varying coefficient approach, Growitsch et al. (2013) find that the two major trading hubs in Germany (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 initially hindered the realisation of permanently equal prices, but this impact has been reduced as a result of the improved connection of the German networks. In addition, they conclude that the German NCG market and the Dutch TTF have also become 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 affect 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; LECC, 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 field⁵ (Groningen), and a number of small fields, both

⁵ A field with a high well-head pressure enabling the operator to quickly change the level of production.

Fig. 4. Market share of TTF and number of active parties, 2007–2013 (per day)(Source: GTS).

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 with the networks in Germany, Belgium and the United Kingdom. The connections with German and Belgium are used both for import (mainly H-gas) and export (mainly L-gas), while the connection with the United Kingdom is only used for export. Since October 2010, the UK–NL interconnector is bi-directional. This is one of the institutional changes we discuss at the end of this section. The net flows to Germany and Belgium, defined as Dutch import minus Dutch export, as well as the exports to the United Kingdom have a strong seasonal pattern which is related to the unique characteristic of the Groningen field to offer flexible supply as mentioned above (Fig. 1). The net flow to Belgium is always negative, meaning that the export to this country continuously exceeds imports. The net flow to Germany is mostly negative as well, but it is positive during some summer days when imports exceed exports. In our analysis we will include heating degree days to capture the effect of cold weather on gas flows.

The 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 that brings 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 is fairly stable, both for H-gas and for L-gas (Figs. 2 and 3). For H-gas we see a small increase, while for L-gas the export capacity increased by 10 MW. Both capacities were 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; Hallack and Vazquez, 2013). Hence, they book capacity on a firm basis which means that they 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.

Fig. 5. Day-ahead gas price in the Dutch market (TTF), 2007–2013 (Source: Bloomberg).

Fig. 6. Difference in the day-ahead gas price in the Dutch market (TTF) and the German market (NCG), 2007–2013 (Source: Bloomberg).

Fig. 7. Highest daily utilisation of infrastructure for the export of H-gas to Germany (NCG) and differences in highest daily prices on TTF and NCG, 2007–2013 (Source: GTS/Bloomberg).

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 2013, 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 was 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, 1.29 Euro/MWh/h/year in 2012 and 1.35 Euro/MWh/h/year in 2013.⁶ These tariffs were constant during a year.

The liquidity of the TTF has grown substantially. The share of the TTF in the Dutch gas market increased from 5% in 2007 to about 40% in 2011 and remained on that level (see Fig. 4). In addition, the number of active players increased strongly. The churn ratio between the volumes of traded and the volumes actually delivered on the TTF increased to above 20. Note, that a churn ratio above 10 indicates that a market is a mature market (GTS, 2012; Heather, 2012). The churn of the NCG, however, is about 3 (Growitsch et al., 2013), 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.

The day-ahead price on the TTF during the period 2007–2013 is depicted in Fig. 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 (the correlation coefficient is 0.994).

The price difference between TTF and NCG does not reveal a seasonal pattern, but it has clearly declined over the past years (Fig. 6). In 2007, substantial differences in prices existed, but gradually these differences have become smaller.

The cross-border infrastructure is increasingly efficiently used: compared to a number of years ago, in 2013 fewer hours showed price differences while at the same time the infrastructure was not

fully used (Figs. 7 and 8). In these hours, traders apparently face restrictions in using the infrastructure to benefit from arbitrage opportunities. Nevertheless, in 2013 price differences still frequently occurred, which might be caused by remaining bottlenecks in using the infrastructure.

In this paper, we analyse the impact 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. Moreover, the connection with the UK market was strengthened 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 (Van Dinther and Mulder, 2013), 2011 and the policy of the Dutch incumbent gas supplier GasTerra, to deliver all gas for the domestic market on TTF instead of factory or city gates (Heather, 2012).

Two institutional changes affected the connection of the Dutch and the German networks. In 2008, the operator of the Dutch network (GTS) acquired a significant part of the German market, now called Gasunie Deutschland (GUD). And in 2013, new mechanisms were introduced to improve the allocation of cross-border capacity.

Within the German market also several institutional changes occurred. After the introduction of an entry–exit system in October 2007, several networks were 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. In addition, in 2012 the second part of the connection between the German network and the Russian gas fields (i.e. Nord Stream) was realised.

In the next analysis, we will analyse the impact of each of these institutional changes separately. In addition, we will determine the joint effect of a number of similar changes. Therefore, we distinguish the following groups of institutional changes: a) changes within the German market, b) changes within the Dutch market, c) changes on the border between the Dutch and the German market and, finally, d) changes regarding the connection of both the Dutch and the German market to other markets.

⁶ Source: website Gas Transport Services: <http://www.gasunietransportservices.nl/en/products-services/terms-and-conditions/tsc>.

Fig. 8. Highest daily utilisation of infrastructure for the export of L-gas to Germany (NCG) and differences in highest daily prices on TTF and NCG, 2007–2013 (Source: GTS/Bloomberg).

Table 1

Institutional changes in the Dutch and German gas markets, 2007–2013.

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	NetConnect Germany (NCG) results from pooling of areas of E.ON and Bayernets
D_3	1 October 2008		
D_4	1 July 2009	Abolishment of the obligation to book quality-conversion capacity	NCG network is extended with GRTgaz Deutschland, ENI and GVS
D_5	1 October 2009		
D_6	1 October 2010	Introduction of backhaul on BBL	NCG network is extended with Thyssengas
D_7	1 April 2011	New balancing regime; Obligation to deliver gas on the TTF	
D_8	8 October 2012		Finalizing second line of the North European Gas Pipeline project (Nord Stream)
D_9	1 April 2013	Introduction day-ahead auctioning of bundled capacity and introduction of secondary market for capacity	

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_3 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.

4. Empirical model and data

4.1. Dependent variable

We measure the economic integration of the Dutch and German gas markets through absolute 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 the availability of cross-border capacity. Since the 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. We use these data to estimate the model in which the dependent variable is the absolute difference between the highest daily day-ahead price on the Dutch market (TTF) and the German market (NCG). We take the absolute difference implying that smaller values indicate stronger integrated markets.

Table 2 reports descriptive statistics for various subsamples that reflect the institutional changes reported in Table 1. Table 2 shows that absolute price differences were relatively large in the first part of the sample. The biggest difference of 0.860 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 absolute price difference steadily decreases to 0.276 euro/MWh in 2013. A similar pattern is observed for the median of the absolute price differences. The standard deviation reaches its lowest value in the period between October 1, 2010 and March 31, 2011. The absolute gas price difference shows a long right tail (positive skewness) especially in the period between April 1, 2011 and Mar 31, 2013, and the distribution of the price difference is peaked relative to the normal distribution (kurtosis coefficient > 3) for all periods.

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 A). 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.⁷

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 variables.

⁷ See Appendix B for the specification of GARCH models.

Table 2

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

	Mean	Median	Std. dev.	Skewness	Kurtosis	Obs.
Oct 2007–Jun 2008	0.442	0.300	0.524	3.559	22.934	186
Jul 2008–Sep 2008	0.672	0.500	0.700	2.120	7.479	62
Oct 2008–Jun 2009	0.860	0.500	1.050	3.021	16.262	185
Jul 2009–Sep 2009	0.183	0.100	0.192	1.648	5.311	65
Oct 2009–Sep 2010	0.280	0.150	0.334	2.129	7.670	249
Oct 2010–Mar 2011	0.191	0.150	0.157	1.356	5.422	125
Apr 2011–Sep 2012	0.235	0.150	0.313	6.860	81.862	381
Oct 2012–Mar 2013	0.293	0.150	0.534	6.627	57.250	120
Apr 2013–Dec 2013	0.276	0.250	0.238	1.297	4.980	191

Data source: Bloomberg.

The infrastructure constraint is included by 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:

$$U_t = \frac{FN_t + IN_t - BN_t}{FC_t} \quad (2)$$

where t is the suffix for days.⁸ 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.⁹ For unidirectional clusters,¹⁰ we net the interruptible forward with the backhaul nominations (BN). After all, backhaul results in lower net flows.¹¹ For bidirectional clusters, this is not needed because, in that case, 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 average daily value.¹² Moreover, as separate infrastructures exist for H- and L-gas, we include the utilisation rates for both export of H-gas (U^{EX-H}) and export of L-gas (U^{EX-L}).¹³

Tables 3 and 4 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 (mean and median) is fairly constant from year to year while the volatility (standard deviation) decreases towards the end of the sample. Moreover, the distributions of the time series are slightly skewed and peaked relative to the normal distribution (kurtosis < 3).

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

⁸ 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 working day.

⁹ 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.

¹⁰ 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.

¹¹ Backhaul means that a flow in one direction is reduced by the flows which are meant to in the opposite direction. Hence, through backhaul it is possible to use a one-directional pipeline to have flows in the two opposite directions.

¹² The daily average and daily maximum utilisation rates are, however, strongly connected with a correlation coefficient of 0.99. This implies that the maximum utilisation rate is also a very good indicator for the average utilisation rate over a day. Hence, there is no need to include an additional measure for the daily duration of a high level of utilisation.

¹³ There is no import of gas from NCG.

Table 3

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

	Mean	Median	Std. dev.	Skewness	Kurtosis	Obs.
Oct 2007–Dec 2013	0.675	0.670	0.187	−0.033	2.151	1564
Jul 2008–Dec 2013	0.662	0.649	0.182	0.040	2.311	1378
Oct 2008–Dec 2013	0.666	0.650	0.182	0.053	2.282	1316
Jul 2009–Dec 2013	0.667	0.655	0.179	0.022	2.452	1131
Oct 2009–Dec 2013	0.670	0.658	0.181	−0.006	2.473	1066
Oct 2010–Dec 2013	0.692	0.670	0.170	0.223	2.397	817
Apr 2011–Dec 2013	0.691	0.668	0.162	0.360	2.794	692
Oct 2012–Dec 2013	0.680	0.659	0.132	0.309	2.278	311
Apr 2013–Dec 2013	0.698	0.692	0.131	0.297	2.086	191

cannot be influenced by trade decisions on that same day (which result in flows the next day).

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) 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 absolute price differences. These variables are also lagged one period to avoid possible biases due to reverse causation.¹⁴

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).¹⁵ In addition, we include dummies for months (M_i) to capture seasonal patterns.¹⁶ We also include year dummies (Y_i) to control for annual changes in cross-border tariffs.

What we have described above is the base model for absolute price differences in euro/MWh between TTF and NCG (denoted as $dP^{tff-ncg} \equiv |P^{tff} - P^{ncg}|$) which is formulated as:

$$dP^{tff-ncg}_t = \alpha_0 + \beta_0 U^{EX-H}_{t-1} + \chi_0 U^{EX-L}_{t-1} + \delta_0^G NX^{GER}_{t-1} + \delta_0^U NX^{UK}_{t-1} + \delta_0^B NX^{BEL}_{t-1} + Z_t \gamma + \varepsilon_t \quad (3)$$

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 absolute difference in the daily day-ahead prices.

4.3. Alternative model with institutional changes

In the alternative model we capture the effect of institutional changes by including dummy variables (D_i , $i = 1 \dots 9$). With this model, we analyse the impact of a number of institutional changes in both the Dutch and the German market (Table 1). The dummy 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

¹⁴ 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.

¹⁵ The temperature in the Netherlands is closely related to the temperature in the NCG area; the correlation coefficient appears to be 0.95. Hence, we use the average daily Dutch temperature as a measure for the daily temperature in the whole market area.

¹⁶ Although the net flows between the Dutch market on the one hand and the neighbouring markets on the other are characterised by seasonality (see Fig. 1), these flows also depend on other factors (since gas is also used for non-heating purposes, such as feedstock in chemical industry). Hence, it may make sense to include a specific seasonal variable.

Table 4

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

	Mean	Median	Std. dev.	Skewness	Kurtosis	Obs.
Oct 2007–Dec 2013	0.420	0.398	0.209	0.247	1.737	1564
Jul 2008–Dec 2013	0.409	0.379	0.210	0.356	1.832	1378
Oct 2008–Dec 2013	0.417	0.392	0.209	0.308	1.802	1316
Jul 2009–Dec 2013	0.408	0.371	0.205	0.367	1.832	1131
Oct 2009–Dec 2013	0.420	0.395	0.204	0.282	1.803	1066
Oct 2010–Dec 2013	0.429	0.415	0.213	0.192	1.736	817
Apr 2011–Dec 2013	0.401	0.353	0.216	0.461	1.908	692
Oct 2012–Dec 2013	0.479	0.470	0.208	−0.002	1.739	311
Apr 2013–Dec 2013	0.367	0.338	0.168	0.598	2.310	191

comparable levels of utilisation of the cross-border infrastructure (Tables 3 and 4), 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 for the alternative model for the absolute difference in maximum spot prices is as follows:¹⁷

$$\begin{aligned}
 dP_t^{tf-ncg} = & \alpha_0 + \sum_{i=1}^9 \alpha_i D_i + \beta_0 U_{t-1}^{EX-H} + \sum_{i=1}^9 \beta_i D_i U_{t-1}^{EX-H} + \chi_0 U_{t-1}^{EX-L} \\
 & + \sum_{i=1}^9 \chi_i D_i U_{t-1}^{EX-L} + \delta_0^G NX_{t-1}^{GER} + \sum_{i=1}^9 \delta_i^G D_i NX_{t-1}^{GER} + \delta_0^U NX_{t-1}^{UK} \\
 & + \sum_{i=1}^9 \delta_i^U D_i NX_{t-1}^{UK} + \delta_0^B NX_{t-1}^{BEL} + \sum_{i=1}^9 \delta_i^B D_i NX_{t-1}^{BEL} + Z_t \gamma + \varepsilon_t.
 \end{aligned} \quad (4)$$

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 absolute value of the cross-border price difference of that policy.

The hypotheses are that the institutional changes led to reduced absolute differences in the highest daily prices between the Dutch gas market and the German gas market. These hypotheses can be tested from parameters $\beta_1, \dots, \beta_9$ and $\chi_1, \dots, \chi_9$.

5. Results

Before we report the estimation results, we show that the variables 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. In Appendix A, we test formally that we need to apply GARCH models in which Eq. (3) is the mean equation.

From Table 5, that reports the results for the base model, we conclude that, on average for the whole period of analysis, the degree of utilisation of the cross-border infrastructure is unrelated to cross-border differences in price levels. The absolute differences in price levels appear to be positively related to the size of cross-border flows between the Netherlands and Germany. The net cross-border flows between the Netherlands and the UK had no effect on the absolute price differences with Germany, while the net cross-border flows between the Netherlands and Belgium reduced the absolute price differences. Note that in the base model the effects of these variables on the absolute price differences are constant and result from many factors, including the institutional changes we focus on this paper.

The outside temperature, measured by the heating degree days, negatively affects absolute price differences, which means that when the

Table 5

Results for the base model with t -distributed errors, 2007–2013 (Obs = 1637).

	Dependent variable: absolute difference in price levels	
	Coefficient	Std. error
Constant	0.362***	0.056
U^{EX-H}	−0.015	0.040
U^{EX-L}	0.001	0.055
NX^{GER}	0.00011***	0.00004
NX^{UK}	−0.00005	0.00006
NX^{BEL}	−0.00015***	0.00004
D_{UKR}	0.556	0.396
HDD	−0.004***	0.001
$Month_1$	0.096**	0.024
$Month_2$	0.087***	0.022
$Month_3$	0.056**	0.023
$Month_4$	0.023	0.028
$Month_5$	0.022	0.030
$Month_6$	−0.045	0.031
$Month_7$	−0.045	0.032
$Month_8$	−0.032	0.033
$Month_9$	−0.053*	0.030
$Month_{10}$	0.016	0.022
$Month_{11}$	−0.010	0.016
$Year_2$	−0.024	0.038
$Year_3$	−0.138***	0.035
$Year_4$	−0.177***	0.036
$Year_5$	−0.144**	0.035
$Year_6$	−0.180***	0.034
$Year_7$	−0.053	0.035
$AR(1)$	0.305***	0.017
$\alpha_1, ARCH(1)$	0.103***	0.007
$\lambda_1, GARCH(1)$	0.897***	0.007
t -Dist dof	2.984***	0.096
Log likelihood	−52.580	

*** Significant at 1%.

** Significant at 5%.

* Significant at 10%.

Table 6

Results for the alternative model with t -distributed errors, 2007–2013 (Obs = 16,373). Results for the intercept, D , M , Y and UKR dummies, HDD , and net flows are available on request.

	Dependent variable: absolute difference in price levels	
	Coefficient	Std. error
U^{EX-H}	0.081	0.496
$D_1 * U^{EX-H}$	0.220	0.546
$D_2 * U^{EX-H}$	−0.036	0.700
$D_3 * U^{EX-H}$	−1.218	0.773
$D_4 * U^{EX-H}$	1.182***	0.422
$D_5 * U^{EX-H}$	−0.437***	0.162
$D_6 * U^{EX-H}$	0.534***	0.191
$D_7 * U^{EX-H}$	−0.318*	0.176
$D_8 * U^{EX-H}$	−0.072	0.139
$D_9 * U^{EX-H}$	−0.138	0.174
U^{EX-L}	1.796**	0.701
$D_1 * U^{EX-L}$	−1.990**	0.777
$D_2 * U^{EX-L}$	−1.480*	0.896
$D_3 * U^{EX-L}$	1.859**	0.887
$D_4 * U^{EX-L}$	−0.118	0.453
$D_5 * U^{EX-L}$	−0.036	0.381
$D_6 * U^{EX-L}$	0.552**	0.278
$D_7 * U^{EX-L}$	−0.799***	0.215
$D_8 * U^{EX-L}$	0.317**	0.157
$D_9 * U^{EX-L}$	−0.192	0.220
$AR(1)$	0.185	0.018
$\alpha_1, ARCH(1)$	0.089***	0.006
$\lambda_1, GARCH(1)$	0.911***	0.006
t -Dist dof	2.727***	0.067
Log likelihood	59.431	

*** Significant at 1%.

** Significant at 5%.

* Significant at 10%.

¹⁷ In this equation, 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.

Table 7 Joint significance (a) and significance of the sum (b, c) of the coefficients of dummies for institutional changes with *p*-values in brackets.

Dummy variable	C(1), coefficient interaction term with U^{EX-H}	C(2), coefficient interaction term with U^{EX-L}	(a) $H_0: C(1) = 0, C(2) = 0$ vs $H_1: C(1) \neq 0$ and/or $C(2) \neq 0$ F-statistic (<i>p</i> -value)	(b) $H_0: C(1) + C(2) = 0$ vs $H_1: C(1) + C(2) \neq 0$ t-statistic (<i>p</i> -value)
<i>Absolute differences in price level</i>				
D_1	0.220	−1.990	3.780 (0.023)	−1.694 (0.090)
D_2	−0.036	−1.480	1.744 (0.175)	−1.097 (0.273)
D_3	−1.218	1.859	5.745 (0.003)	0.460 (0.646)
D_4	1.182	−0.118	4.051 (0.018)	1.650 (0.099)
D_5	−0.437	−0.036	3.665 (0.026)	−1.100 (0.271)
D_6	0.534	0.552	6.196 (0.002)	3.300 (0.001)
D_7	−0.318	−0.799	8.971 (<0.001)	−4.140 (<0.001)
D_8	−0.072	0.317	2.269 (0.104)	1.130 (0.258)
D_9	−0.138	−0.192	0.627 (0.534)	−1.119 (0.263)
(c) $H_0: \sum C(\cdot) = 0$ vs size			$H_1: \sum C(\cdot) \neq 0$ t-statistic (<i>p</i> -value)	
D_1, D_3, D_5	−1.602		−0.889 (0.374)	
D_2, D_9	−1.846		−1.305 (0.192)	
D_4, D_7	−0.054		−0.078 (0.938)	
D_6, D_8	1.331		3.345 (0.001)	

gas demand is relatively large due to low temperatures, markets have less difficulties to realise equal prices.¹⁸ Finally, the Ukraine gas crisis had no effect on the absolute differences in prices implying equally strong effects on gas prices in the Netherlands and Germany.

From Table 5 we also learn that seasonal effects play a significant role explaining absolute cross-border price differences. In the winter months (January–March), the price differences are relatively large. The coefficients for the year dummies indicate that the absolute price differences gradually drop which may be caused by annual changes in cross-border tariffs.

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 utilisation variables for H-gas and L-gas (Table 6). Because the utilisation 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.¹⁹

Table 7 shows two tests based on the coefficients of the dummies interacted with the maximum daily utilisation rates for exports of L-gas and H-gas. Test (Table 7, column a) tests the null that both coefficients are zero against the alternative that at least one coefficient deviates from zero. From Table 7 we conclude that each of the dummies D_1 and D_3 to D_7 has a significant influence on the differences in price levels. The sign of the coefficients for H-gas and L-gas differs, however, in several cases. In order to determine the overall effect, we test the hypothesis that the sum of coefficients deviates from zero (Table 7, column b). It appears that the introduction of an entry–exit system in Germany (D_1) as well as the liquidity-enhancing measures in the Dutch market together with the extension of the NCG network in April 2011 (D_7) significantly reduced the price differences. The abolition of the obligation to book quality-conversion capacity in 2009 (D_4) and the introduction of backhaul on the BBL (D_6), however, raised the differences in cross-border price levels.

In order to assess the joint effect of a group of similar type of measures, as introduced in Section 3, we conduct an additional test (Table 7, column c) whether the sum of the coefficients of a number measures deviates from zero.²⁰ The measures referring to the integration on networks in

Germany (D_1 , D_3 and D_5) have a negative effect on price differences, although this effect is statistically not significant at the usual levels of significance. The estimate for this effect is −1.602 which means that the implementation of these three changes in the German market together has reduced the absolute value between the Dutch and the NCG market by 1.602 euro/MWh.

The measures directed at increasing the liquidity of the Dutch market (D_4 and D_7) also had a negative, but statistically not significant influence on price differences. We learn from Table 7 that the estimate for this effect is much smaller than the estimate for the effect of the German network integration.

The measures which are directed at network integration between the Netherlands and Germany (D_2 and D_9) also have a negative, but statistically not significant effect. The estimate of this effect is −1.846, which is large compared to the other joint effects.

Finally, the measures fostering the connections with other countries (D_6 and D_8), enlarged the absolute differences in prices on TTF and NCG.

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 2013, the absolute level of the difference in price levels was 0.276 euro/MWh while the highest level was 0.860 (from October 2008 to June 2009). Over the last 4 years of the period of analysis, the absolute level of price difference was, however, fairly stable.

Controlling for a number of external factors, we find evidence that several institutional factors have contributed to the increased integration between the Dutch and the NCG market in Germany. In particular, the integration of networks within Germany had a positive effect on this market integration. This finding is in line with the conclusion of Growitsch et al. (2013) who found that the efficiency of the German market increased strongly after the introduction of the entry–exit system and the creation of the NCG market zone. We also find that the improved connections between the Netherlands and Germany contributed to market integration. Both had on average a joint effect of about −1.7 euro on the absolute value of the price difference.

For the measures increasing the liquidity within the Dutch market, the effect on market integration appears to be negligible. Although these measures likely have contributed to the strong increase in liquidity of the TTF, as was shown in Section 3, they did not have a measurable joint effect on market integration. The increased connections to the UK market and the supply from Russia, however, reduced the integration between the Dutch and the NCG market.

¹⁸ If we use, as a sensitivity analysis, the heating-degree days based on the average daily temperature in the NCG area (source: Deutsches Wetterdienst; <http://www.dwd.de/>), the coefficients for the other variables are not affected. Hence, the model results are robust for the way this variable is measured.

¹⁹ These results are robust to specifications that (i) include Heating Degree Days in the NCG area, (ii) delete Heating Degree Days in the Netherlands, and (iii) delete all month dummies.

²⁰ Table 7, column c shows the size of the combined effect and indicates whether it deviates from zero. It should be noted that significance may be underestimated because of collinearity.

From these findings, we learn that measures directly reducing barriers within networks are most effective in realizing more integrated markets. Examples of such measures are the merging of networks into larger networks and introduction of market-based mechanisms to allocate capacity on primary or secondary markets. Although connecting networks to other markets appear to increase price differences within these networks, such connections can be beneficial for gas consumers if they increase the availability of gas and, hence, the security of supply (Dieckhöner et al., 2013). A similar remark must be made for measures which are directly meant to increase the liquidity of markets. Although these measures appear to have a negligible effect on market integration, they may reduce costs for traders which is beneficial for gas consumers at the end of the day (Hallack and Vazquez, 2013).

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. Testing

Table A1

Autocorrelations of the differences and squared differences in maximum daily gas prices (TTF–NCG), sample period: June 2007–December 2013.

Lags	Price differences	Squared price differences
1	0.435*	0.158*
2	0.375*	0.129*
3	0.313*	0.079*
4	0.246*	0.040
5	0.237*	0.038
6	0.231*	0.038
7	0.218*	0.035
8	0.219*	0.030
9	0.204*	0.046
10	0.246*	0.047

* Significantly different from zero at approximately the 5% significance level if the autocorrelations exceed $2/\sqrt{N}$ ($= 0.049$ with $N = 1639$).

Tests for stationarity using the Augmented Dickey–Fuller test of the maximum prices (both TTF and NCG) reject the null of a unit root at the 5% significance level. This is confirmed by the Kwiatkowski–Phillips–Schmidt–Shin test. Both tests also clearly indicate that the cross-border absolute difference in maximum prices clearly is stationary. Hence, the dependent variable in Eq. (3) is 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). 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 observed in financial time series. As a consequence, external shocks leading to a change in volatility are permanent.²¹

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 financial 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 (i.e., $\chi^2(1)$ exceeds the 1% critical value in all models). With t -distributed errors, the log likelihood ($\ln L$) is higher than assuming that the errors follow a generalized error distribution.²² So, we estimate the model assuming that the errors are t -distributed. The degrees of freedom (dof) for the t -distribution is smaller than 3.0 for the price difference model. These estimates which are shown in the tables in the next section suggest that the error distribution is fat tailed.²³

The ARCH LM test applied to the IGARCH models indicate that there is no autoregressive conditional heteroskedasticity up to any order in the standardized residuals for the base model and the alternative model 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.

Summarizing, we apply IGARCH (1,1) models to the absolute differences in daily gas prices in the Netherlands (TTF) and Germany (NCG) over the period June 2007–December 2013. We use a mean Eq. (3) that includes a constant, month and year dummies, lagged net gas flows, lagged maximum daily utilisation 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 Table A1.

Appendix B. ARCH models

ARCH models have been developed to correct for clustered volatility (see Engle, 1982; Bollerslev et al., 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 ,

$$y_t = x_t' \beta + \varepsilon_t, \quad (\text{B.1})$$

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 , $i = 1, \dots, q$) as well as by p lags of the unconditional variance terms (ε_{t-i}^2 , $i = 1, \dots, p$):

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \lambda_j \sigma_{t-j}^2, \quad (\text{B.2})$$

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 Eq. (B.1), retrieve the residuals ε_t , and regress the squared

²¹ Caporale et al. (2003) and Mikosh and Stărică (2004) examine why volatility may not be mean reverting. They refer to nonstationarities and structural breaks.

²² Obviously this is confirmed by Akaike's Information Criterion ($AIC = 2k - 2 \ln L$, where k is the number of parameters which is the same for the generalized error distribution and the t -distribution).

²³ The t -distribution approaches the normal if the degrees of freedom get infinitely large.

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 $1 / (1 - \sum \hat{\alpha}_i + \sum \hat{\lambda}_j)$. 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.

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