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Spot and forward gas price dynamics in the gas hub market of Western Europe

Intermarket and intertemporal relationships and the role of pipeline capacity

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Preface and acknowledgements

During an internship at the structured finance – oil and gas department of ING I obtained a sincere interest in energy finance. After being involved in transactions involving gas pipelines I wondered how a pipeline affects the co-movement of spot prices in the markets it connects and whether a pipeline is also important for co-movement of the forward prices in the markets it connects. I would like to thank my supervisor, Dr. Nalan Basturk, for her guidance and enthusiasm during the writing process.

Abstract

The past decade new gas hubs emerged in Europe, which are points in a network where gas is exchanged between owners. Market integration of the gas hubs is a EU policy goal. This thesis addresses the cointegrating relationship between prices at the three most liquid hubs. By means of the Johansen test this thesis establishes that cointegration between the longer maturity markets is weaker than in the spot and the month ahead market, which has not been addressed earlier. Previous studies established that a pipeline shutdown may cause decoupling of the spot prices in the markets it connects. By means of an ARMA model this thesis establishes that this is the case for the Interconnector pipeline but not for the BBL pipeline. This thesis adds to the literature by establishing that forward prices at different hubs may also decouple, but less substantially. The decoupling of forward prices does not occur during the shutdown but when the contracts trade that deliver gas during the period of the shutdown. This thesis then addresses the relation between spot and forward prices at the same hub. This thesis finds that the spot market is more reactive to short-term disturbances. Related to this, by means of an error correction model this thesis finds that the forward market leads the price discovery process. This finding implies that market participants could consider using the forward price as benchmark price in newly concluded or revised long-term contracts to capture the most valid price signal.

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1. Introduction

Gas prices at the gas hubs in the Netherlands, the United Kingdom and Belgium are analysed. For each hub over-the-counter contract prices for contracts of four different maturities are examined. This study consists of two parts. The first part of this study derives its relevance from the observation that studies concerning market integration of the European gas hubs have focussed exclusively on cointegration of spot prices. This study complements the current literature by including the forward market. The fact that the cointegration literature has overlooked the forward market is surprising considering that approximately 90% of gas volumes in Western Europe are traded under mid- and long-term contracts (month ahead – year ahead). Previous studies have concluded that pipeline capacity is of importance for intermarket cointegration. This study addresses whether a pipeline shutdown affects the cointegrating relationship of the spot and forward prices at the hubs it connects in the same manner. This yields the following research questions:

1. Are gas prices of spot contracts traded at the hubs covered in this study cointegrated?
2. Are gas prices of longer maturity contracts trading at the hubs covered in this study cointegrated?
3. Does a pipeline shutdown cause decoupling of spot prices at the markets it connects?
4. Does a pipeline shutdown cause decoupling of forward prices at the markets it connects?

By applying the Johansen test, the first part of this study finds that gas prices of spot and month ahead contracts traded at the hubs are cointegrated. Prices in the quarter and year ahead market are either not or weakly cointegrated, which may be related to the infrequent trading of longer maturity contracts or to characteristics of the over-the-counter market. As integration of natural gas markets is a policy goal of the European Union, the weaker integration of longer maturity forward markets could be taken into account when evaluating gas market integration policy.

This study then addresses the effect of the annual maintenance shutdowns of the pipelines that connect the United Kingdom with the Netherlands and Belgium. The effect of a pipeline shutdown depends on which pipeline is considered. The shutdown of the Interconnector pipeline causes substantial decoupling of spot prices. Cointegration of forward prices is affected to a lesser extent by the Interconnector shutdown. Moreover, decoupling of forward prices does not occur during the shutdown but when the contract trades that delivers gas in the period of the shutdown. The reason that cointegration between forward prices is affected less by the pipeline shutdown seems to be that the forward market is not that sensitive to short-term events. The BBL pipeline shutdown does not lead to divergent price patterns in both the spot markets and the forward markets it connects. The different effect that shutdowns of the Interconnector and the BBL pipeline have is attributed to the fact that the BBL pipeline does not have substantial physical flow capacity from the United Kingdom towards the European continent. Flow capacity in this direction is particularly important during the annual pipeline shutdowns in the summer as during that time the United Kingdom deals with an oversupply of gas that needs to be transported to Continental Europe.

Whereas the first part of the study examines the spot and forward markets individually, the second part of this study addresses the relationship between spot and forward prices at the same hub. This relationship is termed the intertemporal relationship. As the first part of the study indicates that the spot market is more reactive to short-term disturbances, the forward market may better and faster reflect relevant information. Due to the latter the forward market may lead the price discovery process. The research questions that are addressed in the second part of this thesis are as follows:

5. Are gas prices of spot and forward contracts traded at the same hub cointegrated?
6. Is one of the contracts leading the price discovery process?

It is established that spot and month ahead prices are cointegrated at each hub. Spot and quarter ahead prices are cointegrated at some hubs while spot and year ahead prices are cointegrated at none of the hubs. These results are attributed to the observation that the seasonal patterns of quarter and year ahead prices are substantially different from the seasonal patterns in spot and month ahead prices.

The second part of this study finds that when a deviation from the long-run equilibrium between spot and forward prices occurs, the spot prices makes the largest adjustment to restore the equilibrium. Therefore, the month ahead forward price leads the spot price in the price discovery process. As such, using the month ahead price as benchmark price in newly concluded or revised long-term contracts is likely to capture the most valid price signal. Furthermore, using the month ahead price as benchmark would also preclude participants from being affected by the higher reactivity of the spot price to short-term disturbances.

This study is structured as follows: section 2 is a general introduction to gas hub trading and its history in Europe. Section 3 constitutes an overview of academic literature that addressed similar subjects. Section 4 constitutes an overview of the theoretical framework. Section 5 provides an overview of the data. Section 6 and section 7 address the research questions and provide the results. Section 8 summarizes all results and sets out the implications of the results, addresses limitations of the current study and addresses directions future research might take.

2. The European natural gas market

This study is undertaken in the context of the ongoing development of the European natural gas market. Therefore, section 2 explains the role of gas trading hubs in the European market for natural gas. Firstly, a general introduction to the gas hubs is provided. Secondly, insight is provided into the drivers behind the move from oil-linked pricing to hub-based pricing. The third and fourth subsections provide insight into the trading mechanisms available on the hubs and the market participants making use of those. The last subsection provides details on the hubs covered in this study.

2.1. Introduction

Gas hubs are points in a natural gas pipeline network where gas is exchanged between owners. The hubs are essential to the facilitation of fair competition throughout the European Union. On the hubs natural gas is traded as a commodity and its price is determined by supply and demand of sellers and buyers, a mechanism referred to as gas-to-gas competition. This has constituted a major change on the natural gas market as before the hubs came into existence natural gas has mostly been traded in the form of long-term contracts, indexed to a basket of oil products. The rationale behind the oil price link, that end-users have a choice between burning gas and oil products, originated from the 1970s. In the meantime this rationale has become obsolete as oil is used much less by energy generators as oil-burning-equipment, is more costly, less efficient and not in line with environmental standards related to emissions (Stern & Rogers, 2011).

Experts agree that European long-term contracts need to move from oil-indexed prices to hub prices in order to accurately reflect supply and demand conditions in the gas market. Furthermore, hub markets offer a more transparent way of buying energy as customers can make commercial comparisons with transparent reporting of prices in the hub market environment (Heather, 2012). Currently the market for natural gas is a hybrid price market with gas both imported under long-term oil-indexed contracts with producers such as Gazprom, Statoil and Gasterra and gas priced at the hubs.

The move to hub-based pricing does not necessarily constitute a move to short-term pricing as existing and new long-term contracts may still be concluded, but can be linked to hub prices. This requires there to be an agreed benchmark hub. As Heather (2012) points out there is currently an active discussion about which hubs are most suitable to function as benchmark and whether the idea of a single European price for gas is feasible. Heather also points out that several large-scale gas consumers have expressed the desire of having all their gas needs served on the basis of one European hub price. Currently, the more liquid Western European gas hubs seem the most likely candidates to act as benchmark. Furthermore, it could also be that several hubs will serve as a benchmark for a certain area within Europe. Recent publications, e.g. Stern and Rogers (2011), Heather (2012) and Petrovich (2013), address general characteristics of hubs that make them more or less suitable to function as price benchmark. Market participants generally prefer a more stable and liquid hub to act as benchmark. For the move towards hub-based pricing to continue it is crucial that the price dynamics of natural gas contracts are well understood.

Trading at the gas hubs experienced such a level of growth that in 2011 and 2012 volumes of physically delivered natural gas on European hubs covered respectively 70% and 80% of the total consumption of natural gas in the countries covered by those hubs. (European Commission, 2013)

2.2. Drivers of change

The European Union has been working towards a liberalised internal market for natural gas since 1998. The main goal is to create a fully functioning, interconnected and integrated natural gas market within Europe. Introducing competition in the gas sector should increase economic efficiency and lower costs for final consumers (International Energy Agency, 2008). An appropriately functioning internal market should also deliver more resilience in the event of supply disruptions, thus increasing gas supply security. The introduction of the European Gas Directive (98/30/EC), the Second Gas Directive (2003/55/EC) and the Third Gas Directive (2009/73/EC) have brought fundamental changes to the natural gas sector across many European countries already (Growitsch, Stronzik and Nepal, 2012).

The latest Directive[1] still identifies several shortcomings with respect to the functioning of the European natural gas market. It concludes additional measures are necessary to guarantee fair competition. Many European countries are dominated by vertically integrated energy companies that besides the distribution of gas (mainly via pipelines), are also involved in production, storage and power generation. The main pillar of measures included in the Third Directive concerns the unbundling of these vertically integrated systems. Countries are required to designate distribution system operators, which should be legally independent from all activities not related to the distribution of gas. These system operators should ensure third party access to the distribution system and new entrants should be provided with information on tariffs and access on a transparent and non-discriminatory manner. Another issue that has been identified concerns limitations on trade in natural gas between member states, due to insufficient cross-border pipeline capacity. New investment in pipelines should facilitate natural gas flow across the European Union and should aid

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[1] Information on the EU Gas Directives is available at http://ec.europa.eu/energy/gas_electricity/legislation/third_legislative_package_en.htm

countries in meeting demand and enhance the integration of national markets. Heather (2012) points out that further integration also requires coordinated network codes across the European Union and approval of each member state.

While the legislative framework is certainly important, a truly liberalised hub market cannot exist without willingness on the side of the market participants. Market developments during the past years played a significant role in the attitude of market participants towards hub-based pricing (Heather, 2012). In 2009 natural gas prices under long-term oil-indexed contracts decoupled from prices at the hubs. As of 2009 the prices under oil-indexed contracts increased due to a rising oil price, while prices at the hubs remained low due to low demand and abundant supply. Demand has been low as a consequence of the European recession. Furthermore, during this time the United States substantially reduced its need for imported natural gas due to its unconventional gas resources. This caused liquefied natural gas exports, initially meant for the United States, to be redirected to Europe. The large gap between prices under long-term contracts and prices at hubs were a reason for concern for European utilities that were buying expensive gas under long-term oil-indexed contracts, but asked by their own customers to sell at the lower spot prices of the hubs (European Commission, 2012a). The demand for change primarily came from the side of the buyers. The producers have been the beneficiaries of the high prices under the long-term oil-linked contracts and have been opposing the transition. Stern and Rogers (2011) point out that long-term contract terms contain an option to be revised every three years and that these contracts contain a clause stating that “changed economic conditions beyond the control of both the seller and the buyer” may lead to a price review. Whether this is the case may be settled by arbitration. In this process the buyers are likely to point out that the original rationale of the oil price link has become obsolete, as pointed out earlier.

While the price developments of the past years might have accelerated the transition to hub-based pricing, experts have warned that hub-based market prices not necessarily mean low prices. Theoretically, there is no reason why hub-based prices could not exceed oil-linked prices as a consequence of supply and demand conditions in oil and gas markets. The main argument for the move to hub-based pricing should remain that conditions in the gas rather than the oil market should set gas price levels. As such, the discussion should focus on price formation rather than price level (Stern & Rogers, 2011).

2.3. Trading platforms

Different trading platforms enable participants to trade gas at the hubs. The platforms are brokered markets, exchanges and bilateral trade without a broker (IEA, 2008). Most trades still occur in the over-the-counter market, commonly referred to as the OTC market. Heather (2012) estimates that OTC and exchange trades respectively constitute 70% and 30% of the trades that take place. Table 1 provides an overview of each of the trading platforms. This study concerns prices at the spot and forward OTC market and therefore this subsection compares this platform to exchange trading, which is the area currently experiencing the steepest growth in terms of traded volumes. The fourth column of table 1 describes the bilateral market without involvement of a broker or exchange. Such trading occurs mostly at the illiquid trading hubs or for exceptional trades outside regular business hours (IEA, 2008).

Table 1. Overview of natural gas trading platforms (based on IEA, 2008)

	OTC	**Exchange**	**Bilateral without broker**
Contracts	Agreement between the parties	One agreement with the exchange	An agreement between the companies is needed
Trading method	Through broker (electronic platform or telephone)	Electronic platform	Personal contact
Counterparty	Other company	Exchange	Other company
Transaction costs	Medium	High	Low
Transparency	Good, many publications on end of day prices	High	None
Anonymity	Company has to reveal it self to other	Anonymous	Companies are familiar with each other
Main usage	All products	Most liquid products	Illiquid products and large volumes
Type of agreement	Framework contract	One agreement with exchange	Bilateral contract

Both brokers in the OTC market and exchanges offer electronic trading platforms where traders can post bids and offers. However, important differences between the several platforms exist. The longer maturity contracts on the exchange are standardised futures contracts which are specific to a certain exchange. The forward contracts in the OTC market are agreements between two parties and are standardised to a lesser extent than futures contracts on the exchange. Therefore, the legal and financial framework of the OTC marketplace is an important element of OTC trading. Master trading agreements have been developed by organisations such as the European Federation of Energy Traders and the International Swaps and Derivatives Association, these framework contracts contain the basic legal text for most standard provisions and should simplify the negotiation process. In the OTC market the market participants face some degree of counterparty credit risk, while this is largely absent at the exchange (IEA, 2008). Related to this is the fact that in the OTC market the parties involved in a transaction have to reveal their identity to the other party when conducting a trade, while the exchange market enables parties to remain anonymous. While the revealing of identities in the OTC market is a disadvantage for some individual participants that may not want to reveal their strategies, it also increases the transparency in the market.

Exchange trading has several advantages compared to hub-based trading. However, transaction costs charged on the exchange are high (Leykam, 2008) and the lower level of liquidity on the exchanges may refrain some market participants from trading at the exchanges.

While the United Kingdom has had an active OTC market for much longer period than Continental Europe, the growth of the OTC market of Continental Europe has been astonishing. OTC trading in Continental Europe started at the Zeebrugge hub in Belgium in 2000. In 2000 total traded volumes were approximately 5 billion cubic meters of natural gas.The total traded volume increased to 55 billion cubic meters in 2005 and 550 billion cubic meters in 2011. In comparison, the total OTC volume at the hub in the United Kingdom, the NBP, was 1159 billion cubic meters in 2011. (Heather, 2012)

2.4. Market participants

Leykam (2008) distinguishes three categories of participants in natural gas trading at the hubs. Firstly, integrated companies owning assets such as production fields, long-term contracts, storage facilities and pipelines use the trading hubs to optimize their gas portfolio. These companies often have contractual obligations to supply gas to consumers. For such participants the spot market is crucial as it enables these companies to balance their portfolios in the short-run, as long-term contracts may constitute a large share of their portfolios. Secondly, Leykam mentions speculative traders that place bets on the gas prices or aim to arbitrage between locations or time periods. These activities can be undertaken by physical as well as financial positions. Lastly, there are companies that use the hubs for risk management purposes. These companies are exposed to gas price risk and use the hubs for hedging purposes. Heather (2012) notes that natural gas hubs are increasingly being used for risk management, which adds liquidity to the hubs. Higher liquidity attracts non-physical market participants and in turn these increase liquidity even further.

Stern and Rogers (2011) identify that there are concerns among the market participants with respect to price formation at the natural gas hubs, mainly related to market manipulation of individual hubs and price volatility. Concerns over market manipulation are related to the finding by Hegde and Fjeldstad (2010) that at many gas hubs in Europe the majority of trading is done by incumbent gas companies and domestic producers. While this is especially the case at the less liquid hubs in Southern and Central Europe, it is even apparent at the more liquid hubs. This situation may gradually change due to the liberalisation efforts of the European Union. As hubs gain additional participants and become more liquid, the ability for a single player to manipulate prices is likely to be diminished. However, concerns among market participants over increased price volatility is an inevitable consequence of the move towards hub-based pricing as the long-term oil-linked contracts contain averaging clauses specifically aimed at minimising price volatility (Stern & Rogers, 2011). To reduce volatility market participants could include similar averaging clauses in contracts with hub-based pricing. Another strategy is to manage the higher volatility by obtaining an increased understanding of the hub price dynamics.

2.5. Hubs covered in this study

This study covers the National Balancing Point (NBP) in the United Kingdom, the Zeebrugge hub in Belgium and the Title Transfer Facility (TTF) in the Netherlands. These three hubs are the most mature and liquid hubs in Europe, with only the two German hubs having achieved comparable trading volumes (Heather, 2012).

Table 2. Hubs covered in this study

Hub	Location	First year of operation	2011 Traded Volume TWh	Classification by Heather
National Balancing Point	United Kingdom	1996	18000	Trading hub
Title Transfer Facility	The Netherlands	2003	6300	Trading hub
Zeebrugge	Belgium	2000	870	Transit hub

Traded volumes retrieved from: Gas Transport Services (2012)

As mentioned before, the NBP was the first hub in Europe and the total volume traded on this hub exceeds the total volumes traded on all Continental European hubs combined. The NBP is connected with the gas market in Continental Europe by the Interconnector and the Balgzand to Bacton Line (BBL) pipeline. The Interconnector pipeline connects the NBP with the Zeebrugge hub, while the BBL pipeline connects the NBP and the TTF. The Interconnector pipeline has substantial gas flow capacity in both directions while the BBL pipeline only has substantial capacity from the TTF to the NBP. Trading at the NBP occurs both in the OTC market and on futures exchanges.

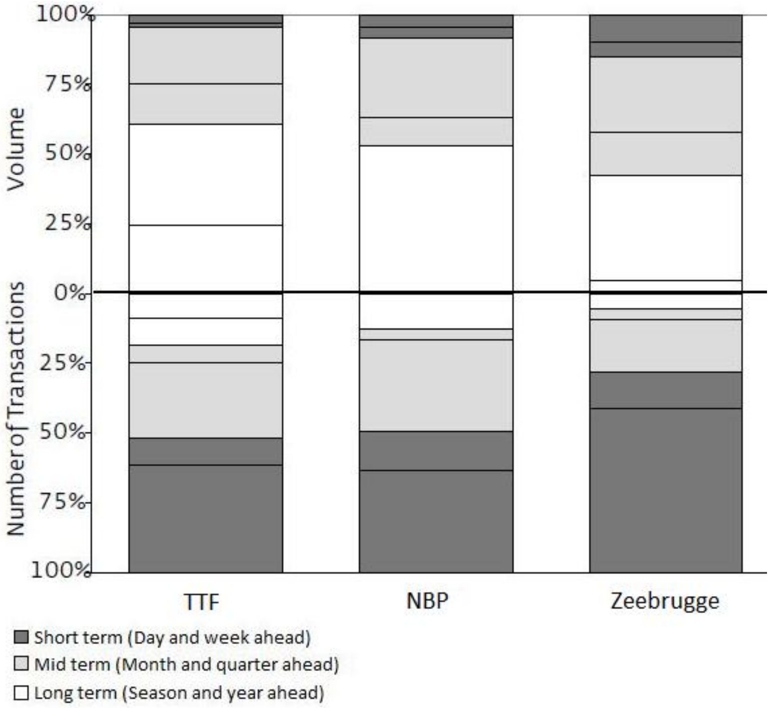
The Zeebrugge hub was the first gas hub in Continental Europe. The Zeebrugge hub is closely linked to the NBP, both physically and in terms of pricing. The fact that trading at the Zeebrugge hub occurs in pence per therm, the standard unit in the United Kingdom, underlines the existence of a strong connection between these hubs. Mainly due to the substantial Interconnector pipeline capacity, traders can exploit the arbitrage potential between the two markets and as such the price differential between the locations is small (IEA, 2008). Trading activity on the Zeebrugge hub increased substantially between 2000 and 2009 but the growth has stabilised last years (Heather, 2012). Trading at the Zeebrugge hub occurs primarily in the OTC market.

The TTF in the Netherlands came into existence in 2003 and is the most liquid hub in Continental Europe. The majority of trading at the TTF still happens in the OTC market but exchange traded gas volumes are growing fast and may overtake the dominance of OTC trading at the TTF in the future (Heather, 2012). The Dutch government has initiated the so-called Gas Roundabout Strategy aimed at further consolidating the position of the TTF in the European gas market. The goal of this strategy is to secure the long-term supply of gas of the Netherlands (The Netherlands Court of Audit, 2012). The latter is particularly relevant since indigenous production in the Netherlands has been declining. The explicit government support could encourage further development of the TTF.

Table 2 displays that the NBP and the TTF are classified by Heather (2012) as trading hubs, indicating that these hubs have reached a substantial level of maturity and are being used for financial risk management and hedging purposes. This is partly a consequence of the fact that the NBP and the TTF are virtual trading hubs, while the Zeebrugge hub was still a physical hub in the period considered in this study. Near the end of 2012 Zeebrugge also launched a virtual trading hub, named ZTP. Virtual trading hubs cover an area with multiple points where gas can be delivered at the same price, creating wide and easy access (IEA, 2008). At a physical hub the gas is to be delivered at a specific point in the network, which decreases the liquidity as it makes trading more difficult. The Zeebrugge hub is classified as transit hub as market participants mainly use the Zeebrugge hub for onward transportation of gas between the United Kingdom and Continental Europe.

To illustrate the differences in trading activity on the hubs, figure 1 displays the relative number of trades in contracts of different maturities and the relative volumes these trades cover. The figure yields several interesting insights that are valid for each hub. It is evident that short-term trades constitute a small proportion in terms of gas volume while these trades constitute the majority in terms of number of trades. This means that short-term trades occur often and the underlying is a relatively small volume of gas. A significant proportion of these trades likely belongs to the integrated companies that use the spot market to optimise their portfolio in the short-run, as the portfolios often primarily consist of long-term contracts. Long-term trades constitute a large proportion in terms of gas volume but only a small proportion of the total number of trades, indicating that these trades occur much less frequent but the underlying is of larger volume. With respect to mid-term contracts the total volume traded and the number of trades are more in proportion, indicating that their trading frequency and volume of the underlying are in between the short-term and long-term products. This provides insight into the different functions that contracts of different maturity have for traders.

Figure 1. Transactions of different maturity contracts in terms of volume and number (Gas Transport Services, 2012)



An important insight is the fact that the TTF and the NBP have a much larger share of trades further down the forward curve than the Zeebrugge hub, especially in terms of number of trades. This is related to the earlier statement that the TTF and NBP have already reached a substantial level of maturity and are being used for financial risk management and hedging purposes, as especially those trades require longer maturity contracts (Gas Transport Services, 2012). Such activity also attracts non-physical players such as financial institutions.

The fact that the total traded volume at the TTF is smaller than at the NBP while the TTF is equal to the NBP in terms of proportions of longer term trades, is one of the reasons the TTF is considered to have a large potential to grow (Heather, 2012). It should also be noted that while Zeebrugge is lagging behind the NBP and TTF in terms of long-term trades, relative to most other European hubs its proportion of long-term trades is still quite large.

Other gas hubs that are of importance to the European gas market but not included in the current study are located in Germany, France, Italy and Austria. Heather (2012) classifies these hubs as transition hubs due to the fact that these hubs have not reached a mature level yet. It should be noted that all these hubs in Continental Europe only came into existence during the past decade and that activity at these hubs may increase in the future. Whether individual hubs will experience growth depends partly on whether the European gas market will increasingly use benchmark hubs. If the latter is the case, these benchmark hubs may attract the majority of the trading volume.

3. Literature review

While section 2 provided the necessary background to the gas hubs in Europe, this section introduces academic papers that address similar research questions as this study does. For a more extensive background on the gas hubs, readers are referred to IEA (2008), Hegde and Fjeldstad (2010), Stern and Rogers (2011) and Heather (2012). The first subsection of the literature review summarises studies adressing intermarket cointegration (cointegration between prices in different markets) and compares these to the current study. The second subsection does the same for the relationship between prices of spot and foward contracts traded at the same hub, which is termed the intertemporal relationship.

3.1. Intermarket cointegration of spot gas prices

Among the studies addressing cointegration of gas prices there is much variety with regard to the market and the time period considered. As the European gas hub market is relatively young, studies concerning other geographical markets and other trading platforms than the OTC market are also included in this subsection. Studies considering cointegration at European gas hubs typically date from the last seven years. It should be noted that these studies focus exclusively on cointegration of spot markets, which is complemented in the current study by including forward markets.

Liberalisation of the natural gas market in the Unites States took place as of the late 1980s and this process has been the topic of several studies. De Vany and Walls (1993) consider 190 pairs of market locations in the United States and conclude that the proportion of cointegrated market pairs went up from 46% in 1987 to 66% in 1991. The high number of market pairs is a consequence of the fact that the market in the United States is divided in a high number of market areas, whereas European countries generally only have one, two or three hubs to cover a single country. De Vany and Walls attribute the increase in the proportion of cointegrated market pairs to the fact that as of 1985 the relevant regulatory agency in the United States allowed pipeline owners to offer pipeline capacity to third parties, creating an active market for transportation rights. De Vany and Walls stipulate that due to the latter participants likely started to seek arbitrage opportunities, which decreased differentials between market areas. Cuddington and Wang (2006) state that at the end of the research period of De Vany and Walls (1993) gas market integration in the United States was not yet satisfactory. Subsequently, Cuddington and Wang find that market integration in the United States continued from 1992 to 1997 as in 1997 74% of the market pairs are cointegrated. The study also finds that for most price gaps, the estimated half-lives are in the range of 2 days to 2 weeks, which, according to the authors, suggests rapid adjustment towards the market equilibrium.

One of the first studies on cointegration of European gas prices considers German gas import prices from Europe’s three main gas suppliers: the Netherlands, Norway and Russia (Asche, Osmundsen, & Tveteras, 2002). This study does not consider hub prices, but average monthly pipeline prices at the German border. This primarily considers gas delivered under long-term contracts. While the authors find substantial differences in mean prices from each supplier, cointegration tests do show that the different border prices for gas delivered in Germany move proportionally over time, indicating an integrated gas market. The authors hypothesize that the difference in mean prices from each supplier are associated with the volume flexibility these suppliers offer and perceived political risk associated with the suppliers.

Neumann, Siliverstovs and von Hirschhausen (2006) use time-varying coefficient models and apply a Kalman filter model to test whether spot price convergence between the NBP, the Zeebrugge hub and Bunde (a former German gas hub) was taking place between 2000 and 2005. Their conclusions are that almost perfect price convergence has occurred between the NBP and the Zeebrugge hub while they find no evidence of price convergence between Bunde on the one hand and the Zeebrugge hub and NBP on the other hand. As such, the authors conclude liberalisation on the European continent was not yet satisfactory during the examined period.

Leykam (2008) focuses on the NBP, TTF, Zeebrugge and the Bunde hub in Germany and studies spot price series from March 2005 until May 2008. Leykam finds evidence of a cointegrated relationship between 2005 and 2008 for all four markets. An interesting finding is that the paper finds the least strong cointegration between the TTF and the NBP, the two most liquid hubs. Leykam addresses the effect of the Interconnector pipeline shutdown and finds that it increases the spot price differential between the NBP and the Zeebrugge hub, but not between other hubs. The first part of the current study can be viewed as an extension of the study done by Leykam. This study extends Leykam’s analysis by including forward prices and by also including the BBL pipeline in the analysis. The BBL pipeline was not yet operating during the period that Leykam examined. It is interesting to see whether since operation of the BBL pipeline the TTF and NBP prices have become more cointegrated. Leykam neglects to explain how supply and demand dynamics are affected by a pipeline shutdown and how individuals price series are affected, which is something this study clarifies.

Gianfreda, Grossi and Carlotto (2012) study cointegration and causality between five European hubs (NBP, TTF. Zeebrugge and the hubs in Austria and Italy) from 2009 to 2011. The authors find that not all considered markets are interrelated. As expected the authors find an important causal role for the NBP hub. However, against expectations, the authors find a quite important causal role for the Italian hub as well. The authors do not address the issue that the traded volume at the Italian hub is the smallest of all European hubs and a lack of competition has caused the hub to suffer from illiquidity (Honore, 2013). Therefore, the finding that the Italian hub drives European prices is very unlikely.

Kuper and Mulder (2013) examine daily gas prices of the TTF and the German NetConnect hub between June 2007 and March 2011. Kuper and Mulder find that prices at these hubs markets have become more integrated over the examined period. The authors find that a policy measure to establish gas quality-conversion capacity at the TTF has made the Dutch market less vulnerable to cross-border constraints. The authors also conclude that the availability of flow capacity from the Netherlands to the United Kingdom in the BBL pipeline reduced the integration of the Dutch and German market due to the fact that the TTF became more closely related to the NBP in the United Kingdom.

Petrovich (2013) provides a correlation analysis of the European gas market. What primarily distinguishes Petrovich’s study is that she does not analyse broker reported OTC prices or exchange prices, as most studies do, but anonymised price data of every single trade on each European hub. She concludes that the correlation between OTC and exchange prices at the European hubs is very high. In most recent years the annual Pearson correlation coefficient between OTC and exchange prices has been in the range of 0.9 – 0.99. This is an important conclusion as particularly the exchange is considered to be rather illiquid and therefore exchange prices may be expected deviate from OTC prices. She also comes to the conclusion that the TTF seems the most appropriate benchmark hub in Europe as the correlation with the TTF is highest and most stable in all pair-wise comparisons. This is a rather interesting conclusion as earlier literature has mostly advocated the NBP as benchmark hub due to its high traded volumes. The first part of this study extends Petrovich (2013) by applying more advanced methods than Pearson correlation to investigate intermarket relationships and by also considering markets of longer maturity than one month. Furthermore, while Petrovich does mention the critical role of the Interconnector, her analysis on the role of pipelines is rather limited.

Honore (2013) provides an overview of the Italian gas market. As part of her study she addresses how illiquidity, lack of competition in the Italian gas market and pipeline capacity constraints cause the spot price at the hub in Italy to be substantially higher than other hubs in Europe. While the current study does not address the Italian hub, the observation that ineffective policy can cause prices at a hub to trade at a premium is a relevant insight.

3.2. Price dynamics of natural gas spot and forward prices

Swieringa (2012) investigates price discovery on the European energy exchange markets. The price discovery process is the manner by which new information is impounded into prices (Fu & Qing, 2006). When market i is more informationally efficient than the other, it means that information disseminates in market i first and subsequently in the other market (Fu & Qing, 2006). In this case there is a flow of information from market i to the other market and price discovery takes place in market i (Srinivasan, 2011). Among other markets, Swieringa addresses the natural gas market and finds that the futures contract displays an important role in the price discovery process. However, Swieringa does not investigate contracts as far down the forward curve as this study aims to do.

Nick (2013) analyses price discovery and arbitrage efficiency between spot and futures markets at the NBP, TTF and a hub in Germany by means of a threshold error correction model. A threshold error correction model is able to identify whether corrections from the long-term equilibrium between two prices only takes place after the differential between the prices has reached a certain level. However, Nick concludes that the threshold does not add to the model. Nick focuses on the exchange market while this study addresses the more liquid OTC market. The included futures contracts are the one, two and three month ahead contracts. Nick finds that price discovery takes place in the futures market, with the spot price subsequently following the futures market price. Nick also finds evidence of significant market frictions constraining arbitrage and suspects that those frictions are related to illiquidity and technical constraints related to storage and pipeline capacity. Lastly, Nick finds that the NBP is the most liquid hub as arbitrage opportunities are exhausted most quickly at this hub. Nick considers this finding counterintuitive considering the fact that the NBP suffers from relatively inflexible gas storage facilities and high dependence upon a small number of pipelines. The second part of this study differs from Nick both with respect to the methodology employed, the selection of hubs and the type of prices considered. This study is able to assess whether the OTC forward market shows similar behaviour as the futures market (on the exchange) by comparing the findings to Nick.

Studies addressing other energy markets usually find that price discovery primarily takes place in the forward or futures markets, e.g. Figuerola-Ferretti and Gonzalo (2007), Rittler (2009), Fu and Qing (2006). However, there are exceptions such as Srinivasan (2011).

4. Theoretical framework

This section seeks to explain the rationale behind each of the relationships examined in this study, which constitute intermarket and intertemporal cointegration. Lastly, this section explains why it is likely that spot and forward (or futures) prices react differently to changes or shocks in variables related to supply and demand.

4.1. Intermarket cointegration

The rationale behind the expectation of intermarket cointegration (cointegration between prices at different hubs) is that in efficient markets homogenous goods should have identical prices at different locations, which is referred to as the Law of one Price. Kuper and Mulder (2013) distinguish the absolute Law of One Price, which implies that prices in all regions are equal and the relative Law of One Price, which implies prices move in the same direction. For the Law of One Price to hold remaining price differentials should only reflect transportation and transaction costs. If transport of goods is not costless, which is likely to be the case in the gas market, price differences between regions may persist, but they should not exceed the costs of transportation and other transaction costs. This leads to the following conditions, in which P_i and P_j refer to the prices in market i and j and TC to the transaction costs between these markets:

$$\begin{aligned} &P_i - P_j \leq TC_{ji}\,; \\ &P_j - P_i \leq TC_{ij} \end{aligned} \qquad (1)$$

Kuper and Mulder (2013) indicate that constraints between regional markets may cause the relation between the markets to be disturbed, which may lead to divergent price patterns over the period in which the constraint occurs. On the other hand they also note that indirect relationships may still cause co-movement of prices if there are common drives such as temperature or if the markets are both linked to a common third market.

De Vany and Walls (1993) state that prices at different markets must indeed be free of arbitrage opportunities but within that limitation prices may vary with respect to each other, which corresponds to condition 1. According to De Vany and Walls cointegration can function as a test of arbitrage free pricing in the series P_i and P_j. The series P_i and P_j in 1 are generally non-stationary. If arbitrage occurs between two markets, prices are expected to lie within stable limits. In that case, the spread between P_i and P_j is stationary and the series are likely to be cointegrated. If P_i and P_j are found not to be cointegrated, the spread is non-stationary, which indicates that the spread is not bounded by arbitrage. This would indicate that market particpants are constrained in their execution of arbitrage.

The hubs covered in this study are relatively well connected and the good traded is indeed homogeneous, therefore gas prices at the NBP, TTF and the Zeebrugge hub should not deviate much from each other. A more intuitive explanation may be that if a spot gas contract of similar maturity at another hub trades at a significantly higher price, gas would flow to the higher priced market, therefore increasing supply and decreasing prices in that market.

4.2. Intertemporal cointegration

There are several theoretical models in the literature that explain the relationship between spot and forward prices of commodities. The actual relationship between spot and forward prices depends on factors such as the storability of the commodity, its relative importance in the world economy, seasonal factors, market expectations and the random realization of news. It should be noted that the relationship between spot and forward markets is of long-run rather than short-run nature.

In the short-run to shocks or occurrences such as thin trading (low trading frequency), lags in information transmission, insufficient inventory levels, seasonal patterns of consumption or other factors, there might be deviations from the long-run equilibrium between spot prices and forward prices. In the long-run, it can be argued that spot and forward prices are driven by the same fundamentals such as interest rates, macroeconomic variables and the price of other commodities as the underlying asset of spot and forward contracts is the same. This relationship can be tested by examining whether spot and futures prices are cointegrated. (Maslyuk & Smyth, 2009)

Examination of the relationship between spot and forward prices is often based on the following model:

$$S_t = \alpha + b_1 F_t + \epsilon_t \qquad (2)$$

In equation 2, $\mathrm{S_t}$ is the spot price and $\mathrm{F_t}$ is the forward contract maturing at time t and ϵ_t is an error term with mean zero. A theory that dominates the spot and forward literature is the theory of storage. To incorporate the theory of storage, the constant in equation 2 should contain the time-invariant spread between forward and spot prices that can be assigned to the convenience yield, storage costs and the interest rate. There is a convenience yield from holding commodities because these can be inputs to the production of other commodities (such as electricity) or because they can be used to meet unexpected demand (Nick, 2013).

The theory of storage suggests that spot and forward markets for storable commodities are linked through transactions of market participants optimizing their portfolios intertemporally, resulting in a stable long-run relationship between these markets (Nick, 2013). It should be clear that gas storage and the ability to inject gas into storage facilities or withdraw gas from the storage facilities is crucial for intertemporal optimisation. Flexible storages presumably withdraw gas from their storage facility when demand and spot prices are relatively high and inject gas into their storage facility when demand and spot prices are relatively low (Nick & Thoenes, 2013).

The corresponding cost-of-carry hypothesis states that deviations from the spot-forward equilibrium are only of temporary nature, as arbitrage should restore the long-run relationship. The cost-of-carry condition is characterized by the equivalence of the price of a forward contract F(T,t) in period t with the delivery in period T and the compounded spot price St(1 + $r_{T,t}$) plus the storage costs $W_{T,t}$, adjusted for the convenience yield $C_{T,t}$. The long-run condition that arises based on this theory is:

$$F_{T,t} = S_t(1 + r_{T,t}) + W_{T,t} - C_{T,t} \qquad (3)$$

As such, in the theory of storage the difference between contemporaneous spot and forward prices is explained by interest foregone in storing a commodity, storage costs and the convenience yield (Fama & French 1987).

4.3. Dynamics of spot and forward prices and price discovery

While the previous subsection has set out why a long-run equilibrium between spot and forward prices is expected, there are differences in the price dynamics of spot versus forward markets. While such contracts have the same underlying asset, the spot market is likely to be driven by short-term developments to a higher extent than forward prices. Such short-term drivers are for example shocks in the temperature, shocks in pipeline-infrastructure availability and shocks in supply. With respect to the natural gas market in Europe, Swieringa (2012) already noted that prices further down the forward curve seemed less sensitive to shocks in demand caused by unexpectedly higher temperatures. Due to the fact that the spot market is more reactive to short-term disturbances the forward market may be more efficient in processing information and may better and faster reflect relevant information. As such, the forward market may lead the price discovery process for the same underlying asset. In that case, price discovery takes place in the forward or futures market and the price signal is subsequently transmitted to the spot market (Nick, 2013).

5. Data

The data in this study entail spot and forward contract prices of three gas hubs in Europe. The covered hubs comprise the NBP, the TTF and the Zeebrugge hub. The forward contracts examined in this study comprise the month ahead, quarter ahead and year ahead contract. The selection of hubs is limited by the number of hubs of which data is freely available. The data covers the period from the beginning of January 2008 until the end of September 2012 on a daily basis, yielding 1239 observations. The reasons for analysing forward rather than futures prices are twofold. Firstly, the OTC market still dominates the futures market for natural gas in terms of volume and thus its importance to the natural gas market in Europe. Secondly, data on futures markets is less widely available. For instance, the Zeebrugge hub, which is of primary importance in this study due to its pipeline connection to the NBP has no futures data available. Petrovich (2013) has established that the correlation between futures and OTC forward prices is very high, both in the spot and month ahead markets, and therefore conclusions from this study may be applicable to the futures market as well.

Spot and forward contracts at Zeebrugge and NBP are reported in pence sterling per therm whereas prices at TTF are reported in Euro per megawatt hour (MWh). In this study all prices are expressed in Euro per megawatt hour (Eur/MWh), as this is the standard in Continental Europe and enables more straightforward interpretation. According to ICIS[2] the appropriate conversion factor is 1 therm per 0.0293 MWh. The conversion of pence sterling to Euro is done on basis of the daily exchange rate as published by the European Central Bank[3].

In this study the prices as reported by Thomson Reuters are used, which are available on Datastream (mnemonics are attached as appendix I). These are indices that reflect the volume weighted average price of all trades executed via the OTC trading platform at a specific day. What is referred to as the spot contract in this study actually compromises the day ahead contract (which is regular practice in the literature). The day ahead contract is for delivery the next working day. On Friday, day ahead refers to the following Monday. In case the next working day is a public holiday, day ahead refers to the next working day. Month ahead contracts are for delivery the next month. For example, between 01-01-2008 and 31-01-2008 the month ahead contract trades for delivery of gas between 01-02-2008 and 28-02-2008. The quarter ahead contracts are for delivery the next quarter. The quarters compromise the three-month periods beginning on 1 January, 1 April, 1 July and 1 October. For example, between 01-01-2008 and 31-03-2008 the quarter ahead contract trades for delivery of gas

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[2] http://www.icis.com/energy/gas/europe/spot-market-methodology/

[3] http://www.ecb.europa.eu/stats/exchange/eurofxref/html/eurofxref-graph-gbp.en.html

between 01-04-2008 and 30-06-2008. The year ahead contract follows the same principle. For example, between 01-01-2008 and 31-12-2009 the year ahead contract trades for delivery of gas on working days between 01-01-2009 and 31-12-2010.

5.1. Descriptive statistics of level price series

To obtain understanding of the data it is relevant to conduct a comparison both across the three hubs and across contracts of different maturities. The descriptive statistics displayed in table 3 are addressed in the order in which they are displayed. To structure this subsection, each aspect of the descriptive statistics is first compared across hubs and then across contracts of different maturity that trade on the same hub. When relevant, additional background information is provided. Figures displaying the price series at each hub are attached in Appendix II.

Table 3. Descriptive statistics level price series

	National Balancing Point				**Title Transfer Facility**				**Zeebrugge**			
	Spot	**Month ahead**	**Quarter ahead**	**Year ahead**	**Spot**	**Month ahead**	**Quarter ahead**	**Year ahead**	**Spot**	**Month ahead**	**Quarter ahead**	**Year ahead**
Mean	19,81	20,22	21,70	24,38	20,04	20,56	21,79	24,06	20,00	20,43	21,84	24,27
Median	21,82	22,27	22,31	24,43	22,05	22,42	22,63	24,58	22,04	22,31	22,72	24,70
Maximum	41,31	38,82	42,29	43,75	37,75	36,15	40,90	42,12	32,42	39,76	41,96	43,70
Minimum	4,42	7,09	10,37	12,05	7,10	7,84	10,45	11,69	5,74	7,44	10,59	12,04
Std. Dev.	5,90	6,16	7,16	6,17	5,74	6,09	6,89	5,84	5,90	6,25	7,06	6,25
Skewness	-0,51	-0,26	0,49	0,66	-0,60	-0,35	0,24	0,57	-0,57	-0,28	0,44	0,68
Kurtosis	2,36	2,37	3,20	3,72	2,29	2,28	2,77	3,49	2,27	2,35	3,14	3,57
Jarque-Bera	75,35	34,13	52,41	115,94	99,38	52,37	14,68	78,66	94,82	38,30	40,13	112,72
Probability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

The mean and median prices for the spot contracts and the forward contracts of similar maturity are all close to each other. This provides an indication that the three natural gas markets are well integrated over the period sampled. The latter is confirmed by several studies, e.g. Leykam (2008), Neumann, Siliverstovs and von Hirschhausen (2006) and Gianfreda, Grossi and Carlotto (2012).

There are clear differences in both the mean and the median of contracts of different maturity, at each of the gas hubs the contracts of longer maturity tend to have a higher maximum and median price. This is also clear from the graphs in appendix II, which clearly show that the forward contract prices tend to be higher than the spot prices over the entire sample period. This indicates that the market is generally in contango over the period examined (Pindyck, 2001).

Again comparing across hubs, maximum prices of the forward contracts are generally higher at the NBP and the Zeebrugge hub than at the TTF. However, the maximum spot price is substantially higher at the NBP and TTF than at the Zeebrugge hub. These high spot prices at the NBP and TTF occurred in February 2012 and were caused by the so-called “Russian gas supply crisis” when Russia was not able to meet the requested supply of gas in Europe due to an unexpectedly cold winter both in Europe and in Russia itself, a situation which lasted approximately 2 weeks (Henderson & Heather, 2012). However, this situation did not affect the spot prices at the Zeebrugge hub as much as the NBP and the TTF. Furthermore, the graphs in appendix II show that forward prices were barely affected by the “Russian gas supply crisis”.

The graphs in appendix II display it is usually the case that when the spot prices experience a shock, the forward prices not necessarily experience that shock to the same extent. This is particularly true for the quarter and year ahead contracts. An illustrative example of this is the downward spike that occurs around July 2008. In July 2008 the spot prices experience a sudden drop. The month ahead prices move in the same direction, but to a lesser extent, while the quarter and year ahead prices react to an even lesser extent. The downward spike in July 2008 occurs close to the fall of Lehman Brothers during the financial crisis. Nick and Thoenes (2013) also reported that the German gas price was significantly affected by this event. Therefore, the price drop observed at the NBP, Zeebrugge hub and the TTF may be related to the financial crisis. However, in the same period the Brent oil price experienced a severe drop, which may also be responsible for the gas price movements during this period. A graph of the Brent oil price is attached as appendix III. The pattern of the gas prices quite resembles the general pattern that the Brent price follows.

Consistent with the observation that longer maturity contracts have a higher mean and median price, longer maturity contracts also exhibit a higher maximum price. With the exception of the extraordinarily high spot prices at the NBP and TTF, which were merely the consequence of a shock due to the Russian gas supply crisis.

A comparison of minimum prices across hubs, shows that the spot price at the NBP is lower relative to the other two hubs. This minimum of the NBP spot price occurred in September 2011. As such, it is most likely to be caused by the Interconnector maintenance shutdown that occurs in this month. The effect of the Interconnector maintenance shutdown on prices is discussed in section 6. Minimum forward prices tend to be of the same magnitude across hubs. Comparing minimum prices across contracts, the same pattern as for maximum prices holds as minimum prices are, without exception, higher for longer maturity contracts.

An examination of the standard deviation reveals a similar pattern across the three hubs. The quarter ahead forward contract tends to exhibit the highest amount of volatility. The spot price tends to exhibit the least amount of volatility and month and year ahead forward contracts are in between the volatility of the spot and quarter ahead forward. This goes against the observation of Swieringa (2012), who stated that prices further out the forward curve in the gas market are generally less volatile.

An examination of the graphs in appendix II reveals that there seems to be a structural break with regard to volatility as of mid-2010. The period between January 2008 and June 2010 is much more volatile than the period between June 2010 and September 2012. Due to limitations in data availability for the contracts examined in this study the period before 2008 is not examined.

The skewness measure reveals a similar pattern across the gas hubs, with a negatively skewed distribution of spot and monthly forward prices while the quarterly and yearly contracts are positively skewed. The kurtosis measure reveals that the quarter and year ahead contracts, with the exception of the quarter ahead contract at the TTF, tend to display excess kurtosis, which indicates heavy tails and peakedness relative to the normal distribution. While the spot contracts and the shorter maturity forward contracts tend to display negative kurtosis, which indicates light tails and flatness. The null hypothesis of the Jarque-Bera test, which is a joint hypothesis of the skewness and the excess kurtosis being zero, can be rejected for each of the contracts at each hub. Therefore, prices are not normally distributed.

Table 4. Unit root test level price series

	National Balancing Point				**Title Transfer Facility**				**Zeebrugge**			
ADF-test	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year
AIC lag length	17	22	0	1	13	14	3	9	14	11	3	1
t-statistic	-1,68	-1,92	-1,54	-1,29	-1,59	-1,37	-1,4	-1,57	-1,49	-1,42	-1,45	-1,3
Probability	0,44	0,32	0,52	0,63	0.49	0,60	0,58	0,50	0,54	0,57	0,56	0,63
Phillips-Perron												
Newey-West Bandwidth	16	15	7	8	4	14	6	4	10	4	6	6
Adjusted t-statistic	-2,29	-1,73	-1,5	-0,14	-0,74	-0,32	-0,36	-0,45	-0,58	-0,44	-0,36	-0,11
Probability	0,18	0,42	0,54	0,63	0,4	0,57	0,56	0,52	0,47	0,52	0,56	0,65

The Augmented Dickey-Fuller (ADF) test is not able to reject the null hypothesis that any of the level price series have a unit root, as is displayed in table 4. The lag selection is based upon minimisation of the Aikake Information Criterion (AIC). The number of lags selected for the spot and the month ahead forward contracts the number of lags selected is quite high at each of the three hubs. The AIC tends to select a rather small number of lags for both the quarter and year ahead contracts. Further examination indicates that a higher number of lags does not lead to rejection of the null hypothesis for each of these contracts. The Phillips-Perron confirms the results of the ADF test.

Table 5. Unit root test log price series

	National Balancing Point				**Title Transfer Facility**				**Zeebrugge**			
ADF-test	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year
AIC lag length	21	3	0	0	1	7	3	9	12	7	4	1
t-statistic	-1,49	-1,48	-1,47	-1,31	-2,11	-1,37	-1,28	-1,69	-1,39	-1,49	-1,25	-1,36
Probability	0,53	0,54	0,55	0,63	0,24	0,59	0,64	0,44	0,58	0,54	0,65	0,60
Phillips-Perron												
Newey-West Bandwidth	28	14	3	8	0	11	2	2	10	3	8	3
Adjusted t-statistic	1,97	1,51	1,43	-1,40	-2,48	-1,32	-1,43	-1,46	-1,99	-1,58	-1,39	-1,33
Probability	0,31	0,53	0,57	0,58	0,12	0,63	0,57	0,56	0,29	0,49	0,59	0,62

The ADF and the Phillips-Perron test on the log data confirm the results of the tests on the level price data, which is displayed in table 5.

Table 6. Unit root test first differenced price series

	National Balancing Point				Title Transfer Facility				Zeebrugge			
ADF-test	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year	Spot	Month	Quarter	Year
AIC lag length	16	22	0	0	12	13	2	8	13	22	2	0
t-statistic	-10,25	-5,88	-35,05	-33,13	-12,83	-9,05	-21,57	-10,12	-12,61	-5,85	-22,53	-31,53
Probability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Phillips-Perron												
Newey-West Bandwidth	21	17	8	7	2	14	5	5	9	4	6	2
Adjusted t-statistic	-39,76	-37,81	-35,06	-33,19	-43	-34,17	-35,81	-39,06	-37,35	-46,2	-35,32	-31,54
Probability	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Lastly, the unit root tests on the first differences data confirm that all series are I(1), as is being displayed in table 6. First-difference stationarity is a typical characteristic of financial time series. This is an important observation as it means the series can be analysed in a cointegration framework.

5.2. Examination of seasonal patterns in level price series

Analysis of the average price per weekday shows there is no day of the week effect for any contract at any gas hub as the average price per weekday, measured over the entire sample period is approximately equal for each day of the week. Appendix IV contains the figures that display this.

Analysis of the average price per month reveals a strong seasonal pattern, which is rather consistent across the gas hubs. Each contract has its own typical seasonal pattern. The seasonal patterns are displayed in figure 2, 3 and 4.

Figure 2. Average monthly prices at the NBP

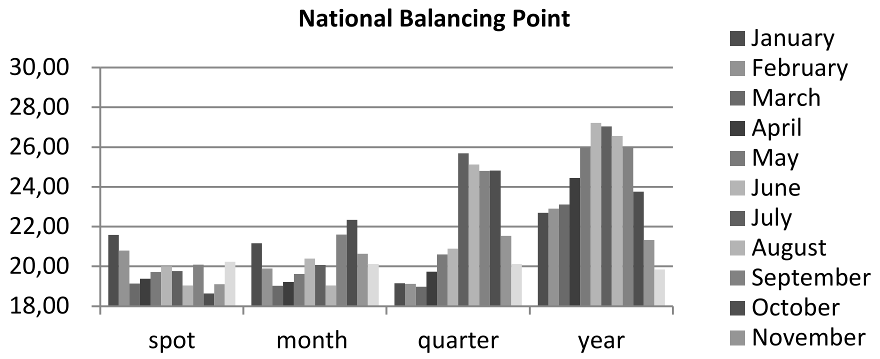


Figure 3. Average monthly prices at the TTF

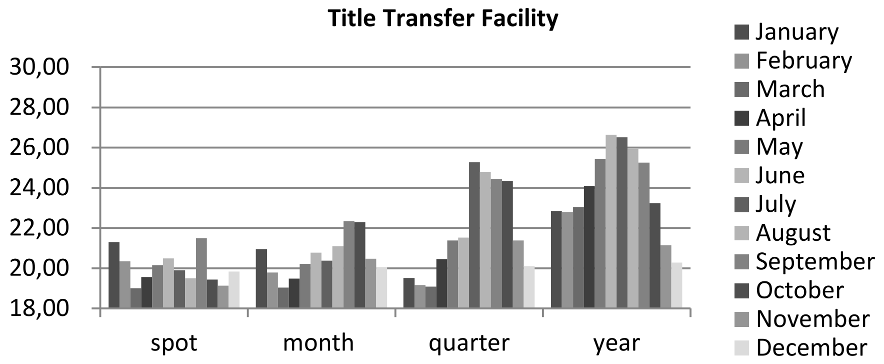
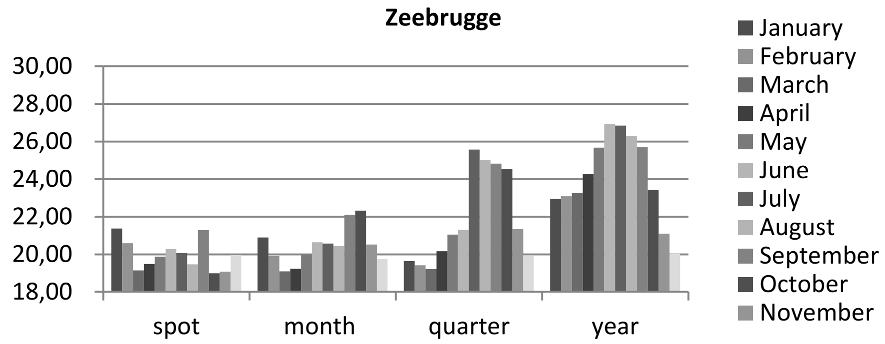


Figure 4. Average monthly prices at the Zeebrugge hub



The spot price tends to be higher in January, February and December. These months are the colder months of the year and as such demand for gas is higher, which drives up the price. Furthermore, the spot price tends to display a spike in the average price in October, however this is more apparent for Zeebrugge and the TTF. The month ahead forward price tends to be higher in October and November across all three hubs, which is no surprise as this compromises the months prior to the start of the winter. The NBP exhibits a substantially lower average month ahead price in August. This is addressed in section 6 as this constitutes the contract that delivers gas during the maintenance shutdown of the pipeline that connects the NBP with the Zeebrugge hub. After the winter, between March and August, month ahead forward prices are depressed. The quarter ahead contracts display a very similar and strong pattern across the gas hubs as the price of this contract tends to be higher between August and October. This constitutes the time when contracts for the first and the fourth quarter of the year are trading, which are the coldest quarters of the year. The year ahead contracts tend to exhibit higher price levels between April and September. It is hard to relate these price increases to the high demand winter period. It could be that the year ahead contracts are affected by the price increases that occur in the quarter ahead contracts, which occur approximately in the same period.

The different seasonal patterns of natural gas contracts with different maturities is recognised be the commodity exchange operator CME group[4], which states that this causes natural gas prices to often deviate from the cost-of-carry relationship described in the theoretical framework.

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[4] http://www.cmegroup.com/trading/energy/files/PM203-Seasonality-and-Storage.pdf

6. Intermarket cointegration and the role of pipelines

As mentioned, previous studies have generally established that spot prices at different hubs are cointegrated, e.g. Leykam (2008), Neumann, Siliverstovs and von Hirschhausen (2006) and Gianfreda, Grossi and Carlotto (2012). While these studies also focus on OTC prices, none of these studies have confirmed whether intermarket cointegration is the case for longer maturity contracts as well. This is an odd observation as the forward market is of major importance to the natural gas market. This has been confirmed by figure 1 in section 2 which displayed that mid-term and long-term contracts constitute approximately 50% of the number of transactions executed at the TTF and NBP and approximately 30% at the Zeebrugge hub. Figure 1 also indicated that approximately 90% of the natural gas volume that is traded on these hubs is traded under mid-term and long-term contracts. Furthermore, it has been addressed that availability of pipeline capacity is essential for the co-movement of spot markets but it has not been established whether this is the case for forward markets as well. Section 6 seeks to answer the following questions that address these deficiencies in the current literature:

1. Are gas prices of spot contracts traded at the hubs covered in this study cointegrated?
2. Are gas prices of longer maturity contracts trading at the hubs covered in this study cointegrated?
3. Does a pipeline shutdown cause decoupling of spot prices at the markets it connects?
4. Does a pipeline shutdown cause decoupling of forward prices at the markets it connects?

The first two questions mainly derive their relevance from their implications for the evaluation of European Union policy goals of gas market integration. The third and fourth question have implications for the suitability of spot and forward prices to function as benchmark price. In this section results are interpreted but the actual implications of these results are addressed in the concluding remarks, section 8.2. The first two research questions are addressed in subsection 6.1. The third and fourth research questions are preliminarily addressed in subsection 6.1 and empirically tested in subsection 6.2. Subsequently, subsection 6.3 explains how the findings with regard to research question 3 and 4 are explained by supply and demand dynamics in the natural gas market. Subsection 6.4 summarises the answers to questions 3 and 4. Subsection 6.5 seeks to verify certain results from subsection 6.1.

6.1. Intermarket cointegration analysis

6.1.1. Intermarket cointegration methodology

The concept of cointegration was developed by Engle and Granger (1987). It states that for two time series, both integrated of order n, with n greater or equal to one, there may exist a linear combination of these series that is integrated of order n − 1. To investigate cointegration this study applies the procedure proposed by Johansen (1991). The Johansen test provides more efficient estimates of the cointegrating relationship than the Engle and Granger test (Gonzalo, 1994). Johansen (1991) tests are shown to be fairly robust to presence of non-normality and heteroskedasticity disturbances (Srinivasan, 2011). The trace test is a joint test of which the null hypothesis is that the number of cointegrating vectors is less than or equal to *r*, against a general alternative hypothesis that there are less than *r* cointegrating vectors. The cointegration analysis is conducted on hub pairs (on bivariate basis) of similar maturity. As such, if markets are cointegrated it is expected to find r = 1 for each market pair. The results of this procedure are addressed in subsection 6.1.2.

If prices at hubs are found to be significantly cointegrated, the relationship between these hubs is to be examined by means of an error correction model. Estimation of an error correction model enables the examination of the cointegrating relationship over time. This should provide insight into whether the spot prices at the different hubs pairs indeed decouple when the pipeline that connects them shuts down and whether the forward prices are affected in a similar manner or not. The error correction models that are estimated have the following representation:

$$\begin{aligned} \Delta NBP_t &= \beta_{NBP,i}(NBP_{t-1} - \theta ZEE_{t-1}) + \sum \alpha_{NBP,i}\Delta NBP_{t-i} + \sum \gamma_{NBP,i}\Delta ZEE_{t-i} + e_t \\ \Delta ZEE_t &= \beta_{ZEE,i}(ZEE_{t-1} - \theta NBP_{t-1}) + \sum \alpha_{ZEE,i}\Delta ZEE_{t-i} + \sum \gamma_{ZEE,i}\Delta NBP_{t-i} + e_t \end{aligned} \tag{4}$$

As an example, the variables NBP and ZEE refer to the price series at the NBP and the Zeebrugge hub, respectively. The model is actually estimated for each hub pair. The error correction coefficient $\beta_{hub,i}$ measures the speed of adjustment to the equilibrium. The other terms compromise the lagged first differences of both variables. The model is estimated twice for each hub pair, once with the spot price series of each hub pair and once with the forward price series of each hub pair. The results of this procedure are addressed in subsection 6.1.3.

6.1.2. Cointegration results and interpretation

Table 7 displays the results of the Johansen test for cointegration between contracts of similar maturity traded at different hubs. The answer to research question 1: “Are gas prices of spot contracts traded at the hubs covered in this study cointegrated?” is clear as the Johansen test indicates that spot prices at different hubs are indeed cointegrated, as it indicates there is one cointegrating relationship for each market pair.

The answer to research question 2 “Are gas prices of longer maturity contracts trading at the hubs covered in this study cointegrated?” is less straightforward as results are rather different at each maturity level.

The Johansen test indicates each hub pair in the month ahead market is cointegrated. In the month ahead market the trace statistic belonging to r=0, indicating no cointegrating relationship, is significantly higher than the critical value in each case. However, in the quarter ahead and year ahead market the trace statistic is either just above or just below the trace statistic. In three cases the Johansen test indicates no cointegrating relationship. As such it can be concluded that cointegration between prices of hub pairs is stronger in the spot and the month ahead market compared to the quarter and year ahead market. To emphasize the robustness of the results it should be noted that for each hub pair the cointegration rank test was also tested for significance based on the maximum eigenvalue statistic. In all cases this yields the same number of cointegrating relationships.

Table 7. Johansen test for intermarket cointegration

Market pair		Trace Statistic	0.05 Critical Value	Prob.	Implication
			Spot market		
NBP-Zeebrugge	r = 0	56,56	25,87	0,00	1 cointegrating relationship
	r ≤ 1	6,85	12,52	0,36	
TTF-Zeebrugge	r = 0	79,95	25,87	0,00	1 cointegrating relationship
	r ≤ 1	6,81	12,52	0,36	
NBP - TTF	r = 0	68,11	25,87	0,00	1 cointegrating relationship
	r ≤ 1	6,84	12,52	0,36	
			Month ahead market		
NBP-Zeebrugge	r = 0	32,32	25,87	0,00	1 cointegrating relationship
	r ≤ 1	3,87	12,52	0,76	
TTF-Zeebrugge	r = 0	61,04	25,87	0,00	1 cointegrating relationship
	r ≤ 1	3,71	12,52	0,78	
NBP - TTF	r = 0	53,05	25,87	0,00	1 cointegrating relationship
	r ≤ 1	3,48	12,52	0,82	
			Quarter ahead market		
NBP-Zeebrugge	r = 0	35,71	25,87	0,00	1 cointegrating relationship
	r ≤ 1	2,71	12,52	0,91	
TTF-Zeebrugge	r = 0	25,99	25,87	0,02	1 cointegrating relationship
	r ≤ 1	2,56	12,52	0,92	
NBP - TTF	r = 0	21,13	25,87	0,17	no cointegrating relationship
	r ≤ 1	2,28	12,52	0,95	
			Year ahead market		
NBP-Zeebrugge	r = 0	14,17	25,87	0,64	no cointegrating relationship
	r ≤ 1	1,97	12,52	0,97	
TTF-Zeebrugge	r = 0	35,49	25,87	0,00	1 cointegrating relationship
	r ≤ 1	2,22	12,52	0,95	
NBP - TTF	r = 0	18,29	25,87	0,32	no cointegrating relationship
	r ≤ 1	2,46	12,52	0,93	

There are two exceptions with respect to the weak intermarket cointegration in the quarter ahead and year ahead markets. These exceptions are the cointegrating relationship between quarter ahead contracts at the NBP and Zeebrugge hub and the year ahead contracts at the TTF and Zeebrugge hub, as in those specific market pairs the null hypothesis of r=0 is rejected with a high trace statistic.

Nevertheless, in general there seems to be a weaker cointegrating relationship between the quarter and year ahead prices compared to the spot and month ahead prices. Figure 1 in section 2 displayed that the number of transactions in the spot and the month ahead market constitute a large share of the total number of transactions taking place, which indicates that these are the most liquid contracts at each of the hubs. Figure 1 also indicated that the number of transactions in the quarter and year ahead markets is substantially smaller than the number of transactions in the short-term markets. This indicates that a smaller number of market participants may be active in the longer maturity markets. It is likely that these mostly compromise large incumbent players as it was explained in section 2 that the longer maturity contracts on average cover a substantially larger amount of underlying natural gas relative to the shorter maturity contracts. It seems reasonable to assume that particularly the large utilities require such amounts of gas to be delivered. The lack of competition and thin trading are a likely cause of illiquidity in the longer maturity markets. The theoretical framework explained that if prices at two hubs lie within stable arbitrage limits, the spread between these prices is stationary and the series are cointegrated (De Vany & Walls, 1993). However, thin trading in the longer maturity markets may cause prices at different hub pairs to be able to deviate from each other without arbitrage trading eliminating the price difference.

Furthermore, the nature of the OTC market may contribute to the finding of no or weak cointegration between the longer maturity contracts traded at different hub pairs. In the introduction it was explained that participants in the OTC market are exposed to a certain amount of counterparty risk and have to incur negotiation costs. It was also explained in section 2 that the longer maturity contracts on average cover a substantially larger amount of underlying natural gas relative to the shorter maturity contracts. It is reasonable to assume that when transactions involve larger amounts of gas, the parties involved have to negotiate more specific or stringent contract terms and will have to include clauses to reduce counterparty risk. Such terms may be party and transaction specific. It is likely that the exactly negotiated contract terms and the amount of counterparty risk a party is expected to be exposed to, affects the price of the gas that is exchanged. Especially since the amount of trades in the longer maturity contracts is relatively low such transaction specific characteristics could affect the reported prices by OTC brokers. The lack of full standardisation in OTC contracts may also make this market less suitable to execute arbitrage strategies. Lastly, It may also preclude market participants to trade such a contract multiple times amongst each other before physical delivery occurs.

While it does not seem counterintuitive that the longer maturity prices are weaker cointegrated due to the lower number of trades and certain characteristics of the OTC market, it is questionable whether it is justified to conclude that the spread between prices of longer maturity contracts at different hub pairs is really unbounded. Especially since the inspection of the level price series indicated that the mean prices of the longer maturity contracts were all quite close to each other. It seems likely that when the spread between the longer maturity contracts trading at different hubs becomes sufficiently large, market participants will exploit the difference in prices and the differential will decrease. However, this certainly occurs to a lesser extent than in the well cointegrated spot and month ahead markets.

6.1.3. The role of pipeline capacity in intermarket cointegration

The fact that natural gas is primarily transported by pipelines is a distinctive feature of the natural gas market relative to other commodity markets. Pipeline capacity plays an important role in the co-movement of the prices in the markets it connects. It is examined whether a pipeline shutdown breaks the co-movement of forward prices at the hubs it connects in the same manner as it breaks the co-movement of the spot prices at the hubs it connects.

6.1.3.1. Introduction to the pipelines

The United Kingdom, being an island, is connected to Western Europe by two pipelines as displayed in figure 5.

Figure 5.The pipelines connecting the NBP with the Zeebrugge hub and the TTF

The Interconnector pipeline connects the NBP with the Zeebrugge hub. The Interconnector allows for bidirectional gas flows. Two weeks a year the Interconnector pipeline shuts down for maintenance. Maintenance usually occurs in September or another summer month, when gas demand is relatively low. The NBP is connected to the TTF by the BBL pipeline. The BBL pipeline only allows for physical transportation of gas from the TTF to the NBP. As of 2011 the BBL pipeline allows for virtual gas flows in the reverse direction but this constitutes only a very small capacity compared to the physical reverse flow capacity of the Interconnector pipeline. Maintenance on the BBL pipeline usually takes place in the month before or after the Interconnector maintenance and lasts six days. The public availability[5] of the maintenance periods creates the opportunity to study the effect of a pipeline shutdown on cointegration between spot prices and cointegration between forward prices.

It is well known that the Interconnector has an active market for transportation rights, which allows transporters on these markets to react quickly to price movements (Petrovich, 2013). On the contrary, a large part of the flow capacity of the BBL is attributed to gas deliveries under long-term contractual arrangements, which decreases the reactivity of the transporters to price movements (European Commission, 2012b). The extent to which users of a pipeline are able to react to price differences between the hubs that the pipeline connects, is referred to as the efficiency of that pipeline. In that sense, the BBL pipeline is of low efficiency while the Interconnector is of higher efficiency.

A priori it seems likely that the effect of a pipeline shutdown on co-movement of spot prices is more pronounced than the effect on co-movement of forward prices. In the spot market participants are able to directly profit from a prevailing price difference between two markets by transporting their gas to a higher priced area. The ability to execute this arbitrage directly depends on pipeline availability. In the case of efficient pipeline operation gas flows from the lower priced area to the higher priced area and a price differential would not persist (Northwest European gas industry stakeholders, 2012), which causes co-movement of spot prices. If a pipeline shuts down, the ability to directly profit from a price differential between to areas is diminished except if there are other pipelines that connect the areas. However, an investigation of the Northwest European gas industry stakeholders (2012) stated that the dominance of long-term contracts for cross-border trade means that the majority of gas transported across the pipelines is not likely to be priced according to spot markets and flows may thus be determined by strategies not related to short-term prices. Therefore, the effect of a pipeline shutdown on co-movement may even be weak in the spot market.

Whether there is any effect of the maintenance period on the forward market is even less clear a priori. For example, the maintenance shutdown of the Interconnector generally occurs in the first two weeks of September. Naturally, month ahead contracts for delivery in September trade in

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[5] BBL pipeline maintenance periods: http://www.bblcompany.com/flow-information/historicflow
Interconnector maintenance periods: http://www.interconnector.com/operational-data/planned-maintenance/

August. The physical delivery period of the month ahead contract that trades in August extends the shutdown period, as the pipeline is already operating during the second half of September. However, market participants will definitely be constrained in their ability to transport gas across the Interconnector when they receive their gas in September. The month ahead contracts that trade during the shutdown in September are for physical delivery in October, which is the first full month of operation after the September shutdown. Because the period that a forward contract trades and its delivery period are more disconnected than in the spot market, co-movement of forward prices seems somewhat less dependent upon the direct availability of pipeline capacity than co-movement of spot prices. On the other hand, subsection 4.2 of the theoretical framework has explained that the spot and the forward markets are linked due to a no arbitrage condition. As such, disturbances in the spot market may also affect the forward market.

6.1.3.2. Error correction in the intermarket relationship

In subsection 6.1.2 it has been established that spot and month ahead prices at different hubs are cointegrated, which implies these contracts can be analysed in an error correction framework. The quarter and year ahead price series are not analysed as not all the hub pairs are cointegrated at these maturities. The consequences of this limitation are not serious as it seems likely that conclusions regarding the effect of pipeline capacity on co-movement of month ahead prices can be extended to forward markets of longer maturity. It should be noted that the error correction models in this subsection are estimated because this is necessary in order to obtain the cointegrating relationships. While the examination of the cointegrating relationship is the primary goal of section 6.1, this subsection reviews the implications of the estimates of the error correction models.

Table 8 displays the results of the bivariate error correction models (equation 4), the coefficients of the lagged endogenous variables are not displayed to preserve space. The model diagnostics indicate that all models are stable as both error correction models indicate that one inverse root of the characteristic AR polynomial is equal to 1 and other roots have a modulus of less than 1 (Lütkepohl, 1991). However, the autocorrelation LM test, up to twenty lags, cannot reject the null hypothesis of no autocorrelation at a few of the higher lag orders for pair 5. Unfortunately, the latter is not resolved by estimating a model with higher lag orders for this pair.

While interpretation of the error correction coefficients is of no value to the examination of the role of pipeline capacity, it does provide insight into which hub is leading the other in the price discovery process. This is relevant because a current discussion relates the question which hub should be used as benchmark price for long-term contracts. Price discovery is a process that is expanded upon in section 7 but at this point it is sufficient to understand that the hub that makes the largest adjustment towards the long-run equilibrium is following the other hub in the price discovery process.

Table 8. Results of VECM for hub pairs in the spot and month ahead market

		Market	Error correction coefficient	Prob.	Stability	No Autocorrelation	Implication
Pair 1	NBP Zeebrugge	Spot	-0.20 -0.01	0.00 0.87	Yes	Yes	NBP adjusts towards Zeebrugge
Pair 2	TTF Zeebrugge	Spot	-0.09 0.21	0.07 0.00	Yes	Yes	Zeebrugge adjusts towards TTF
Pair 3	NBP TTF	Spot	-0.12 0.02	0.00 0.55	Yes	Yes	NBP adjusts towards TTF
Pair 4	NBP Zeebrugge	Month ahead	-0.13 0.01	0.00 0.79	Yes	Yes	NBP adjusts towards Zeebrugge
Pair 5	TTF Zeebrugge	Month ahead	0.01 0.23	0.77 0.00	Yes	No	Zeebrugge adjusts towards TTF
Pair 6	NBP TTF	Month ahead	-0.13 -0.03	0.00 0.02	Yes	Yes	NBP adjusts towards TTF

The finding that gas prices at the NBP adjust towards gas prices at the Zeebrugge hub is quite counterintuitive. As explained earlier, traded volumes on the Zeebrugge hub are relatively small. Furthermore, it is primarily used to transport gas for onward transportation making the Zeebrugge hub a mere intermediary between the NBP and the rest of Europe. Another rather surprising finding is that the NBP adjusts towards the TTF. Studies (e.g. Gianfreda, Grossi & Carlotto, 2012) usually hypothesize that other hubs adjust towards the NBP as this is the most liquid hub. However, the TTF has experienced much growth and is better connected with hubs located in the European mainland and therefore it may have obtained an important role in the price discovery process. Furthermore, Petrovich (2013) found that process at European hubs exhibit the highest and most stable correlation with the TTF, which also points to the significance of the TTF in the hub network.

The fact that the results of the error correction model indicate that the NBP is adjusting towards the TTF and Zeebrugge can be interpreted several ways. It could indeed indicate that prices at the NBP adjust towards prices in the European mainland. Another explanation of the findings could be that deviations arise at the NBP due to the pipeline closure after which prices at the NBP have to readjust to prices at the European mainland. Therefore, the annual pipeline shutdowns may affect the results. If examination of the cointegrating relationship indeed indicates substantial deviations from the long-run equilibrium during the pipeline shutdown, it makes sense to assess whether the estimates presented in table 8 are different after excluding the shutdown periods.

6.1.3.3. Examination of the cointegrating relationship between spot market pairs

The cointegrating relationships based on the error correction model 4 are examined in this subsection. This is done to address research question 3: “Does a pipeline shutdown cause decoupling of spot prices at the markets it connects?". Figure 6, 7 and 8 display the cointegrating relationships between spot prices of each hub pair. Each figure indicates when the Interconnector pipeline was shut down for maintenance.

Before addressing the deviations during the maintenance period, it is worthwhile to address general differences and similarities between the intermarket cointegrating relationships. The cointegrating relationship between the NBP and Zeebrugge generally displays the least deviations from the long run equilibrium relationship and tends to oscillate around 0. There are barely any long periods where the relationship deviates from its equilibrium. This is in line with the study by Neumann, Siliverstovs and von Hirschhausen (2006) which finds near perfect convergence in spot prices of these two hubs.

The cointegrating relationships between the NBP and TTF and between the TTF and Zeebrugge are less stable. These cointegrating relationships deviate much more from 0 and in some cases also over a longer period. This indicates the spot price linkages between these hubs are less strong than the linkage between the NBP and Zeebrugge hub. This is in line with Leykam's study (2008), which finds weak co-movement between the TTF and the NBP spot prices. However, during the time period that Leykam considers, the TTF and the NBP were not yet directly connected by the BBL pipeline. Subsection 6.3 aims to explain why the BBL might be less important in the connection between the hubs, which could explain why the connection between the TTF and the NBP is still rather weak.

Especially the cointegrating relationships between the NBP and TTF and between the TTF and Zeebrugge display many deviations from the long-run equilibrium between July 2008 and March 2009. As mentioned before, gas prices at all three hubs displayed a severe drop in July 2008. Nick and Thoenes (2013) observe a similar development with respect to the German gas price and relate this to the outbreak of the global financial crisis. However, during this period the Brent oil price also experienced large movements (see appendix III), which is likely to affect the gas market as most market participants also procure a large proportion of their gas under oil-linked contracts. So while it is not possible to pin down the cause it should be noted that the volatile period between June 2008 and March 2009 caused many deviations from the long-run equilibrium between most hubs, indicating that prices often decoupled.

Around February 2012 a substantial deviation from the long-run equilibrium occurs. This is likely to be related to the so-called "Russian gas supply crisis", when Russia was not able to meet the requested supply of gas by Europe due to an unexpectedly cold winter both in Europe and in Russia itself (Henderson & Heather, 2012). As observed earlier, this situation caused prices to spike for a short period. Figure 6 and 7 display the cointegrating relationships of the NBP with both other hubs. The fact that the price spike in these figures is upwards indicates that the price spike at the NBP is higher than at the Zeebrugge and the TTF, indicating that the supply shortage affected the NBP more intensively.

Figure 6. Intermarket cointegration of spot prices at NBP and Zeebrugge

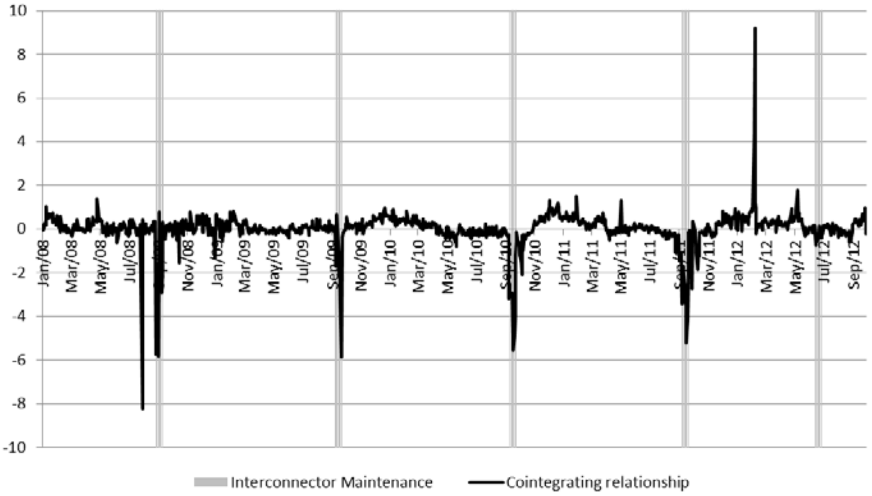


Figure 7. Intermarket cointegration of spot prices at NBP and TTF

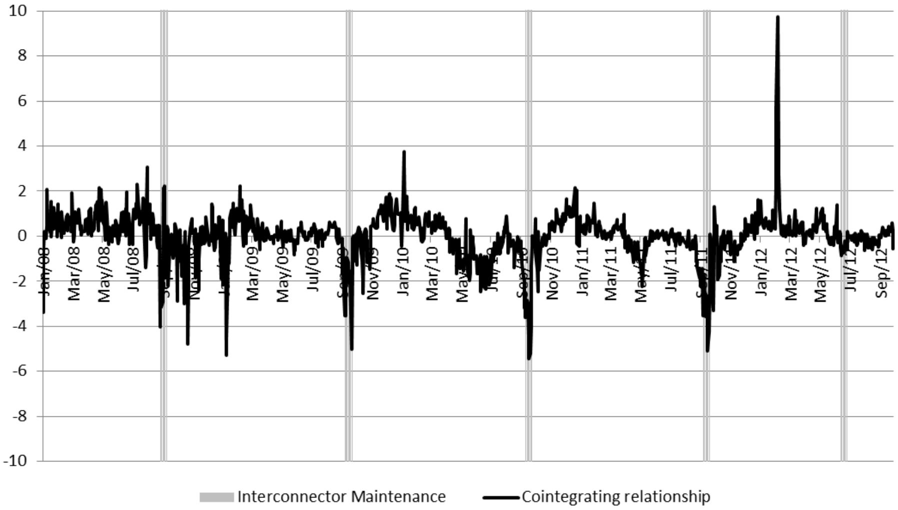
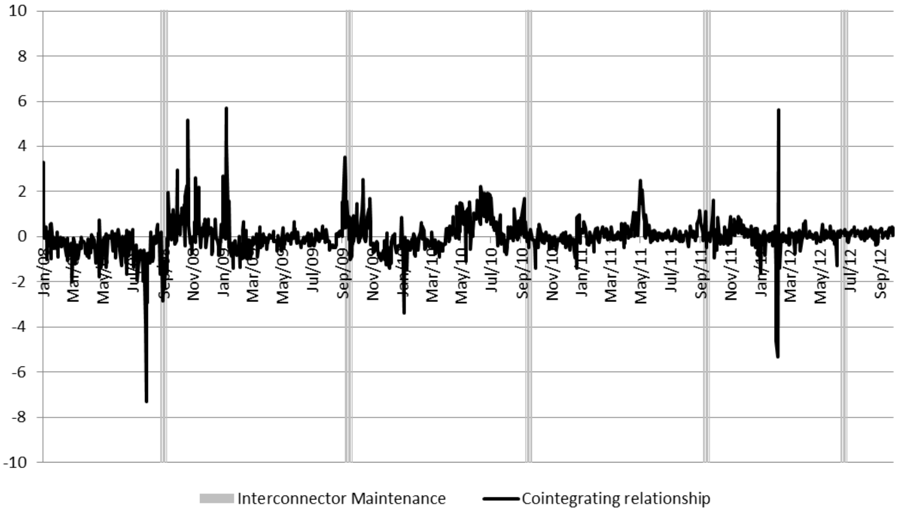


Figure 8. Intermarket cointegration of spot prices at TTF and Zeebrugge



Turning now to the maintenance periods in which the Interconnector is shut down for two weeks, it is evident that substantial deviations in both the cointegrating relationship between the NBP and Zeebrugge (figure 6) and the cointegrating relationship between the NBP and the TTF are occurring (figure 7). However, the cointegrating relationship does not exhibit a similar deviation from the long-run equilibrium during the shutdown in the year 2012. This exception may be related to gas supply and demand conditions that may have been different during the shutdown in 2012, relative to other years. The role of gas supply and demand dynamics is explained in subsection 6.3.

The fact that the cointegrating relationship between spot prices at the Zeebrugge hub and NBP is affected by the pipeline shutdown is most straightforward as these hubs are directly connected by the Interconnector pipeline. The finding that the relationship between the TTF and NBP is also affected indicates that the Interconnector pipeline is an important gateway connecting the NBP and the European mainland. It indicates that prices at the NBP not decouple from Zeebrugge individually but from the European gas market as a whole.

As expected, visual inspection of figure 8 indicates that the relationship between the TTF and Zeebrugge remains unaffected by the Interconnector shutdown. This is in line with expectations since these markets are connected by other pipelines than the Interconnector. Therefore, this observation also supports the assumption that the deviations from the long-run equilibrium are indeed caused by the Interconnector shutdown.

The TTF is connected to the NBP by the BBL pipeline. However, as expanded upon earlier the BBL pipeline is considered to be less efficient. Furthermore, the closure of the BBL pipeline generally only covers six days as opposed to the fourteen days shutdown of the Interconnector. The BBL maintenance tends to happen close to the Interconnector maintenance. Therefore, it is difficult to establish whether the BBL maintenance affects the cointegrating relationship between these hubs based on visual examination on figures of this scale. Especially due to the fact that the BBL shutdown period happens close to the Interconnector shutdown one could interpret deviations caused by the Interconnector shutdown as related to the BBL shutdown. Therefore, it seems most appropriate to base conclusions on the role of the BBL pipeline only on the empirical tests conducted in subsection 6.2.

6.1.3.4. Examination of the cointegrating relationship between month ahead market pairs

Based on the error correction model of which the results have been displayed in table 8, the cointegrating relationships between month ahead prices at different hub pairs are examined. This is done to address research question 4: “Does a pipeline shutdown cause decoupling of forward prices at the markets it connects?”. Figure 9, 10 and 11 display the cointegrating relationships between each hub pair in the month ahead market. Again, each figure indicates when the Interconnector pipeline was shut down for maintenance.

Similar to the hub pairs in the spot market, during the period between July 2008 and March 2009 many deviations from the long-run equilibrium occur. However, the cointegrating relationships between month ahead markets show no deviations around February 2012 when the Russian gas supply crisis occurred, which did cause deviations from the long-run equilibrium between the spot market pairs.

In the spot market the period that a contract trades and the moment of delivery are close to each other. In the forward market the time that a contract trades and the delivery period are more disconnected. Therefore, when examining the month ahead market, it is worthwhile to examine both whether deviations from the long run equilibrium between month ahead prices occur during the shutdown but also during the period when the month ahead contracts trade that deliver gas in the month of the shutdown.

The cointegrating relationships in figure 9, 10 and 11 between month ahead prices display no reoccurring deviations from the equilibrium that occur exactly during the shutdowns of the Interconnector pipeline. This has so far not been addressed in other studies.

Figure 9. Intermarket cointegration of month ahead prices at NBP and Zeebrugge

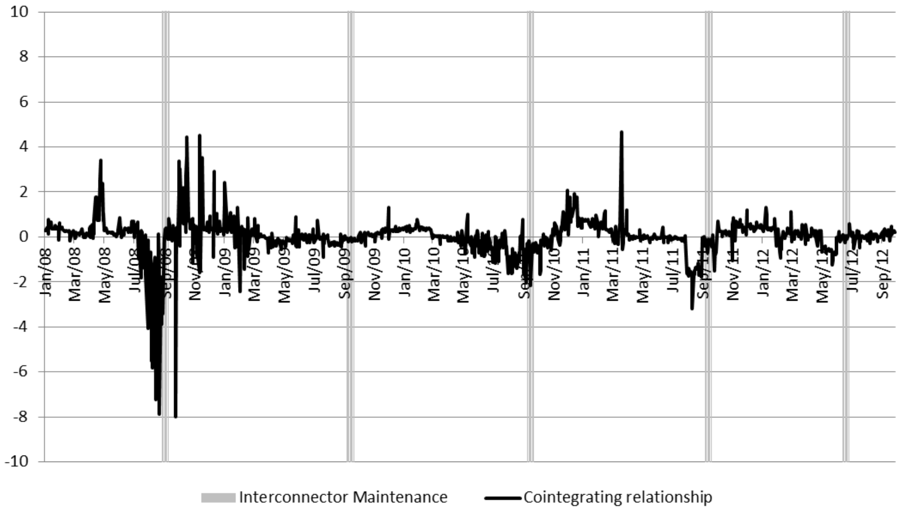


Figure 10. Intermarket cointegration of month ahead prices at NBP and TTF

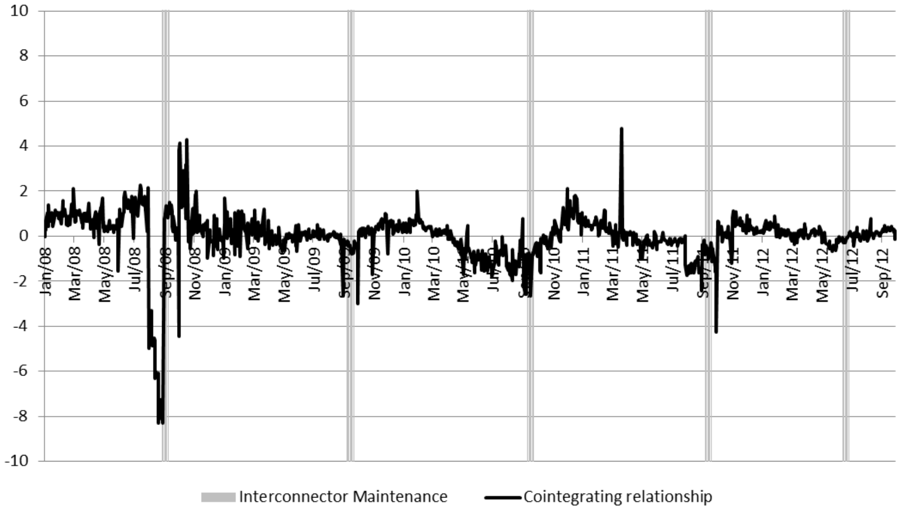
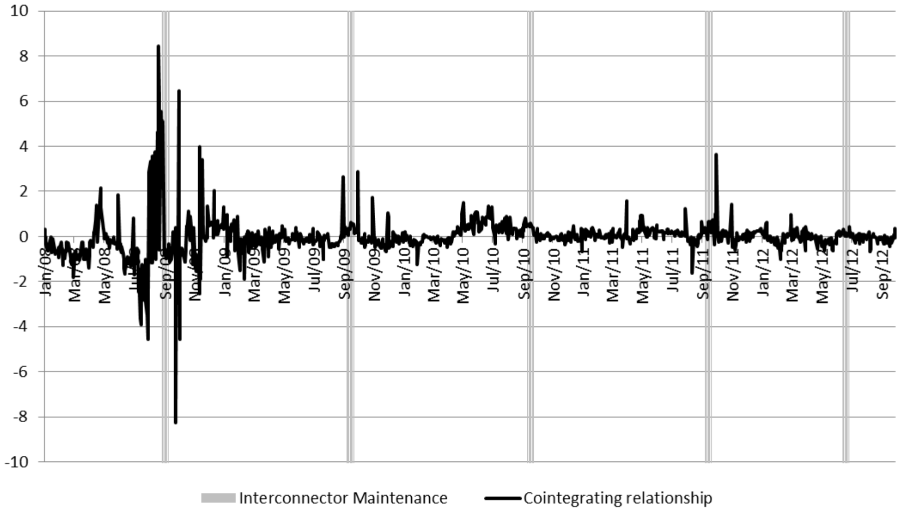


Figure 11. Intermarket cointegration of month ahead prices at TTF and Zeebrugge



Except for 2012, the shutdown always occurs in September, therefore the month ahead contract with delivery in the shutdown month trades in August. Examination of seasonal patterns in subsection 5.2 already displayed that the average month ahead price in August is substantially lower at the NBP than at the TTF and the Zeebrugge hub, indicating prices might decouple. In 2010, 2011 and 2012 there seem to be small deviations from the long-run equilibrium the month prior to the maintenance shutdown of the Interconnector in figure 9 and 10. However, in 2010 these deviations already started as of May and last far beyond the shutdown and therefore it is not possible to state that such deviations were related to the Interconnector shutdown. On the other hand, the observation that these deviations are not so much visible in figure 11 indicates that these deviations might be related to the Interconnector shutdown. Figure 11 shows the relationship between the TTF and the Zeebrugge hub, which are not connected by the Interconnector. Whether there is actually an effect on the price differential between the month ahead contracts that deliver gas in the Interconnector shutdown month is to be confirmed by the empirical tests in section 6.2.

At this point it can be stated that the cointegrating relationship between hubs in the month ahead market is affected to a lesser extent by the Interconnector maintenance shutdown as well as the Russian gas supply crisis. This indicates that the month ahead market is not that sensitive to short-term events. The cointegrating relationship in the month ahead market is affected by the more structural issues that arose in the second half of 2008, whether this is related to the financial crisis or the oil price drop, or both.

6.2. Empirical test of the pipeline shutdown impact

Leykam (2008) introduces a procedure to empirically test the whether the shutdown of a pipeline impacts the relationship between two markets significantly. In this subsection a variant on this procedure is applied to verify the preliminary conclusions of the previous subsection and to address unanswered questions that remain, regarding the effect of the BBL pipeline shutdown and possible decoupling of forward prices when the month ahead contract trades that delivers gas during the month of the shutdown.

6.2.1. ARMA methodology

The procedure by Leykam (2008) tests whether the mean of the difference between two price series changes significantly during a specific event such as a pipeline shutdown. This is done by estimating an autoregressive–moving-average (ARMA) model on the price differential series. The price differential series, $Diff_t$, are obtained by calculating the difference between daily prices at each hub pair at each time t. The representation of the autoregressive model is as follows:

$$Diff_t = \sum_{i=1}^{p} \beta_i Diff_{t-i} + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i} + \delta_i Dummy_t + \varepsilon_t \qquad (5)$$

This is a standard ARMA model including a dummy series as independent variable. This dummy series is 0 when the relevant pipeline is operating and 1 when the pipeline is shut down for maintenance. As such, the dummy variable is able to capture a change in the mean price differential between two hubs when the pipeline is not operating. This test can indicate whether the decoupling of prices at any hub pair is significant.

6.2.2. Price differential data

In section 5 the level price data has been introduced. The price differential series are presented here and not in the data section as at this point the reader has the background to understand how a pipeline shutdown may affect the price differential. Section 6.2 seeks to verify the indication of section 6.1, that the pipeline shutdown affects integration of spot markets differently than integration of month ahead markets. Therefore, the spot and month ahead price differentials are examined. The descriptive statistics of these price differential series are displayed in table 9.

Table 9. Descriptive statistics and unit root tests on differential series

	Spot market			**Month ahead market**		
	NBP Zeebrugge	**NBP TTF**	**TTF Zeebrugge**	**NBP Zeebrugge**	**NBP TTF**	**TTF Zeebrugge**
Mean	-0.19	-0.23	-0.04	-0.22	-0.34	0.12
Median	-0.12	-0.13	-0.02	-0.13	-0.21	0.13
Maximum	8.89	9.59	7.35	4.36	4.41	8.48
Minimum	-8.45	-5.66	-5.59	-8.70	-8.72	-8.49
Std. Dev.	0.81	1.05	0.80	0.88	1.15	0.88
Augmented Dickey Fuller test						
AIC lag length	19	20	9	22	3	22
t-statistic	-4.53	-4.58	-6.04	-3.83	-6.04	-6.11
Probability	0.00	0.00	0.00	0.00	0.00	0.00

The absolute mean of NBP-Zeebrugge and NBP-TTF series are significantly higher than the absolute mean of TTF-Zeebrugge, this is apparent both in the spot and the month ahead market. This could be related to the fact that the TTF and Zeebrugge hub are very well connected and not depend that heavenly on a single pipeline (such as the NBP vis-à-vis the Zeebrugge hub and the TTF). The cointegration analysis indicates that the shutdown of the Interconnector pipeline caused substantial deviations from the long-run equilibrium between spot prices at the NBP and the Zeebrugge hub and between the NBP and the TTF. These deviations increase the mean of the spot price differential between these hub pairs. This explanation is more likely to hold for the spot market as the cointegration analysis showed that the Interconnector shutdown causes less deviations in the month ahead market.

Another relevant observation is the fact that the markets that are least well connected, the NBP and the TTF, also exhibit the largest mean difference and the highest standard deviation of this difference. This is in line with the observation that the cointegrating relationship of this hub pair showed more frequent and persistent deviations from the long-run equilibrium than other hub pairs.

In order to be able to estimate the ARMA models, the price differential series should be stationary. Table 9 also displays the results of the ADF test. The null hypothesis of a unit root is strongly rejected for each price differential series. To verify the results the Phillips Perron test is also conducted and both tests are also applied to the log price differentials, all tests confirming that the price differential series are stationary.

The order of the ARMA models is selected by means of examination of the autocorrelation and partial autocorrelation functions. These indicate that the differential series require a high p order to obtain white noise residuals. The marginal order of p and q at which each model obtains white noise residuals according to q-statistics are slightly different. Out of consistency considerations, for each price difference series a basic AR(2) model is estimated and accordingly an ARMA(10,1) and ARMA(20,1) model. By estimating different order models on the same differential series it is possible to assess whether the order of the ARMA model affects the significance and magnitude of the dummy variable coefficient estimate. The fact that the price differential series require such a high AR order to obtain white noise residuals may indicate there is a monthly pattern in the differential series, as a month includes approximately 20 working days. Adding more MA terms generally did not impact the AR order required to obtain white noise residuals. The shortcoming of the current procedure is that there are many parameters to estimate for the ARMA (10,1) and ARMA (20,1) models compared to the number of data points (1239). This decreases the parsimony of the model. Considering this, it is relevant to assess whether the AR(2) model is able to capture the effect of the pipeline shutdown to the same extent as the higher order models. To account for the fact that there may be remaining autocorrelation and heteroskedasticity in some cases, all models are estimated using heteroskedasticity and autocorrelation consistent standard errors. This prevents a possibly invalid interpretation of the main unit of interest in these models, which is the significance and magnitude of the coefficient on the shutdown dummy variable.

6.2.3. ARMA model spot market results

The results of the ARMA analysis for the spot market differentials are displayed in table 10. The estimates of the coefficients on the AR and MA terms are not displayed in order to preserve space. Examination of the cointegrating relationship between the hubs displayed deviations from the long-run equilibrium in case of the NBP-Zeebrugge and the NBP-TTF pair during the maintenance shutdown of the Interconnector. This is confirmed by the ARMA analysis as the estimate of the coefficient on dummy I is significant in the model for the NBP-Zeebrugge and NBP-TTF differential series.

Table 10. Spot market ARMA models with Interconnector shutdown dummy variable

Hub pair		Model	Dummy I	St. Error	Prob.
NBP	Zeebrugge	AR(2)	-1.69	0.41	0.00
NBP	Zeebrugge	ARMA(10,1)	-1.59	0.29	0.00
NBP	Zeebrugge	ARMA(20,1)	-1.61	0.29	0.00
NBP	TTF	AR(2)	-1.14	0.32	0.00
NBP	TTF	ARMA(10,1)	-1.10	0.26	0.00
NBP	TTF	ARMA(20,1)	-1.10	0.25	0.00
TTF	Zeebrugge	AR(2)	0.23	0.17	0.19
TTF	Zeebrugge	ARMA(10,1)	0.37	0.17	0.03
TTF	Zeebrugge	ARMA(20,1)	0.35	0.16	0.03

The ARMA analysis provides the insight that the shutdown affects the differential between the NBP and Zeebrugge most severely as the coefficient of the dummy variable in this model is larger than the coefficient of the dummy variable in the NBP-TTF model. This is in line with expectations as the Interconnector pipeline directly connects the NBP and the Zeebrugge hub but only indirectly connects the NBP and the TTF.

Examination of the cointegrating relationship between the TTF and Zeebrugge hub displayed barely any deviations from the long-run equilibrium during the shutdown of the Interconnector. On a p=0.01 level of significance all three ARMA models for this hub pair are in line with that observation as the estimate on the coefficient of dummy I is insignificant on that level. On a p=0.05 level of significance the estimate of the coefficient on dummy I in the ARMA(10,1) en ARMA(20,1) models is significant. As the TTF and Zeebrugge hub are not connected by the Interconnector pipeline, but by other pipelines, a higher differential during the shutdown could perhaps be caused by the fact that the Zeebrugge hub is affected more strongly by the Interconnector shutdown than the TTF, which may lead to small disruptions in the relationship between these hubs. However, as figure 8 barely indicated deviations from the long-run equilibrium during the Interconnector shutdown the coefficient on dummy I may merely capture a seasonal effect. However, a p=0.01 significance level may be justified due to the high number of observations (1239) and the fact that the dummy for the other pairs is still significant on a p=0.01 level. On this basis, it is concluded that the differential of the TTF-Zeebrugge series remains unaffected.

Visual examination of the cointegrating relationship between the TTF and NBP spot prices could provide no insight into the effect of the shutdown of the pipeline that connects these hubs, the BBL pipeline. This is the first study addressing the impact of the BBL pipeline closure. It is hypothesized that the BBL shutdown does not have a significant effect as the BBL pipeline only has physical gas flow capacity in one direction and is less efficient in its reaction to price differences between the markets it connects. Also, the maintenance shutdown of the BBL only covers a period of six days. Furthermore, as the maintenance usually takes place when the Interconnector is operating, market participants can still transport their gas between the TTF and the NBP via the Zeebrugge hub. To empirically test the impact of the BBL shutdown an ARMA model is estimated that includes dummy B, which is 1 when the BBL pipeline is shut down and 0 when the BBL pipeline is operating. ARMA models are estimated, once with the Interconnector shutdown dummy variable (dummy I) and once without. Results for the spot price differential series are displayed in table 11.

Table 11. Spot market ARMA models with Interconnector and BBL shutdown dummy variable

Hub pair	Model	Dummy I	St. Error	Prob.	Dummy B	St. Error	Prob.
NBP TTF	AR(2)				0.02	0.36	0.95
NBP TTF	ARMA(10,1)				0.06	0.35	0.87
NBP TTF	ARMA(20,1)				0.03	0.35	0.94
NBP TTF	AR(2)	-1.15	0.32	0.00	-0.15	0.36	0.68
NBP TTF	ARMA(10,1)	-1.12	0.26	0.00	-0.14	0.34	0.67
NBP TTF	ARMA(20,1)	-1.12	0.26	0.00	-0.18	0.35	0.60

The coefficient on the BBL shutdown dummy variable is not significant in any of the models, which confirms the expectation that the BBL pipeline closure does not affect the differential between the NBP and TTF. The finding that the BBL pipeline shutdown does not affect the price differential between the two hubs it connects indicates that the BBL shutdown does not affect the differentials between other hub pairs either.

6.2.4. ARMA model month ahead market results

This subsection only focuses on the Interconnector shutdown as the previous subsection already indicated that the BBL shutdown does not cause a higher differential between the prices in the spot markets it connects. This makes it very unlikely the BBL shutdown would have any effect on co-movement of the month ahead prices, which are generally less reactive. As mentioned earlier, in the month ahead market it is important to distinguish a possibly higher differential both during the maintenance shutdown as well as during the period that the month ahead contract trades that delivers gas in the month of the shutdown.

The examination of the cointegrating relationships of month ahead price series of the hub pairs revealed that there are no deviations from the long-run equilibrium during the maintenance shutdown. This is confirmed by the ARMA analysis of the price differential series in the month ahead market. Table 12 displays that for each hub pair and for each model estimated for the pairs, the estimate of the coefficient on the shutdown dummy variable is not significant. This indicates that the mean of the differential between the prices of month ahead gas at the hub pairs is not significantly different during the maintenance period. This difference with the spot market has not yet been mentioned and tested in other studies.

Table 12. Month ahead market ARMA models with Interconnector shutdown dummy variable

Hub pair		Model	Dummy I	St. Error	Prob.
NBP	Zeebrugge	AR(2)	-0.09	0.16	0.58
NBP	Zeebrugge	ARMA(10,1)	0.15	0.13	0.24
NBP	Zeebrugge	ARMA(20,1)	0.05	0.17	0.75
NBP	TTF	AR(2)	0.02	0.20	0.94
NBP	TTF	ARMA(10,1)	0.14	0.20	0.50
NBP	TTF	ARMA(20,1)	0.14	0.20	0.47
TTF	Zeebrugge	AR(2)	0.26	0.21	0.21
TTF	Zeebrugge	ARMA(10,1)	-0.12	0.17	0.48
TTF	Zeebrugge	ARMA(20,1)	-0.13	0.19	0.51

Visual examination of the cointegrating relationship of month ahead prices could provide no insight into the effect of the maintenance shutdown on the month ahead contract that delivers gas during the Interconnector shutdown. In order to test whether the differential between month ahead prices at different hub pairs is larger when the month ahead contract trades that delivers gas in the shutdown month, the methodology is slightly adjusted. In this case dummy D is 1 when the month ahead contract trades that delivers gas in the shutdown month and 0 otherwise. In each case, except for 2012, the shutdown takes place in September. So in most cases dummy D is 1 when it is August. For example, in 2011 the Interconnector shutdown occurs between the 7th and 21st of September and as such the dummy variable is 1 only during August 2011. It is 0 in September 2011 as the contract that trades in September is for delivery during October, which is the month after the shutdown.

It should be noted that in this case interpretation of the dummy coefficient has to be done more carefully. As the dummy variable is 1 during an entire month, one could misinterpret a seasonal effect in the differential series as related to the shutdown. To be more certain that an increased differential (as indicated by a significant dummy estimate) is related to the shutdown, the effect should be present only in the NBP-Zeebrugge and the NBP-TTF differentials. Those pairs are directly and indirectly connected by the Interconnector. The TTF and the Zeebrugge hub are connected by other pipelines and the differential between these hubs should therefore not be affected. However, if there is a general seasonal pattern in the price differentials, the coefficient of dummy D is likely to be significant in the ARMA model for all the price differential series. Table 13 displays the results.

Table 13. Month ahead market ARMA models for the full sample

Hub pair		Model	Dummy D	St. Error	Prob.
NBP	Zeebrugge	AR(2)	-1,29	0,19	0,00
NBP	Zeebrugge	ARMA(10,1)	-0,97	0,16	0,00
NBP	Zeebrugge	ARMA(20,1)	-0,92	0,21	0,00
NBP	TTF	AR(2)	-1,24	0,58	0,03
NBP	TTF	ARMA(10,1)	-1,27	0,60	0,04
NBP	TTF	ARMA(20,1)	-1,30	0,63	0,04
TTF	Zeebrugge	AR(2)	0,12	0,27	0,65
TTF	Zeebrugge	ARMA(10,1)	0,25	0,24	0,30
TTF	Zeebrugge	ARMA(20,1)	0,26	0,25	0,29

The results in table 13 are approximately as expected. Dummy D is of highest significance in the ARMA model for NBP-Zeebrugge differential, directly connected by the Interconnector. Dummy D is less significant in the ARMA model for the NBP-TTF differential, indirectly connected by the Interconnector. Dummy D is insignificant in the ARMA model for the TTF-Zeebrugge differential, not connected by the Interconnector. However, the magnitude of dummy D in the ARMA models for the NBP-Zeebrugge and the NBP-TTF differentials is almost of the same size as the estimates for the dummy variables in the spot market ARMA models. This is counterintuitive as examination of the cointegrating relationship displayed that deviations from the long-run equilibrium between two spot prices are substantially larger than the deviations between two month ahead prices. This finding may be explained by the fact that in 2008 very substantial deviations occurred in the months surrounding the shutdown, as was seen in figures 9, 10 and 11. Those deviations are likely to be related to structural issues such as the financial crisis and the movements of the oil price. Therefore, the ARMA analysis should exclude the year 2008.

The ARMA model of table 13 is re-estimated without the year 2008. The results are displayed in table 14. The interpretation remains the same: the estimate of the coefficient on Dummy D is of highest significance in the ARMA model for the NBP-Zeebrugge differential, directly connected by the Interconnector. The coefficient on Dummy D is less significant in the ARMA model for the NBP-TTF differential, indirectly connected by the Interconnector. The coefficient on Dummy D is insignificant in the ARMA model for the TTF-Zeebrugge differential, not connected by the Interconnector. For each model, the magnitude of dummy D estimate is now much smaller than in table 13 and indeed smaller than the shutdown dummy in the ARMA models for the spot market. This confirms that co-movement of the prices of month ahead contracts with delivery during the shutdown month is affected, but to a lesser extent than co-movement between spot prices during the shutdown. Decoupling seems to occur in the same direction as in the spot market as the signs of the dummy estimates are similar to those in the spot market ARMA models.

Table 14. Month ahead market ARMA models without the year 2008

Hub pair		Model	Dummy D	St. Error	Prob.
NBP	Zeebrugge	AR(2)	-0,21	0,04	0,00
NBP	Zeebrugge	ARMA(10,1)	-0,79	0,13	0,00
NBP	Zeebrugge	ARMA(20,1)	-0,63	0,13	0,00
NBP	TTF	AR(2)	-0,52	0,24	0,03
NBP	TTF	ARMA(10,1)	-0,50	0,25	0,05
NBP	TTF	ARMA(20,1)	-0,31	0,24	0,03
TTF	Zeebrugge	AR(2)	-0,09	0,10	0,37
TTF	Zeebrugge	ARMA(10,1)	-0,13	0,10	0,17
TTF	Zeebrugge	ARMA(20,1)	-0,07	0,12	0,53

6.3. Examination of average price developments

The previous subsections established that during Interconnector maintenance prices at the NBP decouple significantly from prices at the TTF and the Zeebrugge hub. In the forward market a smaller decoupling occurs when the contract trades that delivers gas during the month that the shutdown occurs. This subsection aims to visualise these price developments. This analysis is done to provide a framework to explain the findings of section 6.1 and 6.2. As it turns out, all the findings are consistent with the demand and supply dynamics of the Western European gas market.

6.3.1. Examination of average prices in the spot market

Figure 12 displays the average spot prices on specific days relative to the shutdown. For example, the NBP spot price at day -10 is the average NBP spot price ten days before a maintenance period. The figure displays that the deviation from the long-run equilibrium between the spot prices is because of the decrease in the NBP spot price and not so much because of distortions in the Zeebrugge hub and TTF spot price. The figure displays that the NBP spot price already decreases one day before the shutdown, which is explained by the fact that spot gas actually refers to day ahead gas. The NBP spot price recouples straight after the pipeline operates again.

Figure 12. Average spot prices during a maintenance shutdown of the Interconnector pipeline

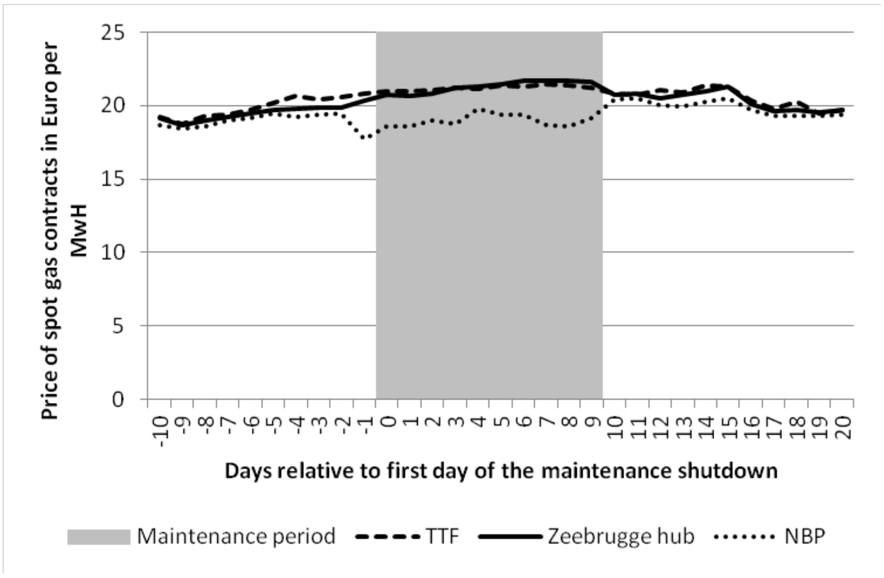


Figure 12 provides a basis to explain why the shutdown of the Interconnector pipeline significantly increases the spot price differential between the NBP vis-à-vis the Zeebrugge hub and the TTF while the shutdown of the BBL pipeline does not. The maintenance shutdowns take place in the summer period, in which the United Kingdom (covered by the NBP) is generally dealing with an oversupply of gas (Petrovich, 2013). To decrease the surplus, gas must flow from the NBP to the European continent. Gas flow capacity in this direction was exclusively offered by the Interconnector pipeline until 2011, after which the BBL pipeline also offered virtual flow capacity in this direction. However, the virtual capacity that the BBL now offers in this direction is very limited compared to the physical capacity the Interconnector offers. Therefore, when the BBL pipeline closes, market participants in the United Kingdom can use the Interconnector to transport their surplus of gas to the European Continent. However, when the Interconnector closes the limited capacity offered by the BBL pipeline cannot temporarily replace the missing Interconnector capacity. Therefore, only during Interconnector maintenance the United Kingdom cannot transport away its gas surplus. The temporary surplus that results is the reason behind the spot price decrease at the NBP during the Interconnector maintenance.

The insight that the deviations from the long-run equilibrium occur due to supply and demand dynamics may also explain why there was no deviation from the long-run equilibrium during the Interconnector maintenance in 2012, as was displayed in figures 6 and 7. It could well be that the United Kingdom was facing less oversupply that year.

Figure 12 provides another insight as Futyan (2006) conducts a similar analysis on price developments of the NBP and Zeebrugge hub during the Interconnector shutdown in 2001, which is before the TTF hub and other European hubs existed. The graph from Futyan's study can be found in appendix V. The graph shows that in 2001 the NBP spot price also decreases during the maintenance shutdown. A remarkable difference is that in 2001 the spot price at the Zeebrugge hub experiences a substantial increase (of approximately 30%) during the shutdown. Such an increase is not present in figure 12. Futyan explains that the increase in the Zeebrugge spot price is a consequence of the fact that when the Interconnector was shut down for maintenance in 2001 the Zeebrugge spot price competed against higher priced long-term oil-linked contracts as there were no other gas hubs in the European mainland during this time. In 2001 the NBP was the only other hub that provided spot gas not linked to the oil price.

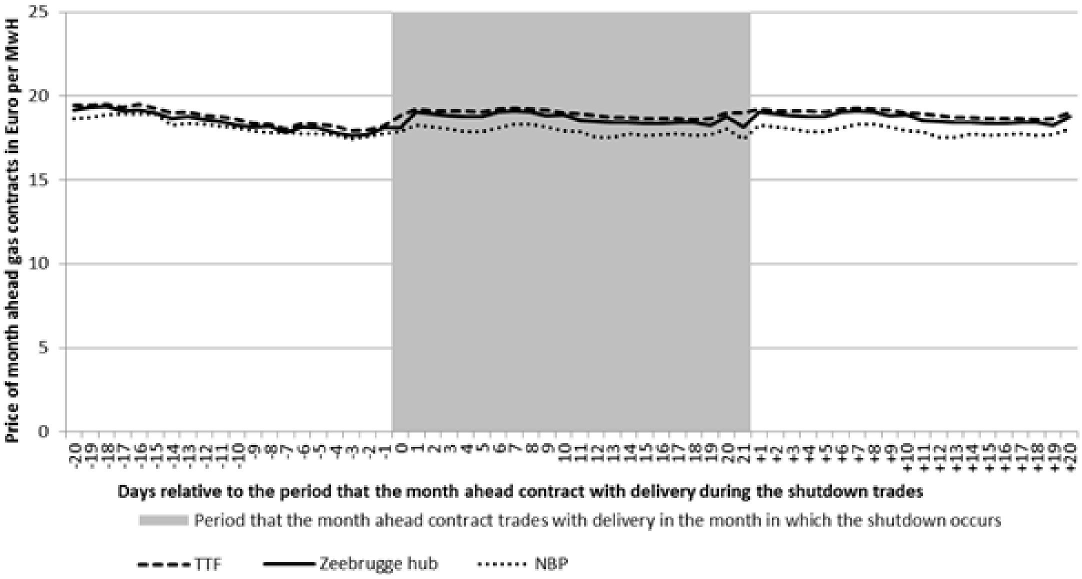
The fact that during the period examined in this study (2008-2012) such an increase in the Zeebrugge spot price is not evident during the maintenance shutdown, is a sign of the changes that have taken place between 2001 and 2008. Today, when the Interconnector shuts down the spot price at the Zeebrugge hub still competes against spot prices at the TTF and other European hubs. Therefore the Zeebrugge spot price does not exhibit an increase such as in 2001. This indicates that between 2001 and 2008 the gas market of the European mainland has become less dominated by oil-linked contracts.

6.3.2. Examination of average prices in the month ahead market

The ARMA analysis indicated that the Interconnector shutdown does not affect the integration of month ahead markets during the shutdown but it does so when the month ahead contract trades that delivers gas in the month that the shutdown occurs. The average prices of the three hubs are displayed in figure 13 and now it is indicated when the month ahead contract trades that delivers gas during the month in which the shutdown occurs. Similar as in the ARMA model displayed in table 14, the year 2008 is not taken into account in calculation of these average prices as this year was very turbulent and may affect the average prices.

In figure 13 the days with “-“ are the days before the period that the month ahead contract trades with delivery in the Interconnector shutdown month. The days with “+” are the days after the period that the month ahead contract trades with delivery in the Interconnector shutdown month. The days without “-“ or “+” is the period that the month ahead contract trades with delivery in the Interconnector shutdown month. As of t=1 the month ahead contract of the NBP trades at a slightly lower average price than at the TTF and the Zeebrugge hub. The average TTF and Zeebrugge hub month ahead prices remain approximately equal. This is in line with the ARMA analysis that indicated significant changes in the NBP-Zeebrugge differential and the NBP-TTF differential but not in the TTF-Zeebrugge differential. This is not counterintuitive considering that during the month that delivery of this contract occurs, the average prevailing spot price at the NBP is considerably lower, as explained in the previous subsection.

Figure 13. Average month ahead prices when the contract trades that delivers gas in the month of the Interconnector shutdown



It seems straightforward that market participants place less value to have gas delivered in the United Kingdom in the month that the Interconnector is shut down most days. In the month that market participants would receive that gas it would be difficult for them to transport that gas to the higher priced markets in Continental Europe. The United Kingdom itself deals with a temporary surplus, which means that immediately selling the gas on the spot market is unlikely to be profitable.

Another interesting finding is that the month ahead prices do not display immediate recoupling when the next month ahead contract, indicated with t=+1 in figure 13. This could be due to the fact that the month after the shutdown, which is October in most cases, also displayed many deviations from the long-run equilibrium between month ahead prices in figure 9, 10 and 11.

6.4. Summary of the impact of a pipeline shutdown

The answer to research questions 3 “Does a pipeline shutdown cause decoupling of spot prices at the markets it connects?” and 4 “Does a pipeline shutdown cause decoupling of forward prices at the markets it connects?” depends on which pipeline is considered. The Interconnector shutdown causes temporary decoupling of spot prices. This is consistent with the theoretical framework which summarized the Law of one Price framework (Kuper & Mulder, 2013) and stated that constraints between markets may lead to divergent price patterns over the period in which a constraint occurs. The effect of the Interconnector shutdown in the forward market is present to a lesser extent. Furthermore, the effect is not present during the shutdown but only when the contract trades that delivers gas in the month that the shutdown occurs. The smaller effect on the forward market is in line with the observation that the forward market is not that sensitive to short-term events. The forward market also remained unaffected by the Russian gas supply crisis. Events of more structural nature, such as the oil price decrease and the financial crisis that both occurred the second half of 2008, do seem to substantially affect the co-movement of forward prices.

It should also be noted that a pipeline shutdown may even lead to divergent price patterns in markets not directly connected by this pipeline. This is illustrated by the fact that the Interconnector shutdown also causes deviations in the cointegrating relationship between the NBP and the TTF.

The shutdown of the BBL pipeline does not lead to divergent price patterns of spot or forward prices at different hubs. This has been attributed to the fact that the BBL pipeline does not have substantial flow capacity from the NBP to the TTF, which is crucial in the summer as the United Kingdom (covered by the NBP) is generally dealing with an oversupply of gas. As such, not each pipeline is equally important in maintaining the connection between markets.

Due to the lack of cointegration between most of the quarter and year ahead prices at the hub pairs, these prices have not been involved in the pipeline shutdown impact analysis. However, as the impact on co-movement of month ahead prices is found to be substantially weaker than the impact on co-movement of spot prices, it seems likely that the impact will be gradually smaller when considering longer maturity contracts. This argument is especially convincing when one considers that a pipeline shutdown of 2 weeks is only a small proportion of the quarter ahead delivery period, which lasts three months. As such, only cross-border constraints that last much longer are likely to impact co-movement of these longer-maturity contracts. However, it must be noted that the impact of such a constraint will be especially difficult to identify if the co-movement of these longer maturity contracts is weak anyway.

6.5. Verification of error correction results

Section 6 has established that a pipeline shutdown can cause significant deviations in the cointegrating relationship between spot prices at hubs connected by that pipeline and that forward market integration is affected to a lesser extent. Examination of the cointegrating relationships also revealed that both in the spot and the forward market substantial deviations were present between July 2008 and March 2009, which may be a consequence of the financial crisis or the volatility of the oil price during this period.

The aim of this subsection is to establish whether deviations occurring during the Interconnector shutdown and between July 2008 and March 2009 have affected the estimates of the error correction model (equation 4) that has been estimated in subsection 6.1.3. Considering the magnitude of the deviations from the long-run equilibrium between spot market pairs occurring during the Interconnector shutdown, the error correction results may be affected by these events. This is particularly relevant since the implication of the estimates, that prices at the NBP adjust towards the prices at the European continent, was considered to be counterintuitive. Therefore the error correction model is estimated once for each hub pair on the sample without the maintenance periods, to separately assess whether this affects the estimates. The error correction model is also separately estimated for each hub pair for the volatile period between January 2008 and March 2009 and for the more stable period between March 2009 and September 2012.

Before re-estimation of the model it has been established that the null hypothesis of a unit root cannot be rejected for each subsample of the level prices series and that all series are stationary after first differencing them. It has also been established that prices of each hub pair are cointegrated, which indicates that estimation of an error correction model is appropriate. Lag length selection is based on the Aikake Information Criterion, which generally indicates a similar amount of lags as for the full sample. The results are displayed per hub pair and per subsample in table 15. The lagged dependent variables are not displayed to preserve space. The first column with estimates contains the results of the original sample, which are to be compared to the columns to the right.

Table 15 displays that the estimates of the error correction coefficients for the sample that excludes the maintenance periods of the Interconnector pipeline are rather similar to the estimates for the full sample. This indicates that the deviations from the long-run equilibrium between spot prices during Interconnector maintenance, even though substantial, have barely affected the estimates of the error correction coefficients.

Table 15. Error correction coefficient estimates for different subsamples

		Market	**Error correction coefficient**	**Prob.**	**Error correction coefficient**	**Prob.**	**Error correction coefficient**	**Prob.**	**Error correction coefficient**	**Prob.**
			Full sample		**Full sample without maintenance periods**		**Volatile period: 01/ 2008 until 03/2009**		**Stable period: 03/ 2009 until 12/2012**	
Pair 1	NBP	Spot	-0.20	0.00	-0.18	0.02	-0.53	0.00	-0.14	0.00
	Zeebrugge		-0.01	0.87	0.08	0.32	-0.13	0.34	0.00	0.89
Pair 2	TTF	Spot	-0.09	0.07	-0.05	0.33	-0.06	0.54	-0.12	0.04
	Zeebrugge		0.21	0.00	0.22	0.05	0.27	0.01	0.17	0.00
Pair 3	NBP	Spot	-0.12	0.00	-0.13	0.00	-0.45	0.00	-0.06	0.04
	TTF		0.02	0.55	0.01	0.04	-0.17	0.11	0.04	0.17
Pair 4	NBP	Month ahead	-0.13	0.00	-0.15	0.00	-0.13	0.03	-0.12	0.00
	Zeebrugge		0.01	0.79	-0.02	0.64	0.02	0.73	-0.02	0.49
Pair 5	TTF	Month ahead	0.01	0.77	0.00	0.91	0.00	0.99	0.03	0.53
	Zeebrugge		0.23	0.00	0.28	0.00	0.23	0.07	0.23	0.00
Pair 6	NBP	Month ahead	-0.13	0.00	-0.17	0.00	-0.12	0.00	-0.14	0.00
	TTF		-0.03	0.02	-0.05	0.01	-0.03	0.03	-0.03	0.21

There are substantial differences between the estimates of the error correction coefficients when separately considering the volatile and stable period. During the more volatile period the estimate of the error correction coefficient of the hub that makes the largest adjustment in the spot market pairs is substantially larger compared to both the full sample and the stable period estimates. This is particularly the case for the NBP in the spot market equations. This indicates that during the volatile subsample, which displayed many substantial deviations from the long-run equilibrium between the hubs pairs, prices had to adjust more substantially to restore the equilibrium. The observation that this seems to be particularly the case for the NBP, may indicate the NBP is more reactive to market circumstances. The latter is in line with the observation that the NBP displayed the highest price increase during the Russian gas supply crisis.

However, this conclusion is not applicable to the month ahead market as the estimates of the error correction coefficient in this market are rather similar in all subsamples. This finding again points out how the spot market is more reactive to prevailing circumstances than the month ahead market.

In summary, the attempt to verify the results of the error correction model of subsection 6.1 indicates that the results are rather robust. In each subsample the estimate of the error correction coefficient on the NBP price is higher than the hub it is paired with. This indicates that the NBP price adjusts towards the other hubs in each subsample. As such the reasoning that these results were merely a consequence of the price decoupling during the Interconnector shutdown, which causes NBP prices having to readjust towards prices at the Zeebrugge hub and the TTF, seems invalid. Therefore, it actually seems to be the case that prices at the NBP adjust to prices in Continental Europe. This may be caused by the fact that the hub market in Continental Europe has grown substantially past years and that the TTF has an important position in this network (Petrovich, 2013).

7. Intertemporal cointegration and the price discovery process

While section 6 considered spot and forward markets separately, this section addresses the relationship between spot and forward prices. This is complementary to the previous section as section 6 indicated that spot and forward markets are differently affected by short-term events such as a pipeline shutdown and the Russian gas supply crisis. These events indicate that the spot market is more reactive to short-term disturbances. However, spot and forward prices cover the same underlying asset. Due to the short-term reactivity of the spot price the forward market may faster and better reflect relevant information regarding the price of the underlying asset, making the forward market more informationally efficient (Nick, 2013). Due to the latter the forward market may lead the price discovery process.

The price discovery process is the manner by which new information is impounded into prices (Fu & Qing, 2006). When market i is more informationally efficient than the other, it means that information disseminates in market i first and subsequently in the other market (Fu & Qing, 2006). In this case there is a flow of information from market i to the other market, with market i leading the price discovery process (Srinivasan, 2011). Understanding the price discovery process is particularly relevant in the framework of the current discussion on using hubs as a benchmark price for newly concluded long-term contracts. If price discovery indeed takes place in the forward market, using the forward price as benchmark is more likely to capture valid price signals than using the spot price.

Price discovery analysis also sheds light on the relative efficiency of arbitrage at the gas hubs. The efficiency of arbitrage between spot and forward contracts can be measured by the time required to correct a deviation from the long-run equilibrium (Nick, 2013). Higher efficiency of arbitrage means that less time is required to correct a deviation from the long-run equilibrium between spot and forward prices, as described in the theoretical framework. This is particularly relevant since section 6 indicated that hubs are adjusting towards the TTF instead of the NBP. It is relevant to assess whether the TTF also exhibits high efficiency of arbitrage, which would support the maturity of the TTF market.

Whether this is the case is to be analysed in an error correction framework, which requires the spot and forward prices at the same hub to be cointegrated. Such cointegration is termed intertemporal cointegration. Cointegration of spot and forward prices is considered to have implications for market efficiency as well. This section addresses the following questions:

5. Are gas prices of spot and forward contracts traded at the same hub cointegrated?
6. Is one of the contracts leading the price discovery process?

Subsection 7.1 addresses question 5 by analysing spot and forward prices by means of the Johansen test. For the spot and forward prices that are found to be cointegrated, subsection 7.2 addresses question 6. Section 7.2 also addresses relative efficiency of arbitrage at the hubs. Subsection 7.3 aims to verify the results of section 7.2 by means of the Granger causality test. The methods applied in section 7 are similar to those in subsection 6 except for the Granger causality test. Therefore the latter is expanded upon in subsection 7.3.

7.1. Test of intertemporal cointegration

While in this study the function of the cointegration test is primarily instrumental as it is a requirement for further testing in an error correction framework, it should be noted that cointegration of spot and forward prices is considered a condition for market efficiency (Lai & Lai, 1991). The market efficiency hypothesis states that the market price reflects all available information and as a consequence there is no strategy by which traders can profit consistently by speculating in the forward market on future levels of the spot price. As such, the forward price should be an unbiased predictor of the spot price and the forward price should not consistently over or under predict the spot price. If the spot and the forward price are not cointegrated, the differential between the spot and forward price is non-stationary. Non-stationarity of the differential implies that the spot and the forward price may deviate apart without a bound. In this case the forward price has little predictive power about the movement of the spot price, which is inconsistent with the market efficiency hypothesis. (Lai & Lai, 1991)

In the data section it has been established that the spot and forward price series are I(1). Therefore, the relationship between the spot and forward markets at the considered hubs can be analysed by means of cointegration. In order to establish the appropriate lag length, an unrestricted VAR is estimated and lag length selection is based upon minimization of the Aikake Information Criterion.

The results of the Johansen cointegration test are displayed in table 16 and provide the answer to research question 5: “Are gas prices of spot and forward contracts traded at the same hub cointegrated?”. Table 16 indicates cointegration of the spot and month ahead forward contracts at each of the hubs. The results indicate no cointegration between the spot and quarter ahead prices at the NBP at $p=0.05$. At the other two hubs the Johansen cointegration test does find evidence of cointegration at the $p=0.05$ level. However, in those cases the trace statistic is only just above the $p=0.05$ critical value, indicating cointegration is weak. Lastly, the results indicate spot and year ahead prices are not cointegrated at each hub.

Table 16. Results of the Johansen test for intertemporal cointegration

	H0	H1	Trace Statistic	0.05 Critical Value	Probability	Implication
			National Balancing Point			
Spot - month ahead	r = 0	r ≥ 1	68.19	25.87	0.00	1 cointegrating relation
	r ≤ 1	r = 2	3.98	12.52	0.74	
Spot - quarter ahead	r = 0	r ≥ 1	25.86	25.87	0.05	no cointegrating relation
	r ≤ 1	r = 2	2.45	12.52	0.93	
Spot - year ahead	r = 0	r ≥ 1	21.84	25.87	0.15	no cointegrating relation
	r ≤ 1	r = 2	2.08	12.52	0.96	
			Title Transfer Facility			
Spot - month ahead	r = 0	r ≥ 1	60.93	25.87	0.00	1 cointegrating relation
	r ≤ 1	r = 2	3.67	12.52	0.79	
Spot - quarter ahead	r = 0	r ≥ 1	28.73	25.87	0.02	1 cointegrating relation
	r ≤ 1	r = 2	2.59	12.52	0.92	
Spot - year ahead	r = 0	r ≥ 1	19.16	25.87	0.27	no cointegrating relation
	r ≤ 1	r = 2	2.46	12.52	0.93	
			Zeebrugge			
Spot - month ahead	r = 0	r ≥ 1	57.92	25.87	0.00	1 cointegrating relation
	r ≤ 1	r = 2	4.02	12.52	0.74	
Spot - quarter ahead	r = 0	r ≥ 1	26.34	25.87	0.04	1 cointegrating relation
	r ≤ 1	r = 2	2.36	12.52	0.94	
Spot - year ahead	r = 0	r ≥ 1	19.10	25.87	0.27	no cointegrating relation
	r ≤ 1	r = 2	2.19	12.52	0.96	

In the interpretation of Lai & Lai (1991) the finding of low trace statistics and no cointegration between the spot contract vis-à-vis the quarter and year ahead contracts indicates a low level of market efficiency in the longer maturity markets. This could well be related to the fact that the number of trades in the quarter and year ahead contracts is relatively low, as was observed in figure 1 in section 2.

However, it can also be a consequence of the fact that contracts further down the forward curve exhibit very different seasonal patterns than the spot price. These patterns have been expanded upon in subsection 5.2. This seems to be a very likely explanation of the results as the contracts that display the weakest cointegration with the spot market also exhibit the most different seasonal pattern relative to the spot market. This is in line with a statement by exchange operator CME[6], that seasonal patterns cause natural gas prices to often deviate from the cost-of-carry relationship.

7.2. The role of spot and forward contracts in the price discovery process

As explained in the theoretical framework, the relationship between spot and forward prices is based upon a long-run equilibrium. For many reasons there might be deviations from this long-run equilibrium in the short-run. These deviations from the long-run equilibrium may be corrected either in the spot or forward market or both. This correcting is assumed to take place due to the fact that deviations from the long-run equilibrium trigger arbitrage opportunities, as has been expanded upon

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[6] http://www.cmegroup.com/trading/energy/files/PM203-Seasonality-and-Storage.pdf

in the theoretical framework. The impact of a deviation on the short-term behaviour of the series can be modelled by a vector error correction model. The error correction models that are estimated have the following representation:

$$\begin{aligned} \Delta S_t &= \beta_{S,i}(S_{t-1} - \theta F_{t-1}) + \sum \alpha_{S,i} \Delta S_{t-i} + \sum \gamma_{S,i} \Delta F_{t-i} + e_t \\ \Delta F_t &= \beta_{F,i}(F_{t-1} - \theta S_{t-1}) + \sum \alpha_{F,i} \Delta F_{t-i} + \sum \gamma_{F,i} \Delta S_{t-i} + e_t \end{aligned} \qquad (6)$$

In model 9 S refers to the spot price and F refers to the month ahead forward price. The quarter and year ahead contracts are not included in this analysis as the Johansen test established that these contracts are not all cointegrated with the spot price. The Johansen test did establish that the prices of spot and month ahead contracts are cointegrated at all three hubs, therefore this subsection focuses on those contracts. This focus is supported by the fact that month ahead contracts are the most frequently traded forward contracts, which makes it more likely that this contract conveys a valid price signal and that participants would be prepared to use this contract as a benchmark price.

Examination of the estimates of the β coefficients in model 6 can provide several insights. The interpretation of the β coefficients in this study is consistent with literature on price discovery, e.g. Fu and Qing (2006), Srinivasan (2011), Rittler (2009) and Nick (2013). Firstly, one can compare the relative magnitude of the β coefficient estimates in the spot and the forward equations of model 6 at a similar hub. The β coefficient estimate that is of largest absolute magnitude makes the largest adjustment in order to re-establish the long-term equilibrium when the cost-of-carry relationship has been disturbed. Price discovery happens in the market where the smallest adjustment is made. The reasoning is that this market already reflects the relevant information and therefore does not have to make an adjustment of large magnitude. As such, the market with the lowest absolute estimate of the error correction coefficient is leading the price discovery process. Secondly, one can compare the absolute value of the adjustment coefficients across hubs. A high absolute value of the adjustment coefficient in the market that is following in the price discovery process, indicates high efficiency of arbitrage in that market. In that case participants are quick in exhausting arbitrage opportunities and restoring the equilibrium between spot and forward prices at the hub.

Table 17 displays the results of the error correction model. The coefficients of the lagged endogenous variables are not displayed to preserve space. Selection of the number of lags is based on minimization of the Aikake Information Criterion.

Two diagnostic tests are carried out in order to assess the adequacy of the model. Firstly, each model is tested for stability based on the inverse roots of the characteristic AR polynomial (Lütkepohl, 1991). A bivariate error correction model is stable, or stationary, if one root is equal to unity and the other roots have a modulus of less than one and lie within the unit root circle. This is the case for each model. Secondly, each model is tested for remaining autocorrelation up to twenty lags. If at one of these lags the null hypothesis of no autocorrelation cannot be rejected, the table indicates a "yes". As can be seen, this was the case only in the model for the Zeebrugge hub. Unfortunately, adding more lags than indicated by the Aikake Information Criterion does not eliminate this issue for the Zeebrugge hub model.

Table 17. Spot –forward error correction model results

	NBP	TTF	Zeebrugge
Error correction coefficient spot	-0.088	-0.114	-0.077
Standard error	0.016	0.018	0.017
t-statistic	-5.52	-6.44	-4.59
Significance	0.00	0.00	0.00
Error correction coefficient forward	0.034	0.007	0.047
Standard error	0.012	0.010	0.016
t-statistic	2.94	0.73	3.05
Significance	0.00	0.47	0.00
Stability	yes	yes	yes
Autocorrelation in residuals	no	no	yes

Although not reported in table 17, it should be noted that the 95% confidence intervals of the adjustment coefficients in the spot price equations do not overlap with the 95% confidence intervals of the adjustment coefficients in the forward price equations. This indicates that the estimates of the adjustment coefficients in the spot and forward equation are substantially different.

At each hub the estimate of the error correction coefficient in the spot market equation is significant and of higher absolute magnitude than the estimate of the error correction coefficient in the forward market equation. In the forward price equations the estimates of the error correction coefficients are significant in case of the NBP and the Zeebrugge hub. This indicates that the forward price adjusts slower towards the long-run equilibrium relative to the spot price, which indicates the forward price leads the price discovery process. The finding of an insignificant adjustment coefficient in the forward equation of the TTF suggests that the forward price is weakly exogenous with respect to the spot price. The forward price at the TTF does not react to deviations from the equilibrium. As such, at the TTF the lead of the forward price is even more pronounced than at the NBP and the Zeebrugge hub.

Nick (2013) performs vector error correction analysis as well, does not include the Zeebrugge hub and focusses on futures (traded at an exchange) instead of forwards (traded over-the-counter). The difference between forwards and futures has been addressed in subsection 2.3. Despite the different characteristics of these contracts, both the signs and the magnitude of the error correction coefficients are much in line with his results. This provides verification of the results in this study and suggests the long-run equilibrium is restored in the OTC forward market and the exchange market (where futures trade) with approximately the same speed. On the one hand this can be considered in line with expectations as Petrovich (2013) finds that the correlation between forward and futures prices of the gas hubs is high. On the other hand, forward contracts cannot easily be traded multiple times among market participants as these may contain transaction-specific clauses whereas futures are standardised. One could expect that the ease of trading in the futures market could mean that deviations from the long-run equilibrium are corrected quicker. It has been addressed in subsection 2.4 that the futures market is less liquid than the forward market. This could explain why the long-run equilibrium in the futures market is not restored quicker than in the forward market even though trading futures contracts multiple times before delivery is better possible.

It has now been established that the forward price is leading the spot price in all cases as deviations from the long-run equilibrium are corrected in the spot market. In order to quantify the relative price discovery contribution of spot and month ahead markets, the common factor weights as proposed by Schwarz and Szakmary (1994) are calculated, which is common in studies addressing price discovery in the commodity markets, e.g. Rittler (2009). The common factor weight formula assumes that price discovery contribution is inversely related to the absolute magnitude of the error correction coefficients:

$$Common\ factor\ weight\ month\ ahead\ contract\text{:}\ \frac{|\beta_s|}{|\beta_s|+|\beta_f|} \qquad (7)$$

$$Common\ factor\ weight\ spot\ contract\text{:}\ \frac{|\beta_f|}{|\beta_s|+|\beta_f|} \qquad (8)$$

The β coefficients in equation 7 and 8 are the estimates for the error correction coefficients of model 6 and are displayed in table 17. β_s is the estimate of the error correction coefficient in the spot market equation while β_f is the estimate of the error correction coefficient in the forward market equation. This leads to the relative contributions displayed in table 18.

Table 18. Common factor weight spot and month ahead contract prices

	Spot	Forward
NBP	28%	72%
TTF	6%	94%
Zeebrugge hub	38%	62%

The common factor weights indicate that at each hub the month ahead market contributes most to the price discovery process. The fact that the relative contribution of the month ahead contract to the price discovery process is largest at the TTF coincides with the observation that at the TTF the share of trades further down the forward curve is largest, as displayed in figure 1 in section 2. If trading in the forward market occurs more frequent, it can be expected that it conveys a more valid price signal. Furthermore, the fact that the relative contribution of the month ahead to the price discovery process is smallest at the Zeebrugge hub coincides with the observation that at the Zeebrugge hub the share of trades further down the forward curve is the smallest. However, as the proportion of forward trades at the NBP is more close to the TTF than to the Zeebrugge hub, it was expected that the relative contribution of the month ahead contract to the price discovery process at the NBP would be more in line with the TTF.

While the implications from the common factor weights generally seem to match the expectations, it should be noted that usage of the common factor weight measure can be considered controversial. The input for calculation of the common factor weights are estimated values with substantial uncertainty, indicated by the relatively high standard error of the estimates, as can be seen in table 17. Furthermore, the error correction coefficient of the forward market equation in the TTF model is not significant, indicating that deviations from the long-run equilibrium are actually only corrected in the spot market. Therefore, it may be more appropriate to interpret the market with the lowest error correction coefficient as the leading market without making statements as to what the relative contribution of both markets to the price discovery process exactly is.

In summary, the results imply that when the long-run cost-of-carry relationship between the spot and the forward contract is distorted, it is the spot contract that makes the largest adjustment in order to re-establish the equilibrium. The implication is that at each of the hubs it is the forward price that leads the spot price in the price discovery process. This provides the answer to research question 6: “Is one of the contracts leading the price discovery process?”. The finding that price discovery takes place in the forward or future markets is consistent with most literature on other commodity markets according to Figuerola-Ferretti and Gonzalo (2007), Rittler (2009), Fu and Qing (2006) and consistent with findings on the gas futures market by Nick (2013). However, there are exceptions, such as Srinivasan (2011).

7.2.1. Relative efficiency of arbitrage and the role of storage

As mentioned, price discovery analysis also provides insight into the relative efficiency of arbitrage at each hub. It has been established that the long-run equilibrium is restored primarily by adjustments in the spot market. In table 17 it can be observed that at the TTF the adjustment coefficient of the spot market is of higher absolute magnitude than in both other markets. This could indicate that market participants at the TTF are best able to execute arbitrage, which causes the equilibrium between spot and forward prices to be restored quickly at the TTF.

Storage is important for the relationship between spot and forward prices because storage is crucial for the no-arbitrage condition, as described in the theoretical framework. Nick (2013) observes that gas storage in the Netherlands (covered by the TTF) has a high degree of operational flexibility, which means that market participants are most capable of adjusting storage levels in response to market conditions compared to participants in other markets. Flexible storages presumably withdraw gas from their storage facility when demand and spot prices are relatively high and inject gas into their storage facility when demand and prices are relatively low (Nick & Thoenes, 2013). The high operational flexibility of the TTF is confirmed in a study undertaken on behalf of the relevant European Commission (Ramboll Oil and Gas, 2008). Appendix VI contains a relevant figure from this study, which displays that the Netherlands possesses a particularly high level of withdrawal capacity compared to other countries.

It is of illustrative value to elaborate on the role of storage with the example of the Netherlands. The average daily gas consumption in 2011 in the Netherlands was 131 million cubic meter (International Energy Agency, 2012). The maximum technical withdrawal capacity per day is 76 million cubic meter and the maximum technical injection capacity of the TTF is 22 million cubic meter[7]. This illustrates that the amounts of natural gas by which the storage system can increase supply (by withdrawal from storage facilities) or decrease supply (by injection into storage facilities) is substantial relative to the average demand for gas. Considering these amounts, it is understandable that storage withdrawal or injection has the potential to correct a deviation in the spot price.

Furthermore, this figure indicates that the United Kingdom (covered by the NBP) is relatively inflexible compared to Northern Europe as its injection and withdrawal capacity is relatively low. This could explain why the error correction results indicate that the error correction process is slower at the NBP, despite the fact that the NBP is a liquid market. The storage inflexibility and its limited capacity in the United Kingdom is an issue recognized by the British government, which commenced a study into the security of gas supply. Appendix VII contains a relevant figure from this study, which indicates that both the United Kingdom and Belgium have a relatively low level of storage capacity compared to gas consumption (House of Commons Energy and Climate Change Committee, 2011).

It must be noted that the finding that the equilibrium is restored most quickly at the TTF is not based upon a test that indicates that the estimates of the error correction coefficients at different hubs are *significantly* different from each other. This conclusion must therefore be taken with caution. The main message from this subsection is that the most liquid hub, the NBP, does not necessarily exhibit

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[7] Information on storage injection and withdrawal capacities of all European hubs is available on http://transparency.gie.eu.com/

the highest level of efficiency of arbitrage and that this could well be related to the gas storage issues the United Kingdom is dealing with.

7.3. Granger causality

Consistent with the finding that price discovery happens primarily in the forward market, there may be a lead-lag relationship between forward and spot prices. Granger (1986) states that if spot and forward prices are cointegrated, causality must exist at least in one direction. Due to the finding of cointegration between spot and month ahead forward prices, causality testing should be based on the error correction model for these hub pairs. Referring back to the equations of the error correction model 6, the forward price at time t Granger causes the spot price at time t if the $\gamma_{S,i}$ coefficients in the spot price equation are jointly significant. Similarly, the spot price at time t Granger causes the forward price at time t if the $\gamma_{F,i}$ coefficients in the forward price equation are jointly significant. If both S_t and F_t Granger cause each other, there is a bidirectional feedback relationship between spot and forward market prices. Granger causality can also be applied to the markets which were found not to be cointegrated. However, in that case the Granger causality test is conducted in a VAR model, which is the case for the Granger causality tests between the spot and the quarter and year ahead contracts. Granger causality tests in the VAR framework are conducted on the first differenced prices series as the Granger causality test requires stationarity.

It should be noted that the methodology in the previous subsection focused on error correction coefficients. However, the Granger causality test focuses solely on significance of lagged dependent variables and may therefore yield contradicting results with regard to the role of spot and forward prices.

Table 19. Granger causality results

	NBP	**TTF**	**Zeebrugge**
	Probability	**Probability**	**Probability**
Month ahead does not Granger cause spot	0.00	0.00	0.00
Spot does not Granger cause month ahead	0.18	0.00	0.01
Quarter ahead does not Granger cause spot	0.00	0.00	0.00
Spot does not Granger cause quarter ahead	0.47	0.38	0.69
Year ahead does not Granger cause spot	0.00	0.00	0.00
Spot does not Granger cause year ahead	0.16	0.11	0.01

The Granger causality test results, displayed in table 19, indicate that at each hub and for each spot-forward pair the null hypothesis that the forward price does not Granger cause the spot price can be rejected. In the relationship between the spot and the month ahead market the Granger causality tests finds bidirectional feedback, expect for the NBP. This could be interpreted as contradictory relative to specific error correction results. The error correction model for the NBP indicates that the month ahead contract has a significant error correction coefficient, indicating that the month ahead price also adjusts towards the spot price to some extent. With respect to the TTF the error correction model indicated that the month ahead equation does not have a significant error correction coefficient, indicating that the month ahead price does not adjust towards the spot price. Therefore, it seems contradictory that the spot price also Granger causes the month ahead price at the TTF.

With respect to the spot price vis-à-vis the quarter and year ahead market the Granger causality test indicates unidirectional causality from the forward to the spot contract price. These relationships could not be examined uniformly by means of an error correction model due to the lack of cointegration of the longer maturity prices with the spot price in most cases.

In summary, the main conclusion from the error correction model was that the forward price leads the spot price, implying that there is a flow of information from the forward to the spot market. The Granger causality indicates that Granger causality in this direction indeed exists at each hub, so in that sense the findings of the previous subsection are supported. However, with respect to Granger causation in the other direction some contradicting results have been found.

7.4. Verification of error correction results

Similar to the procedure section 6 follows, the error correction results of the error correction model estimated in subsection 7.2 are verified by estimation of the same model on different subsamples. The period between July 2008 and March 2009 again displays many substantial deviations from the long-run equilibrium between spot and month ahead prices at the same hub as can be seen in the graphs in appendix VIII, which may affect the error correction results. As the common factor weights are based upon the error correction coefficients these are also calculated for each subsample.

Table 20 displays the error correction coefficients for each of the different subsamples. The estimates of the coefficients on the lagged dependent variables are not displayed to preserve space. Breaking the sample in a more volatile and more stable period affects the estimates. During the more volatile period the estimates of the error correction coefficients are substantially larger, especially in the forward market equations. The same was observed when verifying the results of the error correction model for the intermarket relationships in section 6. This means that larger adjustments are necessary to re-establish the long-run equilibrium between spot and forward prices during the more volatile period. During the more stable period the estimates of the error correction coefficients are rather similar to the full sample estimates, albeit that the spot market coefficients are somewhat larger.

Table 20. Error correction coefficient estimates for different subsamples

		Full sample		**Full sample without maintenance periods**		**Volatile period: 01/ 2008 until 03/2009**		**Stable period: 03/ 2009 until 12/2012**	
		Error correction coefficient	**Prob.**	**Error correction coefficient**	**Prob.**	**Error correction coefficient**	**Prob.**	**Error correction coefficient**	**Prob.**
NBP	Spot	-0.09	0.00	-0.07	0.00	-0.14	0.00	-0.12	0.00
	Forward	0.03	0.00	0.04	0.00	0.08	0.01	0.00	0.86
TTF	Spot	-0.11	0.00	-0.11	0.00	-0.18	0.00	-0.13	0.00
	Forward	0.01	0.47	0.01	0.29	0.01	0.74	0.01	0.34
Zeebrugge	Spot	-0.08	0.00	-0.08	0.00	-0.14	0.00	-0.11	0.00
	Forward	0.05	0.00	0.04	0.01	0.17	0.00	0.01	0.61
		Common factor weights		**Common factor weights**		**Common factor weights**		**Common factor weights**	
NBP	Spot	27%		40%		37%		2%	
	Forward	73%		60%		63%		98%	
TTF	Spot	6%		10%		5%		8%	
	Forward	94%		90%		95%		92%	
Zeebrugge	Spot	38%		35%		54%		6%	
	Forward	62%		65%		46%		94%	

As explained earlier, common factor weights indicate the relative contribution to the price discovery process. The common factor weights are rather similar for the entire sample and the sample without the observations around Interconnector maintenance. During the more volatile period up to March 2009 the relative contribution to the price discovery process of the forward market decreases at the NBP and the Zeebrugge hub. This indicates that during a volatile period the forward market may lose its price signalling function. Only at the TTF does the relative contribution of the forward market remain similar during this period. During the more stable period after March 2009 the relative contribution of the forward market is substantially larger at the NBP and the Zeebrugge hub and remains large at the TTF. This indicates that the lead of the forward market may be stronger during stable periods.

While the conclusion that the forward market may lose its lead during more turbulent periods does not seem counterintuitive, it must again be taken with some caution. Again, the common factor weight calculation did not account for significance of the β estimates of model 6. As such, it may be most appropriate to conclude that during most subsamples the forward market is the leading market, without drawing conclusions with respect to the exact contribution of the spot and forward market. The forward market loses its leading role only once, which occurs at the Zeebrugge hub during the volatile period sample. Besides that exception the estimation of the error correction model for different subsamples has supported the conclusion that the month ahead market leads the spot market.

8. Concluding remarks

8.1. Summary

The first part of this study considers intermarket cointegration, cointegration of similar maturity contracts traded at different hub pairs. Research question 1 considers whether gas prices of spot contracts traded at the hub pairs are cointegrated, which is found to be the case. Research question 2 considers cointegration of longer maturity contracts. It is found that month ahead prices of each hub pair are cointegrated, while prices in the quarter and year ahead markets are either not or weakly cointegrated, which may be related to the relative infrequent trading of longer maturity contracts or to characteristics of the OTC market. In order to examine the deviations from the long-run equilibrium implied by the cointegrating relationship, an error correction model is estimated for each hub pair. Examination of the error correction coefficients provides the insight that prices at the NBP adjust towards the prices in Continental Europe. This behaviour is observed both in the spot and forward market and confirmed by a robustness check. Research question 3 and 4 consider whether a pipeline shutdown affects the cointegrating relationship between spot prices at the markets it connects in a similar manner as it affects cointegration of the forward prices at these markets. Examination of the cointegrating relationship and an empirical test indicate that spot prices at hubs connected by the Interconnector decouple substantially during the shutdown itself. Forward prices do not decouple during the Interconnector shutdown but do decouple less substantially when the contract trades that delivers gas in the month that the shutdown occurs. Empirical testing in an ARMA framework indicates that the maintenance shutdown of the BBL pipeline does not have the same effect as the Interconnector shutdown. In order to understand these findings, average prices during the Interconnector maintenance are examined. This provides the insight that deviations from the long-run equilibrium between market pairs occur primarily due to a decreasing spot price at the NBP, which is a consequence of the gas surplus that the United Kingdom is faced with during the Interconnector shutdown. The BBL shutdown cannot transport away this surplus as its gas flow capacity from the NBP to the TTF is minimal (and only virtual). Due to this limitation, the role of the BBL pipeline in the link between prices at the NBP and European hubs is not that important in the summer period.

The second part of this study considers intertemporal cointegration, cointegration of prices of contracts of different maturity traded at the same hub. As an answer to research question 5 it is established that spot and month ahead prices are cointegrated at each hub. Spot and quarter ahead prices are cointegrated at some hubs while spot and year ahead prices are cointegrated at none of the hubs. It is stipulated that the latter finding is a consequence of the observation that quarter and year ahead contracts have substantially different seasonal patterns than spot and month ahead prices. Research question 6 considers whether the spot or the forward price is leading the price discovery process. The price discovery analysis focuses on the spot and the month ahead contract and establishes that the forward price leads the spot price. Subsequently, Granger causality from the forward to the spot market is confirmed. However, in some cases the Granger causality also indicates causation from the spot to the month ahead price.

The cointegrating relationship between spot and month ahead prices displayed very substantial deviations between July 2008 and March 2009. Therefore, the error correction model is re-estimated for separate samples of the more volatile and the more stable period. The results reveal that the forward market generally remains the leading market under both circumstances. Calculation of the common factor weights indicates that in one case the forward market lost its lead in the more volatile period and that the forward market lead is stronger during the more stable period.

8.2. Implications

The current study has implications both for policy makers and market participants, these are addressed separately.

8.2.1. Policy implications

As explained in section 2, natural gas market integration is an important goal of the European Union. This study establishes that while natural gas OTC spot prices may be cointegrated, longer maturity OTC prices may be not or weakly cointegrated. Other studies addressing market cointegration overlook the longer maturity market while this market constitutes approximately 50% of the number of trades and 90% of the traded gas volume. The European Commission should take this into account when evaluating market integration. According to the findings in this study forward market integration is hampered to a lesser extent by pipeline constraints and therefore the weak forward market integration may have other causes than limited cross-border pipeline capacity. A very likely cause is the relatively low number of trades taking place in these markets.

If the European Commission considers the price decoupling caused by the Interconnector shutdown problematic, it could consider to oblige the BBL pipeline to also offer substantial physical flow capacity in the direction from the United Kingdom to the Netherlands. If this is the case, market participants could use the BBL pipeline to transport gas to the European continent during the Interconnector shutdown. As such, the United Kingdom would not be faced with a temporary surplus of gas and the NBP gas price would remain more stable. This would also prevent the NBP gas price to be substantially affected by unexpected technical issues that might arise at the Interconnector.

8.2.2. Implications for market participants

The current study has relevant implications in the framework of the current discussion on what the most appropriate benchmark price is for newly concluded or revised long-term contracts. Particularly market participants located in Eastern and Southern Europe, where the local gas hubs are less liquid than the hubs included in this study, might want to use a hub in Western Europe as benchmark price.

The current study makes a case for using the month ahead forward price instead of the spot price as benchmark. Heather (2012) indicates that market participants have expressed concerns over price fluctuations in the hub market. The current study establishes that month ahead prices at different hubs only decouple slightly when a pipeline shuts down. Furthermore, the month ahead forward price seems less sensitive than the spot market to short-term occurrences such as the Russian gas supply crisis. Related to this, the study finds that price discovery takes place in the forward market. Therefore, using the forward market as benchmark is likely to capture the most valid price signal.

It must be noted that using longer maturity prices than the month ahead price as benchmark seems less appropriate. Firstly, because quarter and year ahead contracts are rather illiquid compared to the spot and month ahead market. Secondly, the quarter and year ahead market exhibit a substantially different seasonal pattern compared to these markets. Both drawbacks do not hold for the month ahead market. The number of trades in the month ahead market is approximately equal to the spot market and the seasonal pattern is rather similar as well. Once the futures market has become sufficiently liquid it might be worth to consider indexing to futures prices rather than the OTC forward market. The futures market is even more transparent and less likely to be sensitive to purposeful misreporting of prices.

The primary goal of this study is not to determine which hub is most appropriate as benchmark. However, specific findings in this study cast doubt upon the NBP as an appropriate benchmark for market participants in Continental Europe. The NBP spot price decouples from spot prices in Continental Europe when the Interconnector shuts down. Even the NBP month ahead price decouples slightly when the forward contract trades that delivers gas during this shutdown. While the annual maintenance shutdown can be foreseen by market participants, it should be noted that if the Interconnector shuts down due to unforeseen technical issues this is likely to have more severe consequences for the spot price.

This study finds that using the TTF as benchmark is a worthwhile consideration. Results indicate that prices at the NBP adjust towards the TTF. The TTF does not suffer from constrained cross-border pipeline capacity as the NBP does. Further support for the TTF to act as benchmark hub can be derived from the indication in subsection 7.2 that the TTF has a high level of efficiency of arbitrage.

The section also points out that the NBP suffers from limited storage capacity, while the TTF is considered to have ample storage capacity. Therefore, while traded volumes at the NBP are larger, the TTF has more stable prices and does not suffer from pipeline or storage constraints. This adds to the advantage that European market participants would not suffer from currency exposure by indexing on the TTF price. As addressed in the data section, the NBP and Zeebrugge hub trade in pence per therm.

8.3. Limitations

The fact that this study considers forward prices is not a limitation by itself, especially since Petrovich (2013) found that correlation between forward and futures prices is in the range of 90%-99%. However, analysis of OTC prices does lead to the involvement of aspects that the available data is not able to account for. In subsection 6.1 it was argued that the nature of the forward market may contribute to the finding of no or weak cointegration between the longer maturity contracts traded at different hubs. In the forward market the participants are exposed to a certain amount of counterparty risk and have to incur negotiation costs. However, details other than the price of the gas remain private. Futures prices are not affected by such aspects as participants only have the exchange as counterparty. However, it should be noted that analysis of the futures market would involve other issues, such as more severe problems of illiquidity.

8.4. Future research

As mentioned, this study is the first to address that longer maturity forward prices are not necessarily cointegrated when spot markets are. This study could only provide expectations as to why certain longer maturity forward markets were found not to be cointegrated. Future studies could examine whether this is related to thin trading or other causes. Such findings are relevant for the goal of market integration as aimed for by the European Commission.

As pipeline capacity is clearly important for spot market integration it might be so that creating better integrated spot markets has a positive spillover on the integration of forward markets. Whether such interaction exists, is to be confirmed by further studies.

The findings regarding price discovery are in line with Nick (2013), who examines the futures instead of the forward market and finds that the futures price lead the spot price at the exchanges. Nick argues that although the futures contracts eventually result in physical delivery, there is the opportunity to trade the contract multiple times before maturity. Nick states that as a consequence of this, expectations of the market participant are better reflected in the futures price than in the spot price. Nick's reasoning is not necessarily applicable to the forward market, in which trading the contract multiple times is less likely to happen as forwards are transaction-specific agreements. This indicates that the lead of the forward market as well as the lead of the futures market may not necessarily be due to the argumentation of Nick. This study does offer an alternative explanation. This study finds less reactivity of the forward market to short-term circumstances such as the Russian gas supply crisis and pipeline shutdowns. Therefore, it is may be due to the nature of the price dynamics rather than the trading behaviour of participants on the market that the spot market adjusts towards the forward market. Future research could provide clarity on this matter.

Subsections 6.4 and 7.5 are a robustness check of the error correction results. While in both cases the general interpretation of the results remains the same in more turbulent times versus more stable times, it is clear that results are sensitive to the amount of volatility. Particularly the finding that the forward contract may lose its leading role during more turbulent times is interesting. It is worth to study whether this is also the case in other commodity markets and whether this should have any implications for the appropriateness of using the forward price as benchmark price for long-term contracts.

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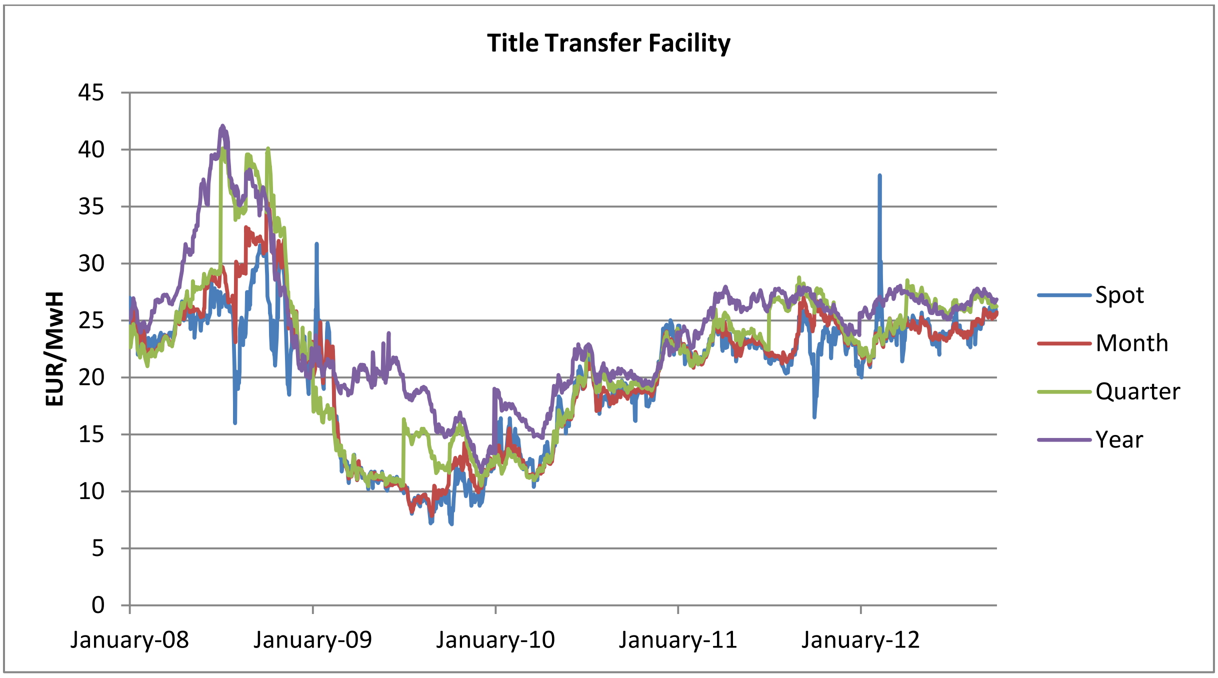
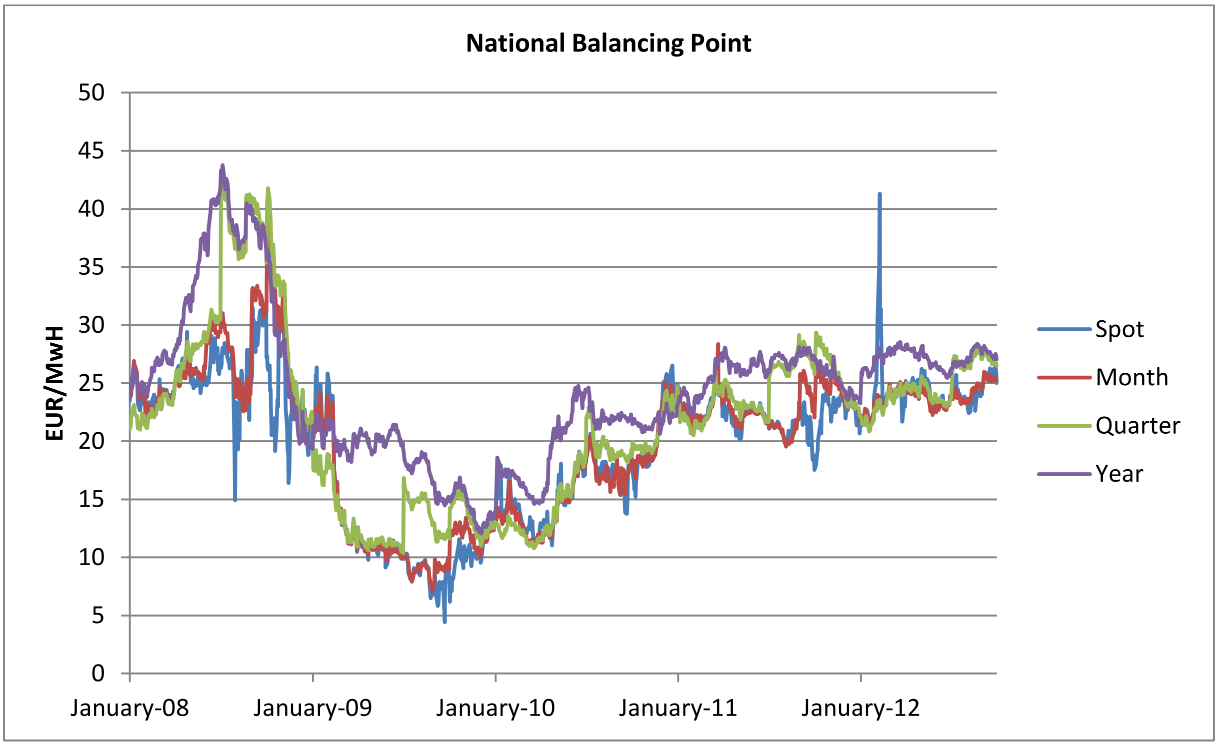
Appendices

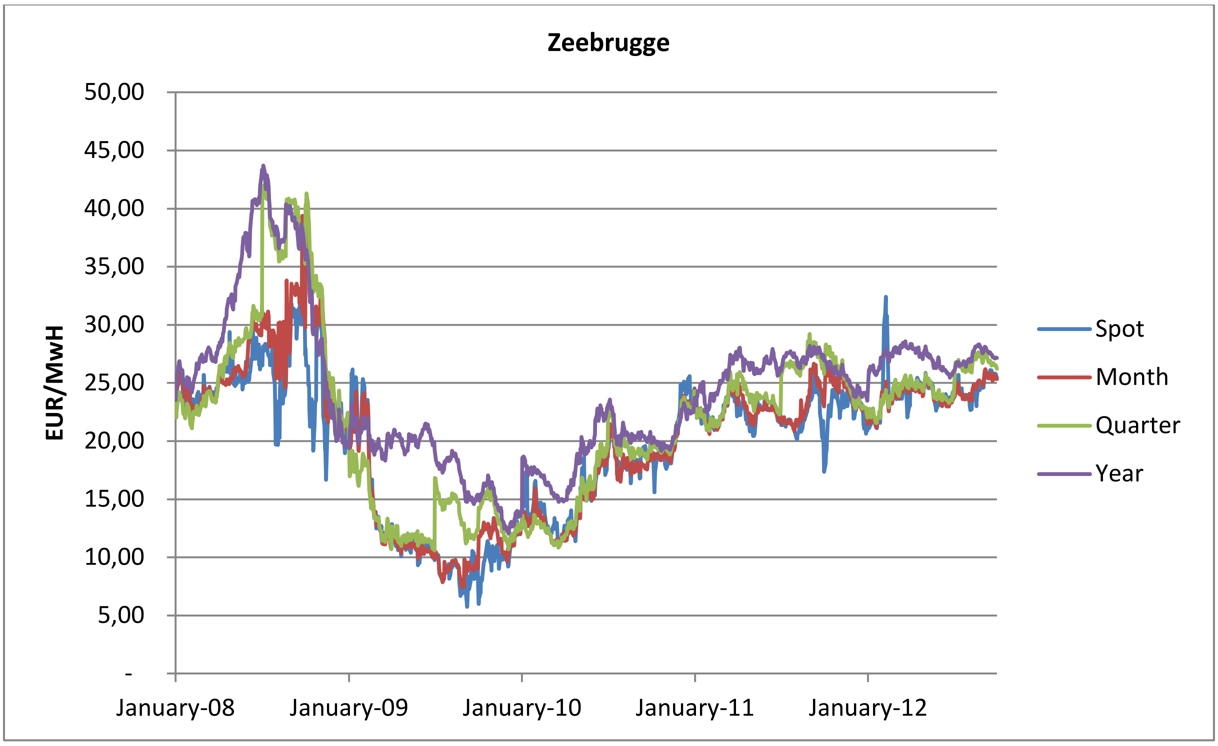
Appendix I: Datastream mnemonics

	Day-ahead	Month-ahead	Quarter-ahead	Year-ahead
TTF	TRNLTTD	TRNLTTM	TRNLTTQ	TRNLTTY
NBP	TRGBNBD	TRGBNBM	TRGBNBQ	TRGBNBY
Zeebrugge	TRBEZED	TRBEZEM	TRBEZEQ	TRBEZEY

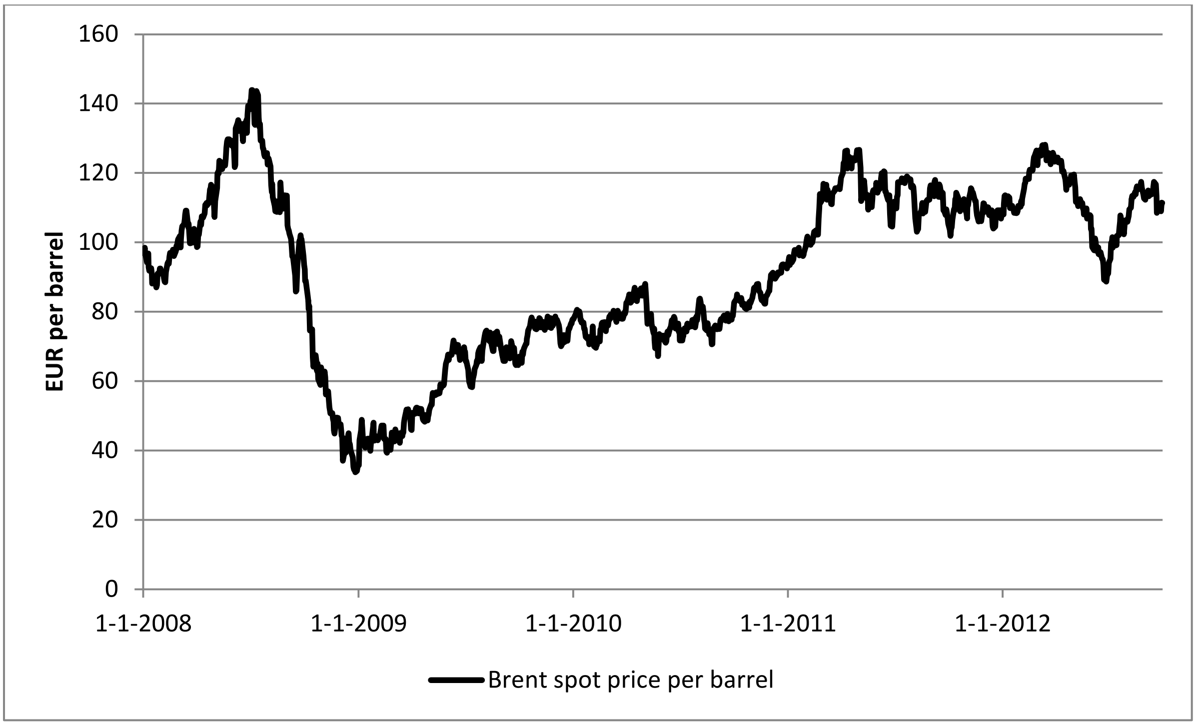
Appendix II: Price series per gas hub



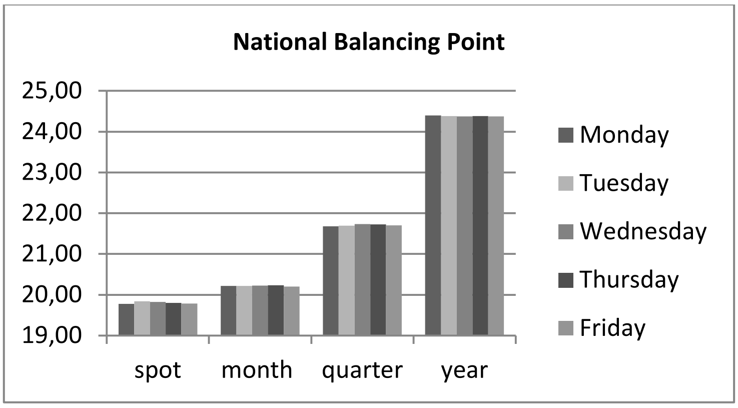


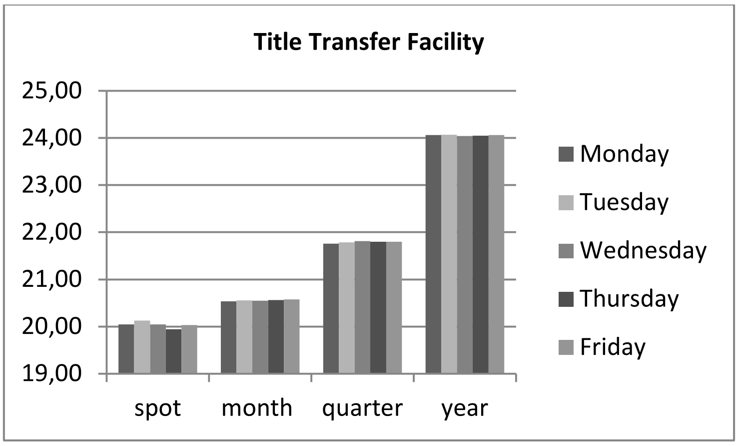


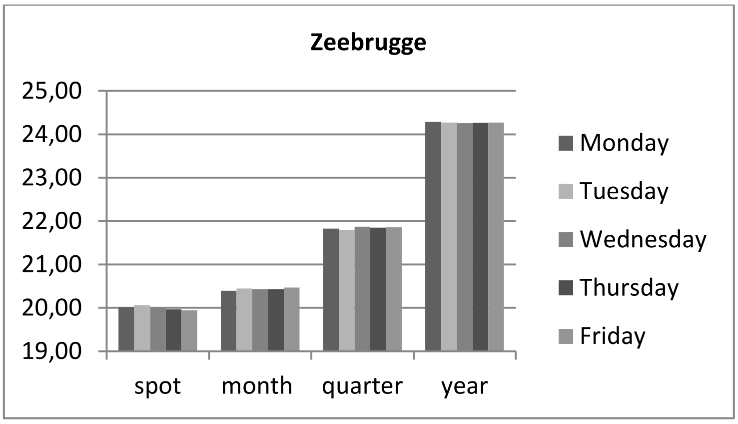
Appendix III: Brent oil price versus the NBP gas price



Appendix IV: Day of the week effect







Appendix V

Figure from Futyan (2006)

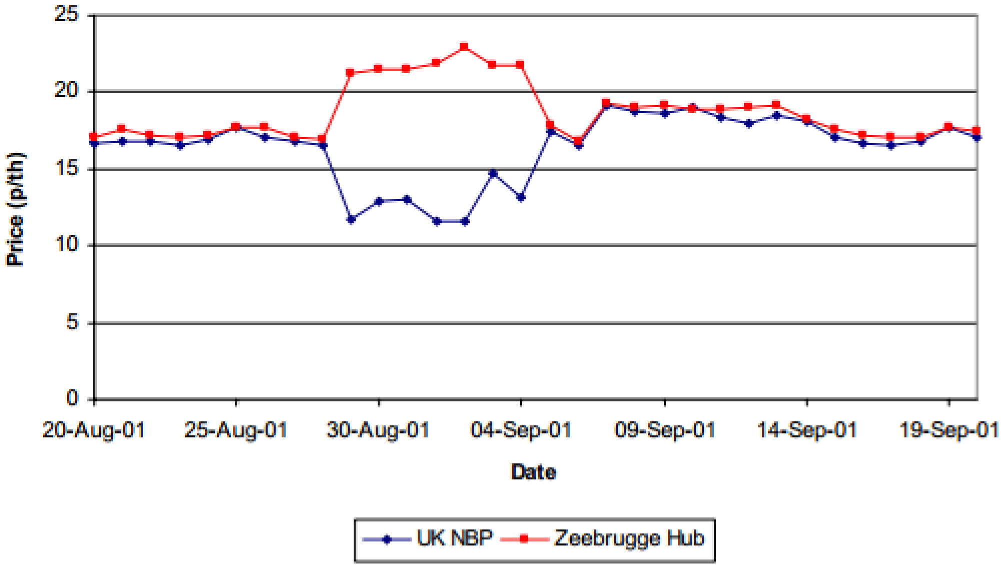
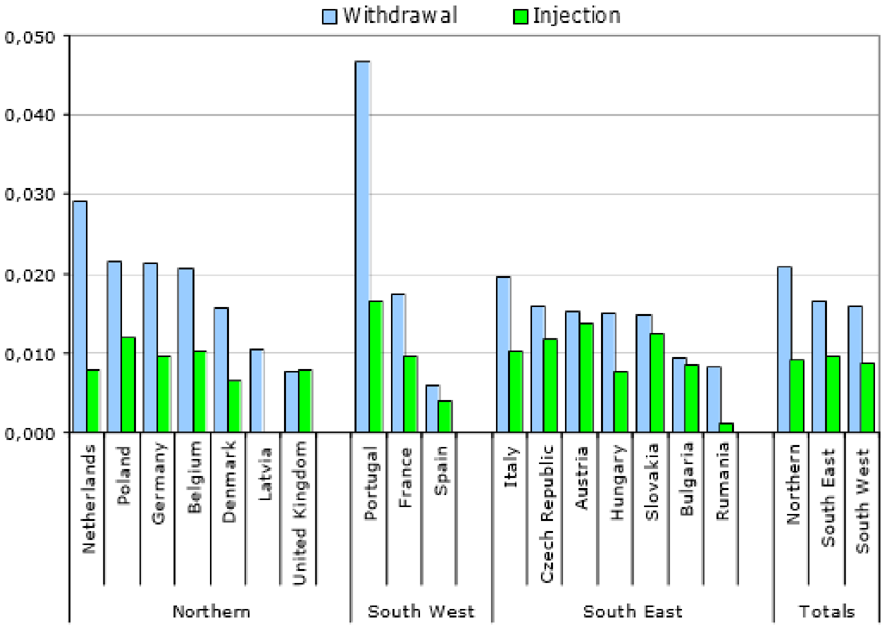


Figure 19: 2001 Shutdown Gas NBP and Zeebrugge Hub Prices (Source: Heren)

Appendix VI

Figure from Ramboll Oil and Gas. (2008)

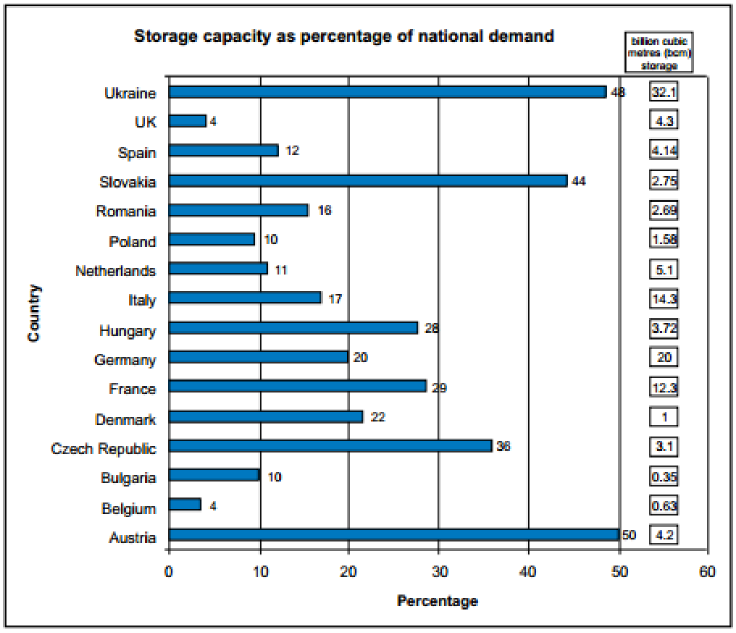
Figure 9 Maximum withdrawal and injection rates per unit of volume capacity 2008



Appendix VII

Figure from House of Commons Energy and Climate Change Committee (2011)

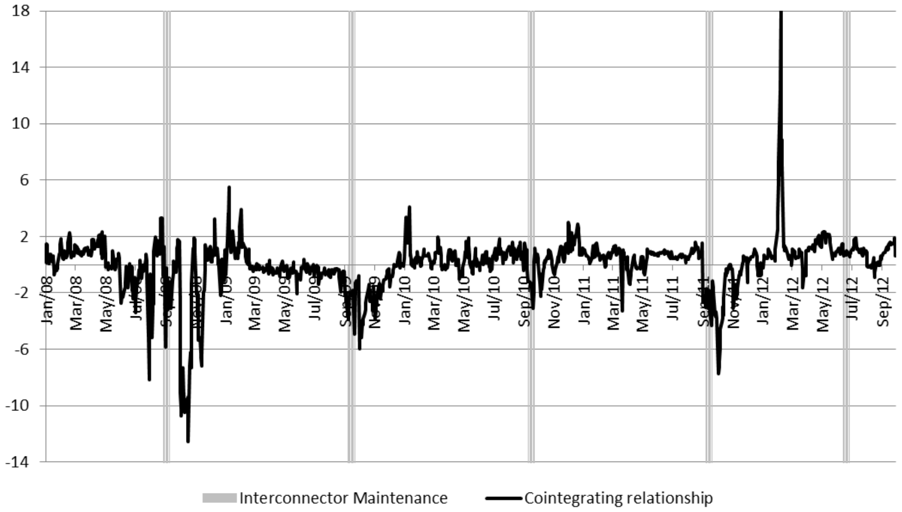
COMPARISON OF EUROPEAN GAS STORAGE CAPACITY AS A PERCENTAGE OF NATIONAL DEMAND



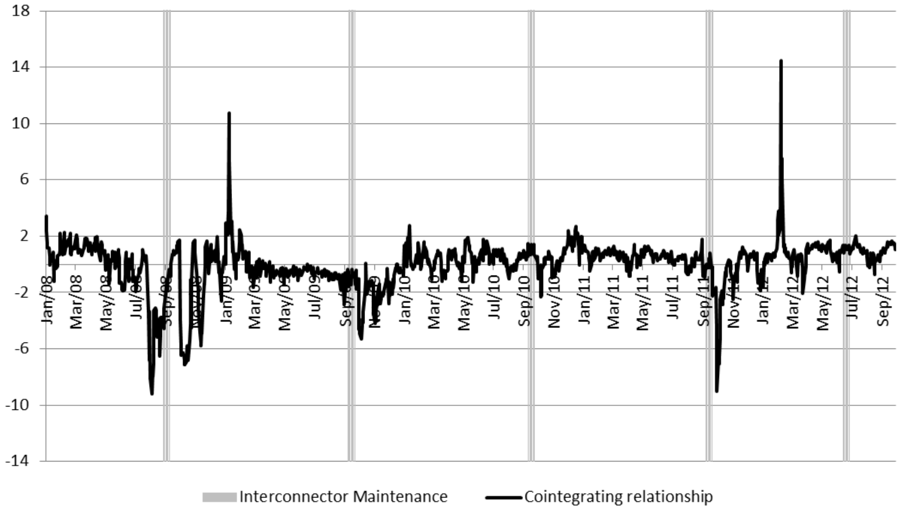
Sources: Gas Infrastructure Europe, CIA World Fact Book 2009, National Grid and International Energy Agency

Appendix VII: cointegrating relationships between spot and month ahead prices at the same hub

Cointegrating relationship between NBP spot and month ahead prices



Cointegrating relationship between TTF spot and month ahead prices



Cointegrating relationship between Zeebrugge spot and month ahead prices