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Impact of natural gas storage on natural gas prices

An empirical analysis of the Western European gas market

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Abstract

This paper examines the effect of natural gas storage on natural gas prices. Using a comprehensive dataset containing daily data for the period 2010-2014 we estimate two specifications for the Dutch, German and British natural gas markets. We do not find evidence of a stabilising effect of natural gas storage on daily price changes. However we do find strong evidence of a positive effect of inventory levels of natural gas storage facilities on intertemporal price spreads.

Keywords: natural gas storage, natural gas prices, Western Europe

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1. Introduction

Natural gas demand is strongly affected by seasonality, mainly due to large differences in temperature between the summer and winter. Typically, natural gas demand follows a sinusoidal pattern with increased demand during the winter and lower demand during the summer (Lyness, 1984). On the other hand, natural gas supply is rather inflexible resulting in a shortage in winter periods and excess supply in the summer. Natural gas storage facilities are a key element in mitigating this problem. Natural gas storage facilities avoid extremely large production and transportation infrastructures, limit extreme price fluctuations and secure natural gas supply by providing seasonal flexibility. With increased depletion of existing natural gas fields, it is expected that the amount of natural gas storage facilities in the form of depleted fields, salt caverns or aquifers increase in the coming decades. However with energy demand expected to rise and production of natural gas in Western Europe to decrease in the coming era, these facilities might be essential to secure natural gas supply and provide enough seasonal flexibility. The Western European natural gas market is undergoing major changes making it a perfect area to conduct research on. The rise of virtual trading hubs for natural gas in Western Europe, like the Title Transfer Facility (TTF), Net Connect Germany (NCG) and the National Balancing Point (NBP), caused the market design to change over the past years. As a result, natural gas demand and supply are expected to be less dependent on the oil price and the natural gas price moves more freely. With the existing trend of the decoupling of natural gas prices and oil prices, and further independency of the United States in terms of energy demand, a vivid economic area is researched. With a more liberalised and integrated market as well as increased import dependency, storage becomes a vital source of flexible supply in the future. This paper examines these changing circumstances resulting in the following research question:

What is the effect of natural gas storage on natural gas prices in the Dutch, German and British natural gas market?

We focus on natural gas prices in The Netherlands (TTF), Germany (NCG) and the United Kingdom (NBP). These three markets are highly integrated and prices on the three markets have almost perfectly converged (Growitsch, Stronzik and Nepal, 2015) We estimate two models to assess the impact of natural gas storage on natural gas prices during the period 2010-2014. The first model examines factors that influence daily changes in natural gas spot and futures prices. Amongst these are daily changes in a storage differential and supply and demand variables. The first sub question is:

What are the main factors influencing daily changes in natural gas spot, month-ahead and year-ahead prices?

In the second model we measure the effects of inventory levels of natural gas storages on price spreads between futures prices and the spot price of natural gas. This leads to the second sub question:

What is the influence of inventory levels of natural gas storage facilities on intertemporal price spreads?

This paper is an extension of the work written by Mu (2007), Brown and Yücel (2008) and Modjtahedi and Movassagh (2005). However our work is remarkably different as we focus on European natural gas markets whereas previous work primarily focused on the natural gas market in the United States. The unique approach focusing on three separate, natural gas markets has not been conducted before. Important literature related to this topic includes the work of Kaldor (1939), Brennan (1958) and Fama and French (1987).

We constructed a dataset with daily observations for the period 2010-2014 by combining several sources of information. The dataset includes both variables that affect demand and supply of natural gas; amongst these are natural gas storage, the oil price, the coal price, temperature, a competition indicator, a productivity indicator and a risk-free rate. Our results indicate that daily changes in the natural gas price can best be explained by changes in the oil price, coal price, and EONIA rate (the overnight lending rate for a panel of European banks). Additionally we find that inventory levels of natural gas have a positive effect on natural gas price spreads, albeit limited in size. With decreased indigenous production and increased demand for natural gas (Lochner and Bothe, 2009), natural gas storages can act as a key element in securing natural gas supply. To provide enough flexibility in the future, it is therefore recommended to increase natural gas storage capacity in the coming decades.

The remainder of this paper is organized as follows. Section two discusses existing literature concerning the drivers of the natural gas price as well as literature related to the storage of natural gas. Section three gives an overview of the natural gas market and discusses aspects like demand, supply and competition in natural gas markets. Section four provides the reader with background information on natural gas storage facilities. The main types of natural gas storage facilities, as well as important characteristics of natural gas storage facilities are discussed. In section five we present the first model on the factors influencing daily changes in the natural gas price. Section six discusses the second model that explains intertemporal price spreads between futures prices and the spot price of natural gas, also referred to as the theory of storage. In section 7 we elaborate on the data and conduct some econometric tests. The results are presented in section 8. In section 9 we will discuss these results, provide some limitations. Section 10 concludes the paper.

2. Literature review

2.1 On the drivers of the natural gas price

The natural gas price is affected by many factors that directly or indirectly have an impact on demand or supply. Traditionally, natural gas prices are closely correlated tot the oil price. With increased liberalisation of natural gas markets, markets become more integrated resulting in price convergence. Furthermore a decoupling of the natural gas and oil price is observed, mainly caused due to the same liberalisation of the natural gas market. In their paper, Brown and Yücel (2008) investigate factors that drive natural gas prices on the Henry Hub in the United States. They state that other factors besides the oil price might influence natural gas prices. Amongst these factors are weather, seasonality, natural gas storage and disruptions in production. The authors calculate a storage differential as the difference between storage in a given week and the average for that week over the past five years. When the filling degree of a natural gas storage facility is above the seasonal norm, it depresses natural gas prices. Chiou-Wei, Linn and Zhu (2013) find that daily changes in the oil price have a positive effect on daily changes in the natural gas price. Cornshaw, Marstrand, Pirovska, Simmons and Wempe (2008) find that as a result of low investments in natural gas infrastructures in Western Europe, supply bottlenecks might arise in the future. Consequently, import dependency rises in the future, mostly in the form of LNG imports. Hintermann (2010) studies the effects of several fossil fuels on emission rights. He finds a positive relation between CO2 emission rights and the natural gas price. If the price of emission rights increases, substitution from coal to natural gas fired power plants occurs stimulating the natural gas price. Sims, Rogner and Gregory (2003) mention renewable sources of energy such as hydro-electricity, wind power, biomass and solar power as potential determinants of the natural gas price. However these renewable energy sources are not able to compete at the most competitive level yet, and often require state-aid in the form o8f subsidies. Asche, Osmundsen and Sandsmark (2006) focus on market integration of natural gas, oil and electricity markets in the United Kingdom. They find an integrated energy market in which the oil price is the leading price. A constant relation between the natural gas price and the oil price is observed. Neumann (2009) found that the natural gas spot prices between Europe and North America have increasingly converged over the past decade. A possible explanation for this finding is the development of trade in LNG and the possibility that LNG cargo vessels can ship to markets with the highest natural gas price. Ferreira Ramos, Pimenta Carlos and Martins de Souza (2009) focus on natural gas market integration in Europe, Japan and North America. They observe a strong integration of European natural gas markets. Growitsch et al. (2015) investigate market integration between the German and Dutch natural gas hubs and observe that prices have almost perfectly converged, with the TTF as the leading price.

2.2 Previous research on natural gas storage

Due to increased demand for natural gas and increased depletion of existing natural gas fields, the necessity for natural gas storage facilities has never been higher. Most of economic literature concentrates on the dynamics of natural gas prices, scarcity of natural gas or variations in production levels. Less emphasis has been put on seasonal flexibility and the role of natural gas storage facilities. This section specifically deals with this topic and reviews some important papers with a focus on seasonal flexibility and natural gas storages.

One of the first papers to discuss the issue of seasonal flexibility is written by Welch, Smith, Rix and Reader (1971). The authors acknowledge the fact that while natural gas supply is relatively constant over time, natural gas demand is influenced by a seasonal pattern. The authors mention five options to deal with seasonal peak demand of natural gas. One of these options is to stock produced goods prior to a peak period, hereby making use of natural gas storage facilities. In a broader perspective, Williams and Wright (1991) find that while some commodities can be stored limitless at zero cost, other commodities are costly to store with increasing cost functions. Natural gas storage is part of the second type of commodities. The authors state that natural gas storage facilities serve as an inter-period provision of supply. Additionally they find that storage serves as a stabilising factor, smoothing out seasonality in demand. Caton (1984) focuses on the British natural gas market. The author identifies a complex natural gas market in which indigenous production is low. To be able to meet variations in demand, storage facilities need to be operated. Investments in new storage require a substantial amount of capital, resulting in a time consuming and costly process. Lyness (1984) emphasizes that investments in natural gas storage facilities are generally long-term projects. Therefore, forecasts concerning peak demand and seasonal gas demand are very important. By making an accurate forecast about future natural gas demand, investments in future storage facilities can be carefully considered before actually being conducted. The author concludes that forecasts concerning peak demand are only reliable in the short-term. In the long-term estimates become increasingly unreliable due to uncertainty in terms of the environment. Höffler and Kübler (2007) provide an estimation of additional demand for natural gas storage over the period 2005-2030 in Western Europe. Due to decreasing reserves and production, countries in Western Europe become increasingly dependent on imports, which are generally less flexible. Additional natural gas storage facilities need to be constructed so that flexibility and hereby supply of storage is secured. Using historical data concerning supply and demand the authors estimate that demand for storage by 2030 ranges from 10,2 (without strategic natural gas storage) to 29,0 billion m^3 (with strategic natural gas storage from non EU-countries) in addition to the existing 40,0 billion m^3 that already is in operation. Joode and Özdemir (2010) extend the analysis by Höffler and Kübler, taking into account that seasonal storage competes with other alternatives to provide seasonal flexibility. These alternatives include pipeline imports and LNG imports. Additionally Joode and Özdemir control for uncertainties in the competitive position of alternative sources. The authors estimate that additional storage capacity is required and ranges from 13 billion m^3 in the low natural gas demand scenario to 20 billion m^3 in the base scenario[1].

2.3 On the theory of storage

The theory of storage is a relation that describes differences between futures prices and spot prices, the so-called basis or spread. This spread can be explained by three factors; the interest rate, marginal storage costs and a convenience yield. This convenience yield might come from holding inventories to meet unexpected demand. The first to describe such a relation was Working (1933) when he wrote his article on price relations between wheat futures.

[1] The low natural gas demand scenario is based on a scenario in which the 2020 European Commission's emission targets are reached whereas the base scenario is based on projections following the current trajectory.

Kaldor (1939) extended this original model and introduced the term convenience yield. Brennan (1958) further improved the model and acknowledged the fact that storage could serve to stabilise the supply of commodities by making use of storage facilities. This is especially useful when a commodity is affected by irregular or seasonal demand while supply is rather stable over time. French (1986) relates inventory levels to spot price predictions. He finds that the magnitudes of seasonal variation increases with the importance of seasonality in supply or demand functions. Fama and French (1987) further developed the model and tested for seasonality in inventories. This seasonality was caused by seasonality in production, demand or supply. Their results predict that commodities affected by seasonality in supply and demand or high-storage costs result in large price differences in the spread. Vice versa, products that are not subject to seasonality in supply and demand have small price differences in the spread. Ng and Pirrong (1996) examine the volatility of natural gas spot and futures prices and find that spot prices are more volatile than futures prices. Routledge, Seppi and Spatt (2000) emphasize that the convenience yield must be seen as a timing option, whose value is zero for predictable variations such as seasonal demand and supply effects but possibly positive for unexpected shocks.

Recent economic literature related to the topic typically tests the validity of the theory of storage. Cartea and Williams (2008) research the relation between storage and the short-term market price of risk. They argue that deviations from expected seasonal storage levels rather than absolute storage levels determine to a large extent this relation. By having a higher supply than initially planned, prices tend to be lower due to the fact that facility owners would like to sell natural gas. This is only possible if the facility owners provide a discount on the natural gas price. Furthermore the authors find that it is irrelevant whether supplies are being put into or taken out of storage. It is more important how these injections and withdrawals compare to what the market expects them to be. For the specific UK market analysed in the paper, the authors conclude that the short-term market price of risk is higher when storage inventories are being depleted more slowly than the seasonal plans expect them to be. From the viewpoint of storage owners, this means that they have to provide a higher discount on the price to prevent that natural gas in the storage facility might not be used. Mu (2007) studies the short-term price dynamics of natural gas futures markets and examines how prices are influenced by weather and storage. Mu identifies a so called ‘storage announcement effect’; information about the weekly change of natural gas storage levels can shift the distribution of daily prices. In addition, for a given storage level unexpected weather changes may result in price changes and uncertainty about future supply conditions. Similar to the natural gas price, natural gas inventory displays a strong seasonal pattern. Mu finds that prices increase when the actual amount of natural gas in storage falls below the market expectation. According to Linn and Zhu (2004) the price is in a new equilibrium after 30 minutes of trading following the release of the storage report. Modjtahedi and Movassagh (2005) estimate a model in which the difference between the futures price and the spot price of a commodity depends on the nominal interest rate and the 'net' storage costs. The authors describe a linear relation between inventory levels and net storage costs. The authors find that intertemporal price spreads are positively by higher inventory levels of natural gas storages. Thompson, Davison and Rasmussen (2009) mention that efficient and reliable natural gas storage is vital for managing fluctuations in natural gas supply and demand. It provides the only significant supply and demand cushion when needed. Haff, Lindqvist and Løland (2008) estimate a model using the same approach as Cartea and Williams (2008). The authors find that storage has a positive effect on the price spread, especially when storage data from continental European countries is included. Le Fevre (2013) argues that volume flexibility is a critical component in natural gas markets. Natural gas storage is one of the most effective means of providing flexibility. Other functions of natural gas storage include strategic supply, commercial requirements, and support of market developments.

3. Overview of the natural gas market

This section presents an overview of the Western European natural gas market with a focus on natural gas storage facilities. Acquiring knowledge of the natural gas market both in a historical fashion as well as in a forward-looking mind-set is necessary before proceeding with more specific information concerning natural gas storage facilities. Important features of the natural gas market like demand, supply and the natural gas price are discussed.

3.1 Demand for natural gas

Demand for natural gas is expected to increase significantly in the next 20 years. This is mainly a result of the increased importance of the share of natural gas in meeting world energy demand (Lochner and Bothe, 2009). Figure 1 graphs the situation identified by the World Energy Outlook 2010 (WEO). The new policies scenario takes into account the policy plans and commitments made by governments around the world. These include plans to reduce greenhouse gas emissions and reduction of subsidies for fossil-energy. The current policies scenario assumes that no actions are taken since mid-2010 and that there are no changes in policies. Furthermore, previous commitments by countries are not carried out. The 450 scenario assumes that countries actually commit to the policies to reduce greenhouse gas emissions and stick to the two degrees Celsius (2°C) goal[2].

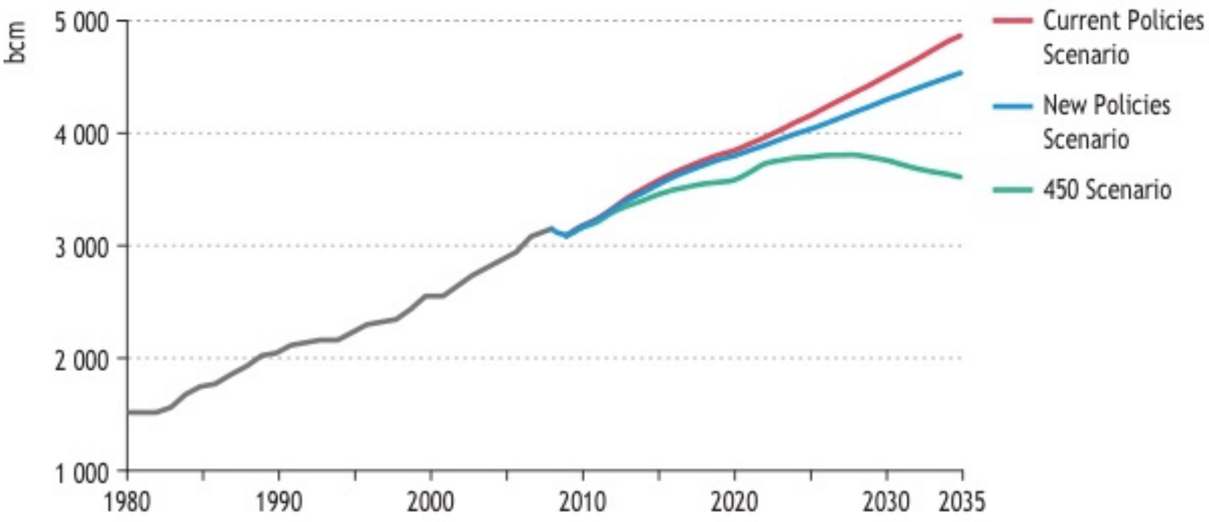

Figure 1, future world natural gas demand by scenario. (Source: WEO 2010)

Under all three scenarios, demand for natural gas is expected to increase enormously. Under the current policies scenario demand is expected to increase by 55% during the period 2008-2035. The new policies scenario predicts that demand is expected to increase by approximately 44%. The most conservative policy scheme, the 450 scenario, expects a smaller increase in natural gas demand, only 15%. Additionally the 450 scenario expects a drop in natural gas demand after 2025, explained by the fact that the share of renewable energies increases and the usage of nuclear power rises.

Demand for natural gas for end users can be divided into three main areas. These three areas are: residential demand, industrial demand and demand for power generation. Together these three sectors account for approximately 90% of total natural gas demand in Europe (Honoré, 2014). The first area of demand for natural gas is the main reason why demand is seasonal. Residential consumers use natural gas as the most important source of heating. During the colder fall and winter periods natural gas consumption increases while consumption is lower

[2] The two degrees Celsius goal is the outcome, referred to as the Copenhagen Accord, of a United Nations conference on climate change in December 2009 held in Copenhagen, Denmark. The Copenhagen accord sets a non-binding objective of limiting the increase in global temperature to two degrees Celsius (2°C) to which all major emitting countries associated themselves. (Source: WEO, 2010)

during spring and summer. The second area of demand comes from industrial users. A vast amount of industrial users use natural gas as a production input. Firms usually aim to maximize profits and therefore choose to make use of the least expensive production input, whether it is natural gas or another type of energy source. The third area of demand comes in the form of power generation. Demand in the third area is expected to increase most significantly, as is confirmed by figure 2. An increasing amount of power plants is natural gas driven and therefore uses natural gas as its primary resource. Especially with policy goals to reduce CO2 emissions, it is expected that the amount of natural gas fired power plants increases significantly at the expense of coal fired power plants in the coming decades.

Figure 2, world natural gas demand forecasts by sector for the years 2008 and 2035. (Source: WEO 2010)

Lyness (1984) identifies three different patterns of peak demand. First of all, a seasonal pattern of natural gas demand with increased demand during the winter period and lower demand during the summer exists. The second pattern is within day peak demand, with peak periods during breakfast and the evening period and lower demand during the night. Lastly a pattern of demand is observed with differences between weekend days and weekdays. Figure 3 graphs the typical seasonality in natural gas demand against changes in temperature, measured by heating degree days.

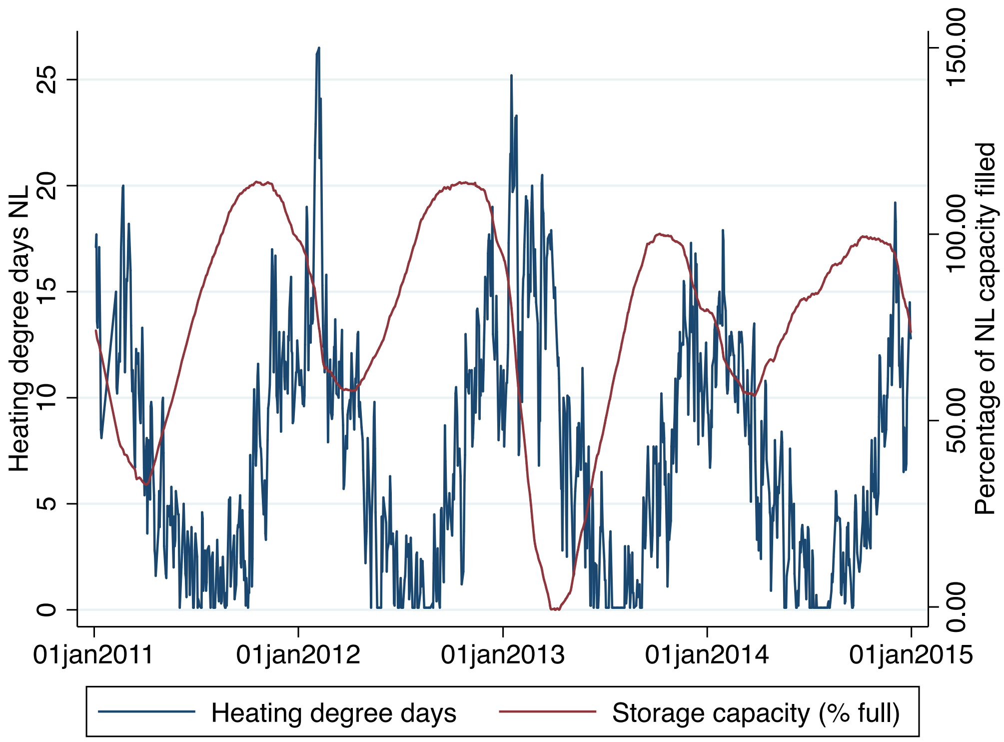

Figure 3, seasonality in natural gas demand: filling degree of natural gas storages against the number of heating degree days in the Netherlands. (Sources: Cedigaz Underground Gas Storage Database, Gas Infrastructure Europe, GasTerra and the *European Climate Assessment and Dataset)*

3.2 Supply of natural gas

Natural gas is an important source for various end-users. The main sources of natural gas supply for Western Europe are indigenous production, imports and storage. Indigenous production is expected to decrease in the coming decades due to depletion of existing reserves (Dickel et al. 2014). As a result, countries become increasingly dependent on imports from countries with vast amounts of natural gas reserves. A third source of supply is natural gas storage facilities, which are mainly used to meet seasonal demand swings. Figure 4 graphs the development of the sources of supply in Western Europe during the period 1995-2004. A significant trend of decreased production can be observed. An opposite trend of increased natural gas storage as source of natural gas supply can be identified as well, whereas the amount of imports shows a stable trend over time. Increased supply by means of natural gas storages accounts for the imbalances created by decreased production levels.

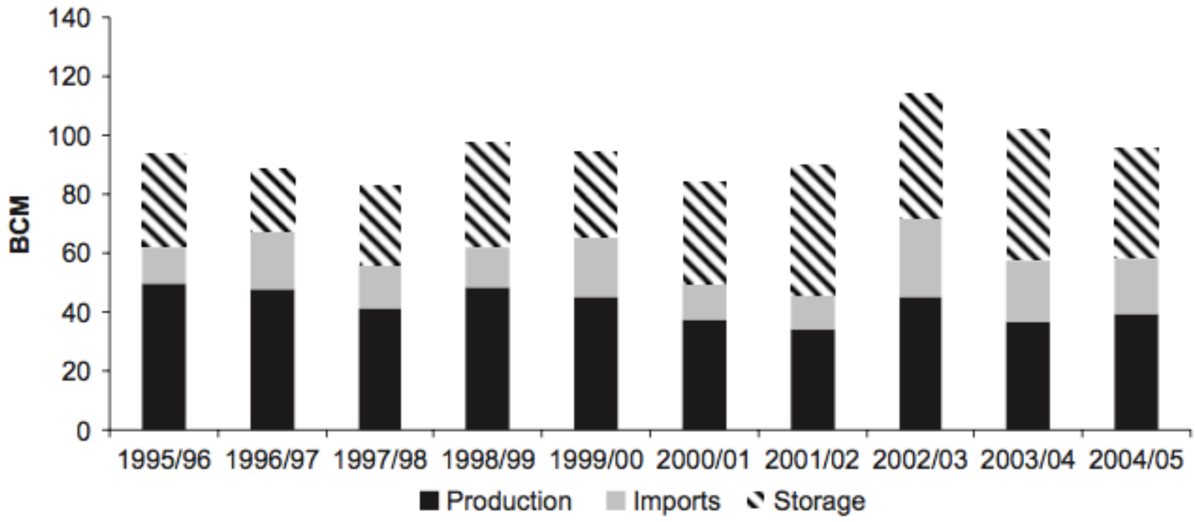

Figure 4, development of the sources of flexible supply in Western Europe 1995-2004. (Source: Höffler and Kübler 2007)

Declining production in the upcoming decades in Western Europe increases dependency on suppliers from outside the region and requires sufficient amounts of natural gas storage facilities to secure natural gas supply. Long transportation distance, political and regulatory issues and transportation costs lead to insecurities in natural gas supply. The dispute between Ukraine and Russia in February 2012 significantly increased market prices and has increased the awareness of the importance of natural gas storage facilities to secure natural gas supply. To be able to meet the decline in production in Western European countries, additional natural gas storage facilities need to be constructed.

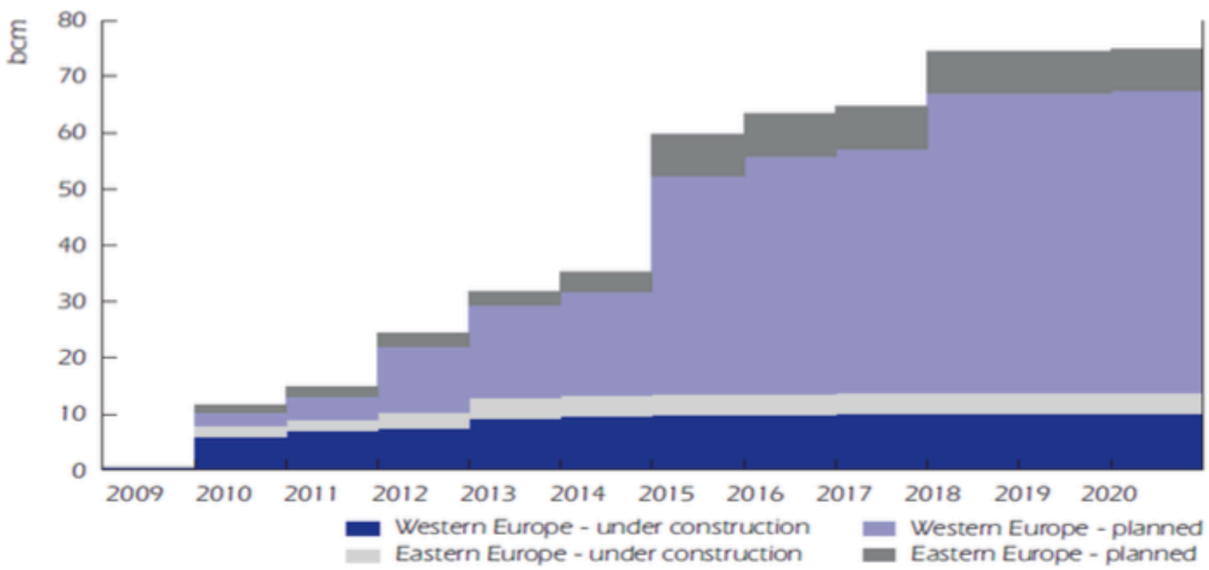

Figure 5, natural gas storage facilities currently planned or under construction in Europe. (Source: Natural gas market review 2009)

Figure 5 provides an overview of natural gas storage facilities that are planned or currently under construction. The actual constructed facilities account for a small percentage compared to the amount of planned facilities. Under-investment in natural gas storage facilities is a result of uncertainties related to regulatory decisions and uncertainty about future demand. Additionally, under investment is a result of very high initial investment costs required to develop a natural gas storage facility.

3.3 Competition and natural gas prices

Since the late 1990's the European Union (EU) has taken significant steps in integrating the fragmented electricity and natural gas markets into a single energy market (IEA 2014). Increased cross-border network investments led to easier access of countries to each other's network and hereby to increased price convergence. Additionally national regulators and transmission system operators were given greater independence resulting in increased competition in the energy sector and further market opening. As a result of the increased liberalisation of the European energy market several physical trading 'hubs' have been formed such as the National Balancing Point (NBP), Title Transfer Facility (TTF) and NetConnect Germany (NGC) in the United Kingdom, the Netherlands and Germany respectively. In the most recent years, hub based trading has increased significantly resulting in higher integration between hubs and a higher level of price equalisation (Petrovich, 2013). With the development of a more integrated natural gas market, the price formation process has also changed. Historically, natural gas was traded on a long-term contract basis with prices linked to oil prices. Hub based trading is based on supply and demand factors and is a dynamic process between traders. Since the liberalisation of the natural gas market the share of natural gas traded on a long-term contract basis has decreased significantly (EC, 2014). Approximately a fifth of al natural gas currently being traded is still based on these long-term contracts. Due to a more market oriented price formation process, prices between hubs have also converged. Amongst others, Kuper and Mulder (2015) find a high degree of integration between the Dutch and German markets. The integration and liberalisation of the several national natural gas markets has resulted in more competitive prices between hubs and a more market oriented price formation process.

4. Natural gas storage facilities

From the theoretical framework it can be stated that seasonal flexibility is a key instrument to mitigate the effects of seasonal natural gas demand. This section elaborates on the different types of underground natural gas storage facilities that are commonly used. Furthermore, important characteristics of these facilities are discussed. In addition, a more specific view on the characteristics per country is presented.

4.1 Characteristics of natural gas storage facilities

A natural gas storage facility is characterised by different variables that are of influence for the specific use of a facility. The maximum capacity available for a natural gas storage facility is called the total storage capacity. Total storage capacity is comprised of base storage capacity and working gas capacity. The base gas capacity is also called cushion gas and is natural gas that is permanently required as inventory in the storage facility to maintain adequate reservoir pressure, hereby ensuring that the deliverability of the facility is held at a constant level. The amount of capacity actually used for operation is working gas. It is the amount of natural gas inventory in addition to the base volume. It is this volume that determines the capacity that is deliverable to the network. Deliverability is the rate at which the reservoir can release natural gas from its reserves during one-day. Deliverability is highest when the reservoir is closest to its maximum capacity and lowest when the reservoir is nearly empty. On the other hand, the injection rate is the rate at which natural gas can be injected into the storage facility for later use. A trade-off exists between the deliverability rate and the injection rate. When the amount of natural gas that is in the facility is increasing, the deliverability increases while the injection rate decreases. This is a result of the fact that the pressure in the facility increases when the reservoir is being filled. Finally, cycling denotes the number of times that the working gas volumes can be injected and withdrawn in a year. In general, there are two important functions of natural gas storage facilities, cover peak-demand and deal with seasonal demand. The first is to cover for unexpected short-term demand. Facilities of this type tend to have high deliverability and injection rates as well as a high amount of cycling. These facilities are used when there is a high amount of unexpected demand or when possibilities of arbitrage exist. The second function is to deal with seasonal demand. With these types of facilities, natural gas is injected in the summer and withdrawn in the winter. Hereby, a stable natural gas supply is secured during the winter. Typically, these facilities have very high working gas capacity.

4.2 Types of natural gas storage facilities

The three main types of natural gas storage facilities are: depleted natural gas fields, salt caverns and aquifers. In addition to these three types another facility that exists is an abandoned mine; however this type of facility is rarely used. Differences in characteristics lead to advantages and disadvantages that differ per type of facility.

The most widely used type of facility is a depleted natural gas field. A depleted natural gas field that was previously used for the production of oil or natural gas is transformed into an underground natural gas storage facility. Depleted natural gas fields have the lowest deliverability and injection rates and are commonly single cycle facilities. In addition they require a substantial amount of base capacity. However, depleted natural gas fields tend to account for most of natural gas storage capacity. This comes due to the fact that depleted natural gas field are abundant in producing regions. Furthermore, the infrastructure is generally already available. Therefore high investments in new infrastructures are not required, something that reduces start-up costs. Due to the fact that the facility was previously used as a production facility the characteristics are well known, therefore it can be secured that this facility is usable as a storing facility.

Salt caverns are facilities that require a vast amount of money to serve as base investment. Salt caverns are developed through a procedure known as solution mining. First, a suitable location has to be found. Once this location is found, a cavern is created within the salt layer. First fresh water is pumped into the cavern. Then some of the salt dissolves against the walls of the cavern creating a strong wall through which it is impossible for natural gas to slip away. The salt water, known as saline[3], is pumped back to the surface. This process is repeatedly performed until the salt cavern has the preferred size and characteristics including a very strong salt wall. Salt caverns have low base gas requirements (typically only 30% of total gas capacity), high deliverability and injection rates and high cycling rates. These facilities are very flexible and due to the high cycling rates capable of dealing with extreme peak-gas demand. Since the facility has to be constructed from zero, this allows a developer of these types of facilities to determine the optimal size. A major drawback of salt caverns is the fact that these facilities generally have a very low capacity, not able to meet base load

[3] Saline is water that contains a high amount of dissolved salts.

storage requirements. When comparing the three types of facilities, salt caverns have by far the highest development costs per cubic meter (Neumann and Zachmann 2008).

Aquifers have deliverability rates, injection rates and cyclical characteristics that fall between depleted natural gas fields and salt caverns. However aquifers require very high amounts of base gas volumes, often up to 80% of the total capacity. Most aquifers were mainly developed during times when the price of natural gas was low, meaning that it was very inexpensive to sacrifice cushion gas. With rising natural gas prices aquifers become more expensive to develop and therefore are the least desirable type of natural gas storage facilities.

4.3 Characteristics of natural gas storage facilities per country of interest

Table 1, presents an overview of the distribution of natural gas storage facilities per country. Interestingly, both the United Kingdom and the Netherlands have a very high share of depleted field as primary type of storage facility. Germany mostly uses salt caverns as primary type of storage facility. A little over 40% of the facilities are depleted fields while a marginal amount of natural gas is stored using aquifers.

Table 1

Natural gas facility characteristics per country

Type of facility	Depleted Field	Salt Cavern	Aquifer	Abandoned mine
Purpose	Long-term	Short-term	Medium-term/Long-term	Short-term
Germany	41,78%	54,40%	3,80%	0,01%
United Kingdom	81,80%	18,2%	-	-
Netherlands	93,75%	6,25%	-	-

(Sources: Cedigaz Underground Gas Storage Database and Gas Infrastructure Europe, own calculations)

5. Explaining daily changes of the natural logarithm of natural gas prices

In the first model we try to estimate factors that influence daily changes in natural gas prices for the TTF, NCG and NBP natural gas trading hubs. Possible non-linear relations are accounted for by taking the natural logarithm of natural gas, oil and coal prices. The model in this paper is in line with the model presented by Mu (2007) and Chiou-Wei et al. (2013). The dependent variable is calculated as the natural logarithm of the daily change in the natural gas price: $\ln(P_{t,i}/P_{t-1,i})$. We estimate the model using the daily change of the day-ahead spot price ($\ln(S_{t,i}/S_{t-1,i})$), the month-ahead futures price ($\ln(M_{t,i}/M_{t-1,i})$) and the year-ahead futures price ($\ln(Y_{t,i}/Y_{t-1,i})$). We include the daily change of a storage differential ($\emptyset_{t,i}/\emptyset_{t-1,i}$) to assess the influence of natural gas storage facilities on changes in the natural gas price. The storage differential is calculated as follows:

$$\emptyset_{t,i} = S_{t,i} - (\tfrac{1}{n} * S_{t-365,i} + \cdots + \tfrac{1}{n} * S_{t-n*365,i}) \qquad (1)$$

where S_t is the weighted percentage of total capacity filled on a given day. $\emptyset_t$ is the actual deviation from the average filling grade of the past n years, measured in percentages. In their paper, Brown and Yücel (2008) use a period of $n = 5$ years for their analysis. In this paper, a period of 3 years is used. The choice to use a period of 3 years is first and foremost a case of data limitations. Reliable data concerning the filling grade of natural gas storages in the respective countries is available from the end of 2007. Since our analysis focuses on the years 2010-2014, a 3-year period therefore best suits the data and is chosen in the empirical specification. To measure the effect of changes in the oil price on changes in the natural gas price we include the natural logarithm of the daily change in the Brent oil price: $\ln(P_t^{oil}/P_{t-1}^{oil})$. Since a vast amount of natural gas is still traded on the basis of oil-indexation, we expect this to positively affect changes in the natural gas price. Natural gas is used as a primary source of power generation and to measure the degree of inter-fuel competition we include the natural logarithm of the daily change in the coal price: $\ln(P_t^{coal}/P_{t-1}^{coal})$. To measure the influence of the weather we include the daily change in Heating Degree Days ($HDD_{t,i}/HDD_{t-1,i}$). Using a base temperature of 18 degrees Celsius, daily HDD date is calculated per country. To account for the effect of competition we include the daily change in the Herfindahl-Hirschman Index (HHI_t/HHI_{t-1}). Since we estimate spot, month-ahead and year-ahead prices we need to account for the time value of money. To measure this effect we include the daily change in the Euro OverNight Index Average (EONIA) as the European risk free rate: $(EONIA_t/EONIA_{t-1})$. To control for general economic activity we include the monthly change of a natural gas consumption weighted average index measuring production of the manufacturing sectors of several Western European[4] countries: $(Industry_m/Industry_{m-1})$. These data is only available on a monthly basis and therefore we appoint the change in a given month to all days in that specific month. We include a dummy to measure the effect of the natural gas dispute between Ukraine and Russia on the 6th and 7th of February: $D^{Ukraine}$. Finally we include a dummy that makes a distinction between the filling season and withdrawal season: $D^{Withdrawal}$. The filling season covers the period from the 1st of April until the 31st of September. The withdrawal season is the period from the 1st of October until the 31st of March. The model can be presented as follows:

$$\ln(P_{t,i}/P_{t-1,i}) = \alpha_0 + \alpha_1 \emptyset_{t,i}/\emptyset_{t-1,i} + \alpha_2 \ln(P_t^{oil}/P_{t-1}^{oil}) + \alpha_3 \ln(P_t^{coal}/P_{t-1}^{coal}) + \alpha_4 HDD_{t,i}/HDD_{t-1,i} + \alpha_5 HHI_t/HHI_{t-1} + \alpha_6 EONIA_t/EONIA_{t-1} + \alpha_7 Industry_m/Industry_{m-1} + \alpha_8 D^{Ukraine} + \alpha_0 D^{Withdrawal} + \varepsilon_{t,i} \qquad (2)$$

where the subscript t indicates a time variable for day, m a time variable for month and i a specific country. $\varepsilon_{t,i}$ is an error term capturing unobserved effects.

Above seasonal norm levels of storage inventories imply that there is excess supply of natural gas. As a result, when unexpected shocks on the demand side occur, storage is able to deal with these discrepancies by supplying additional natural gas. Therefore, storage can be seen as a stabilising factor in relation to the natural gas prices. As a result we expect that changes in the storage differential have a negative effect on natural gas price changes. As earlier described there exists a strong correlation between oil prices and natural gas price. Due to this positive correlation we expect that daily changes in the Brent oil price have a positive effect on daily changes in the natural gas price. Inter fuel competition between coal and natural gas, especially in the power generation sector also increases prices. We therefore expect that changes in the coal price have a positive effect on changes in the natural gas price. The coefficient measuring changes in heating degree days is expected to be positive. A higher amount of heating degree days implies a lower outside temperature, which leads to higher demand for natural gas. Changes in heating degree days should therefore have a positive

[4] We included the manufacturing sectors in Belgium, Denmark, France Germany, The Netherlands and the United Kingdom.

effect on changes in the natural gas price. The HHI index measures the degree of competition in a certain market. Increases in the HHI would lead to a less competitive market and a higher price for natural gas. We therefore expected a positive relation between changes in the HHI index and changes in the natural gas price. We expect a negative coefficient for the EONIA rate. An increase in the EONIA rate means that prices are more heavily discounted resulting in a negative effect on changes in the natural gas price. The industry index measures production in the manufacturing sector in several European countries. Increases in this index indicate higher demand for manufactured goods and thus higher demand for natural gas (as production input). We therefore expect that changes in the industry index positively affect natural gas price changes. We expect that the natural gas dispute between Ukraine and Russia has a positive effect on changes in natural gas prices. The coefficient in front of the dummy capturing the depletion season is expected to be positive. Prices are higher during this season due to increased demand compared to the injection season. A market where unexpected demand and supply shocks are perfectly absorbed by flexible and inflexible supply should lead to an insignificant coefficient measuring this dummy.

6. Explaining the spread between spot and futures prices

In the second model we try to explain intertemporal price spreads between spot and futures natural gas prices. More specifically we examine the spread between year-ahead and spot natural gas prices, and the spread between month-ahead and spot natural gas prices. We try to examine whether the theory of storage is valid for Dutch, British and German natural gas prices. Storage can be considered as a transfer of a commodity from one period to another. Agents holding inventories receive an income stream, known as the convenience yield, which will be rewarding in times of unexpected demand. The cost of holding inventory comes in the form of storage and interest costs. The theory therefore predicts that the difference between the spot and futures prices of a commodity is equal to storage costs plus forgone interests less a convenience yield. It can be presented as follows:

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

Where $F_{t,T}$ is the futures price of the commodity, $S_{t,}$ is the spot price of the commodity, $R_{t,T}$ is the interest rate, $W_{t,T}$ is the marginal storage cost and $C_{t,T}$ the marginal convenience yield. This implies that $F_{t,T} - S_t$ is the return, or the intertemporal price difference (spread) of the commodity. $W_{t,T}$ and $C_{t,T}$ are two indicators that are actually functions of the inventory. This convenience yield might come from holding inventories to meet unexpected demand. It is assumed that the first indicator, $W_{t,T}$, is increasing and the latter, $C_{t,T}$, decreasing in the level of inventory. As a result, 'net' storage costs are positive. We follow the approach taken by Modjtahedi and Movassagh (2005) and construct an estimable equation. They argue that $W_{t,T} - C_{t,T}$ is increasing in the level of inventory I_t and assume a linear relation of the following form:

$$W_{t,T} - C_{t,T} = \alpha_0 + \alpha_1(I_t) \qquad (4)$$

Plugging this result into equation (4) and assigning a coefficient to the interest rate results in a linear equation that is estimable:

$$F_{t,T} - S_t = \alpha_0 + \alpha_1(I_t) + \beta_1 R_{t,T} + \varepsilon_t \qquad (5)$$

Taking the natural logarithm of both the spread and the interest rate allows for non-linear relations between natural gas prices and the interest rate. The following model is estimated in this paper:

$$\ln\left(F_{t,T}\right) - \ln(S_t) = \alpha_0 + \alpha_1(I_t) + \beta_1 \ln(R_{t,T}) + \varepsilon_t \qquad (6)$$

Then according to the theory of storage α_1 should be positive. A higher level of inventory should have a positive effect on the intertemporal price spread. Higher inventory levels denote lower scarcity in the natural gas markets. As a result the spot price will be lower resulting in a higher price spread. The interest rate should have a negative coefficient, indicating future discounting or arbitrage opportunities. If the model is sufficiently specified, α_0 should be statistically insignificant (Fama and French, 1987).

7. Data

7.1 Explaining daily changes in the natural gas price

The first model analyses the influence of several variables on the natural logarithm of daily changes in the natural gas price. Table 2 presents an overview of the ratios that are used in the first model.

Table 2

Overview of the daily changes used as dependent variable in the first model.

	The Netherlands (TTF)	Germany (NBP)	United Kingdom (NCG)
Day-ahead	$\ln(S_{t,NL}/S_{t-1,NL})$	$\ln(S_{t,GER}/S_{t-1,GER})$	$\ln(S_{t,UK}/S_{t-1,UK})$
Month-ahead	$\ln(M_{t,NL}/M_{t-1,NL})$	$\ln(M_{t,GER}/M_{t-1,GER})$	$\ln(M_{t,UK}/M_{t-1,UK})$
Year-ahead	$\ln(Y_{t,NL}/Y_{t-1,NL})$	$\ln(Y_{t,GER}/Y_{t-1,GER})$	$\ln(Y_{t,UK}/Y_{t-1,UK})$

Note: S stand for the spot natural gas price, M for the month-ahead futures natural gas price whereas Y stands for the year-ahead futures natural gas price.

The analysis focuses on three hubs for which daily data is extracted from ICIS Heren for the day-ahead spot natural gas price (S), the month-ahead (M) and year-ahead (Y) futures natural gas price for the period 2011-2014. Whereas the Dutch and German natural gas prices are denominated in Euro per megawatt-hour (Euro/MwH), the British natural gas prices are denominated in pence per therm. To allow easy comparison between the three hubs British natural gas prices are first divided by 100[5] and subsequently multiplied by the Euro/Pound exchange rate to account for exchange rate fluctuations. Finally these prices are divided by 0,02930011[6] to obtain NBP prices in Euro/MwH. Euro/Pound exchange rate data is extracted from the Statistical Interactive Database of the Bank of England. Natural gas is only traded during weekdays and therefore there is no information available for weekend days, limiting the study to weekdays only. Figure 6 plots day-ahead, month-ahead and year-ahead natural gas price data for one of the hubs of interest, the TTF respectively.

[5] 100 pence is equal to 1 British pound.

[6] 1 therm is equal to 0.02930011 MwH.

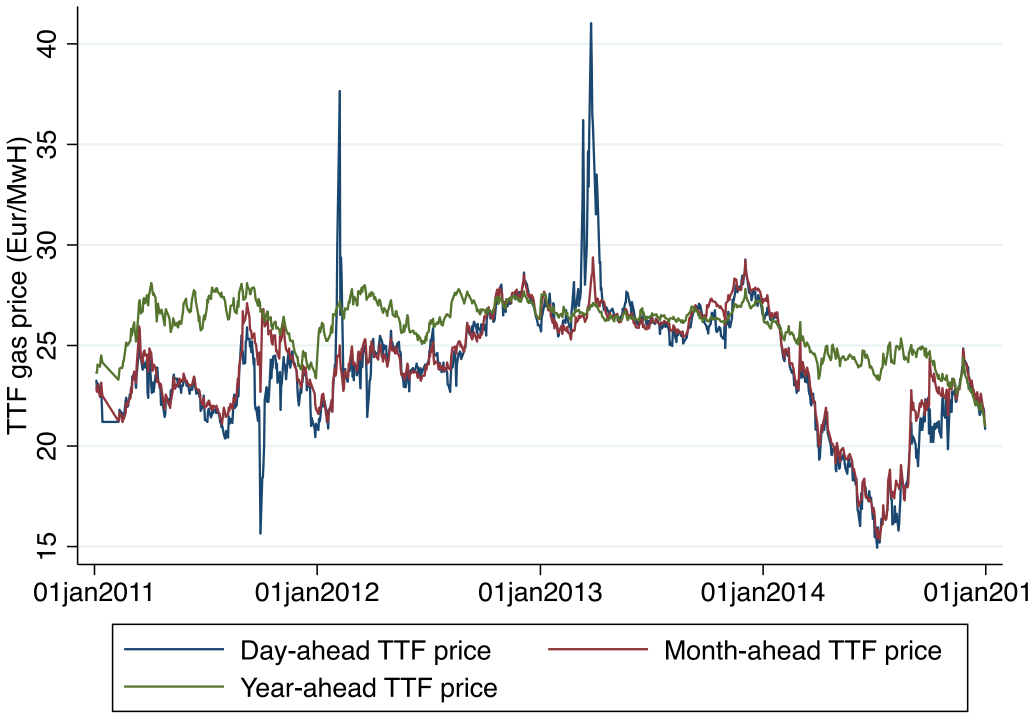

Figure 6, development of the day-ahead, month-ahead and year-ahead natural gas prices on the TTF hub. (Source: GasTerra)

As can be seen in figure 6, the day-ahead and month-ahead prices closely follow each other closely and are equally volatile over time. Some price peaks can be identified which are more severe for the day-ahead price than for the month-ahead price. This is a result of the fact that the month-ahead price is able to smooth out these unexpected disruptions over a longer timer period. Two peaks are caused by the Fukushima nuclear disaster on the 11th of May 2011 and the natural gas dispute between Russia and Ukraine on the 6th and 7th of February 2012. The year-ahead price seems to follow a rather independent path in the figure; in addition these prices are less volatile. An interesting observation is the fact that while the day-ahead and month-ahead prices started to decrease from January 2014 onwards, the year-ahead price only gradually decreased. From August 2014 the day-ahead and month-ahead prices started to increase again ultimately reaching the steady path of the year-ahead price in December 2014.

For an overview of natural gas storages that are currently in operation as well as the sites that are under construction and facilities planned for the future, the Cedigaz Underground Gas Storage Database is consulted. This database includes information on the total available storage capacity in the selected countries in this paper. Appendix C gives an overview of the natural gas storage facilities that are included in the calculation of the storage differential. The second source from which data is extracted is Gas Infrastructure Europe. This association measures the activities conducted by the numerous transmission system operator's (TSO). The dataset includes the daily filling degree of natural gas storages for a very high amount of countries. For the countries of interest for this paper, only data for The Netherlands is limited. This problem is solved for by using data concerning flows into-, and out of natural gas storages in The Netherlands, which is provided by GasTerra. By transforming these flows we obtain a percentage that indicates the filling degree of each storage facility. By combining these percentages, a weighted filling percentage for The Netherlands is calculated. Figure 7 plots the filling degree of natural gas storages over the period 2011-2014 per country. As clearly can be seen from this graph, the filling degrees of natural gas storage facilities strongly follow a seasonal trend. Natural gas storages are being filled during the summer and used as additional supply mechanism during the winter.

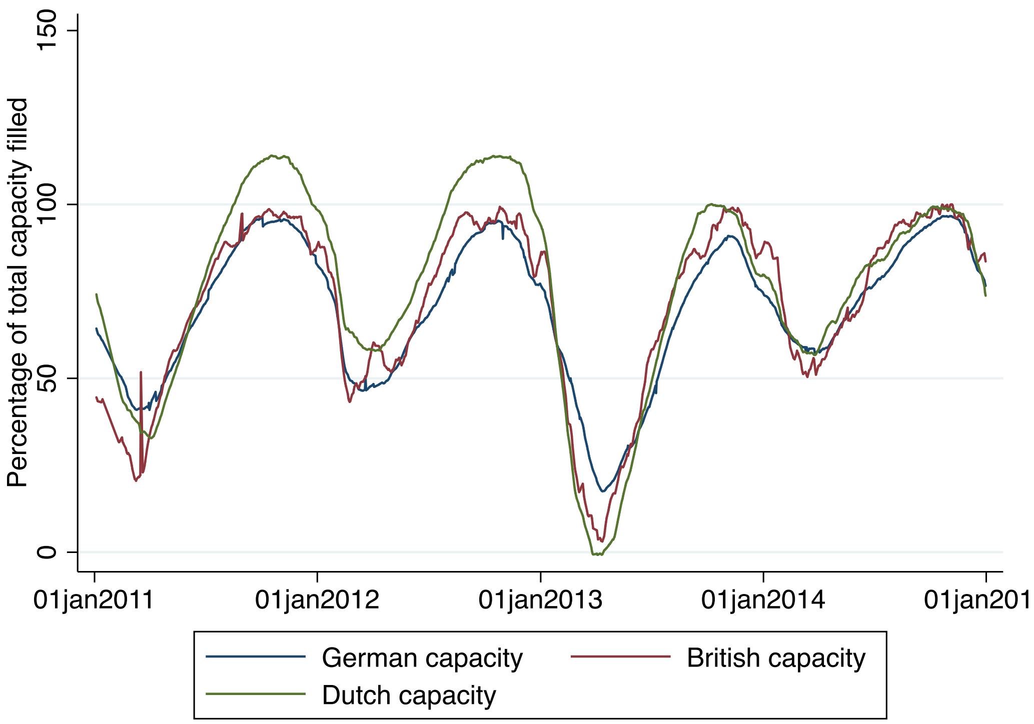

Figure 7, total capacity of natural gas storage facilities filled per country, measured in percentages. (Sources: Cedigaz Underground Gas Storage Database, Gas Infrastructure Europe and GasTerra)

Although actually not possible, the Dutch filling degree indicates a higher filling degree than 100%. This comes due to the fact that not all extractions are reported correctly. Additionally, indigenous production in the Dutch natural gas market mainly accounted for by the

Groningen 'swing-field' (GasTerra, 2014), which allows rapid adaption to changing circumstances. Some of the additionally obtained natural gas out of the production process is then reported as extracted from a natural gas storage facility. The irregular trajectory of the British filling degree suggests high sensitivity to disruptions, possibly caused by shortages in natural gas storage facilities.

One of the explanatory variables is the natural gas storage differential. This natural gas storage differential is calculated as the deviation from the average filling grade over the past 3 years. Figure 8 depicts the storage differential for The Netherlands, Germany and the United Kingdom

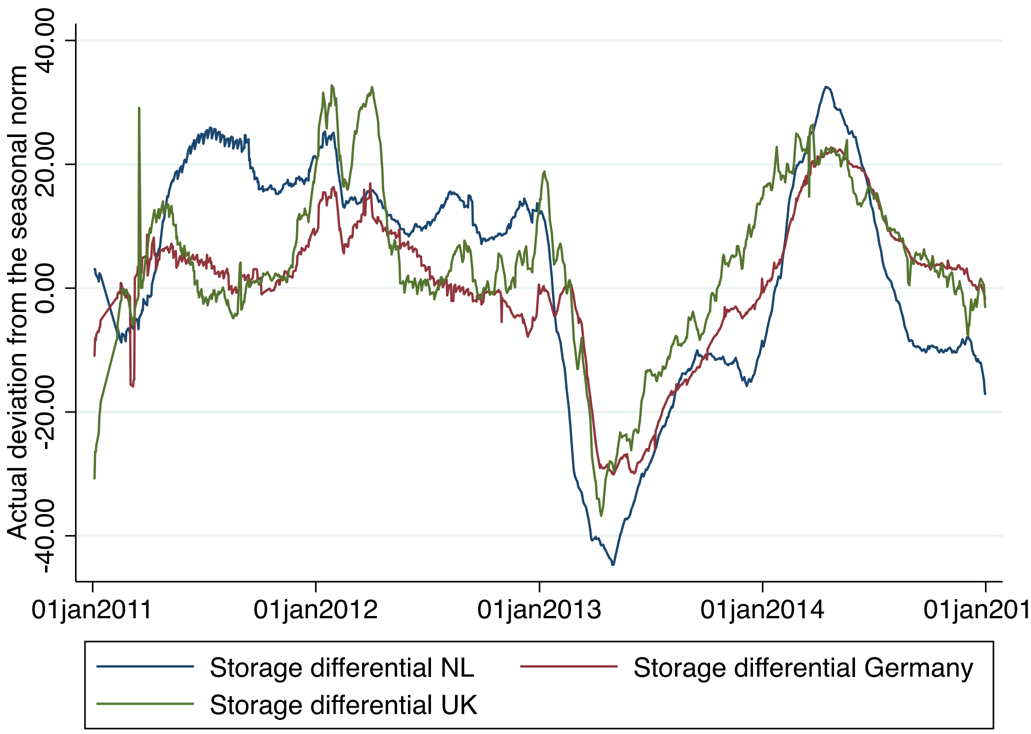

Figure 8, storage differential calculated per country as the deviation from the average filling grade over the past three years. Deviations are measured in percentages. (Sources: Cedigaz Underground Gas Storage Database, Gas Infrastructure Europe and GasTerra)

The storage differential for Germany is the most stable line indicating high flexibility concerning natural gas supply. The Netherlands can be identified by the highest volatility in terms of the natural gas storage differential. The situation in the United Kingdom is fairly similar to that of The Netherlands. In general, a massive decrease in the storage differential can be observed during March 2013, caused by the severe winter in that year (KNMI).

The natural gas price and the oil price are closely related and seem to follow a similar trend. Therefore, the Brent oil price is included as independent variable. The oil price used in this paper is the Brent day-ahead price, measured in dollar per barrel. For ease of analysis this oil price is divided by the US Dollar/Euro exchange rate to obtain a price in Euro per barrel. Subsequently this price is converted from barrel to MwH so that a Brent oil price in Euro per MwH is constructed[7].

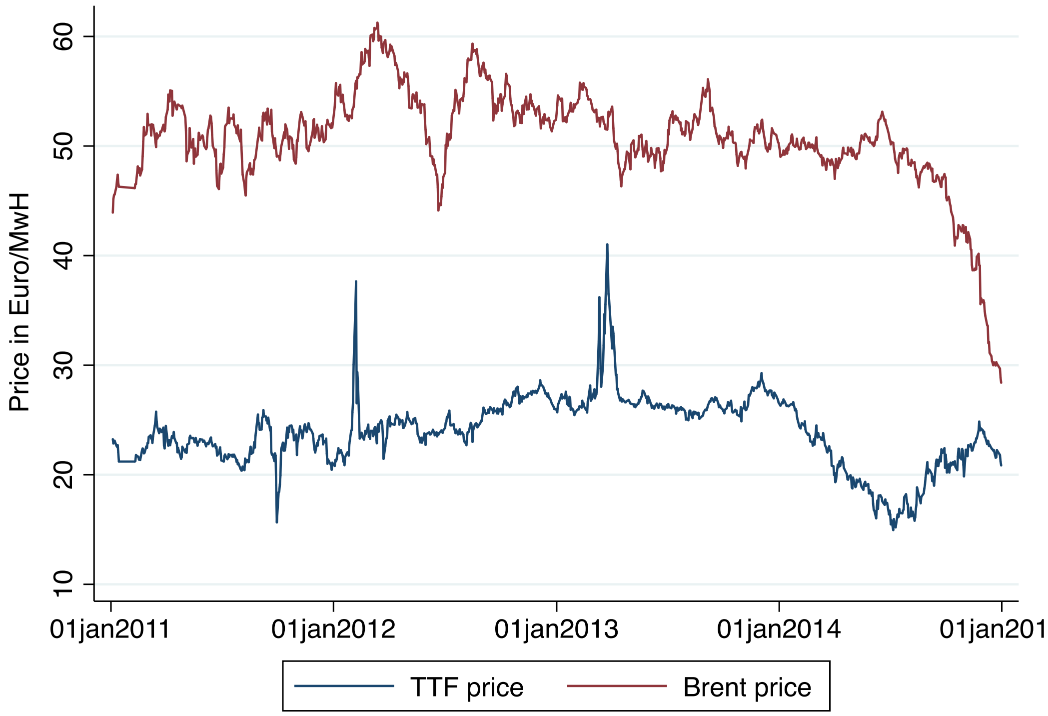

Figure 9, Brent oil price and TTF day-ahead price measured in Euro/MwH. (Source: ICIS Heren)

Figure 9 plots the TTF day-ahead and Brent-day-ahead price and seems to imply a co-movement of natural gas and oil commodities. During the period 2011-mid 2012 a similar movement can be observed. From mid 2012 the natural gas price and oil price diverge little by little and during the second half-year of 2014 actually move in opposite direction, suggesting a decoupling of the natural gas and oil price. Data for the Brent oil price and the US Dollar/Euro exchange rate is extracted from ICIS Heren.

[7] 7,3 barrels of oil are equal to a ton of oil. A ton of oil contains 41,87 GJ of energy, equal to 0,277777778 MwH. Multiplying the Euro per barrel price by $(41{,}87/7{,}3) * 0{,}277777778$ results in the price of oil in Euro/MwH.

To address the effects of the weather on the daily change in the natural gas price, a Heating Degree Days (HDD) variable is calculated. Daily average temperature data is extracted for Germany, the United Kingdom and the Netherlands from the European Climate Assessment and Dataset (ECA&D). Using a base temperature of 18 degrees Celsius, the amount of HDD per country is constructed. Macroeconomic developments are accounted for by including a risk-free rate, we use data for the Euro OverNight Index Average (EONIA). EONIA is the rate at which banks that belong to the EONIA panel[8] can conduct overnight lending activities. Daily data for EONIA is extracted from the European Central Bank's Statistical Data Warehouse. General economic activity is captured by a natural gas consumption weighted average monthly index of production, extracted from Eurostat. The manufacturing sectors in France, the United Kingdom, Belgium, Germany, Denmark and The Netherlands are included. To measure the degree of inter-fuel competition, especially in the area of power generation, we include the coal price. Daily prices are extracted from Bloomberg.

To measure to which extent competition plays a role in the return on natural gas prices, a Herfindahl-Hirschman Index (HHI) is constructed for the relevant market that possibly influences the TTF, NBP or NCG prices. The daily HHI variable is based on daily production data for the countries Russia, Norway, Algeria, the Netherlands, the UK and LNG. Since we do not include production data of other European countries we slightly overestimate the HHI. Typically a country has several entry points at which natural gas enters a country. Additionally several entry points have more than one TSO. Therefore every TSO at the border of a country is taken into consideration. Production data is extracted from Eclipse and measured in MwH. The HHI variable is calculated as the sum of all market shares of the respective supply sources. Figure 10 graphs the development of the HHI over time. The HHI increased from approximately 1850 in January 2011 to 2125 in December 2014 indicating that the market has become less competitive, caused by decreasing shares of small producing countries such as The Netherlands and the United Kingdom. Additionally the market share of LNG decreased significantly during the period 2011-2014. This is probably caused by the nuclear disaster in Fukushima, Japan that led to higher gas prices in that part of the world.

[8] The EONIA panel consists of a group of 35 European and non-European banks which are large international banks. The majority of participating banks are located in one of the Euro membership countries; only 3 banks are located in non-Euro countries.

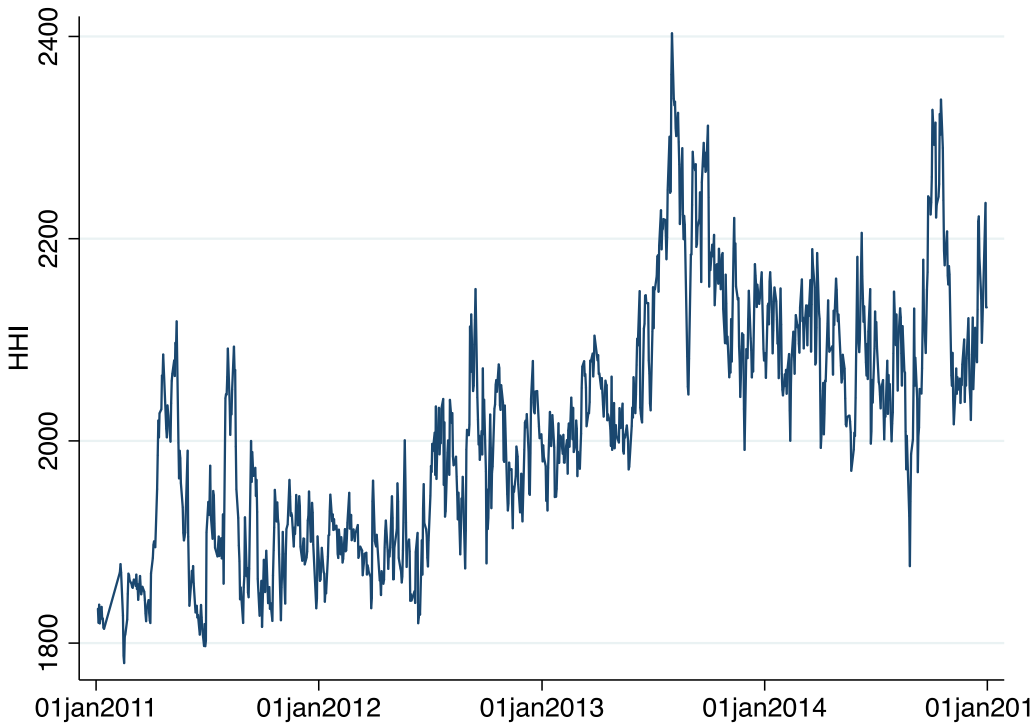

Figure 10, development of the HHI index during the period 2011-2014. (source Eclipse, own calculations)

7.2 Explaining the spreads between futures natural gas prices and the spot natural gas price

In the second model we try to estimate the validity of the theory of storage using data from 2010-14. The dependent variable is the logarithmic spread between month-ahead and spot prices or between year-ahead and spot natural gas prices. Daily data is extracted from ICIS Heren and in a similar fashion as before British data is calculated in Euro/MwH. Hereby six spreads, two for each country, are generated which are presented in table 3.

Table 3

Overview of the natural gas price spreads used as dependent variable in the second model

	The Netherlands (TTF)	Germany (NBP)	United Kingdom (NCG)
MA/DA	Dutch MA/DA spread	German MA/DA spread	British MA/DA spread
YA/DA	Dutch YA/DA spread	German YA/DA spread	British YA/DA spread

Note: DA stands for day-ahead, MA for month-ahead and YA for year-ahead.

Figure 11 graphically shows the month-ahead and year-ahead spread for the TTF hub. Some interesting things can be notified. First of all, the spread seems to converge starting in the year 2012 up to the beginning of 2014. In addition, while the month-ahead spread develops rather constant, a huge peak can be identified in the year-ahead spread.

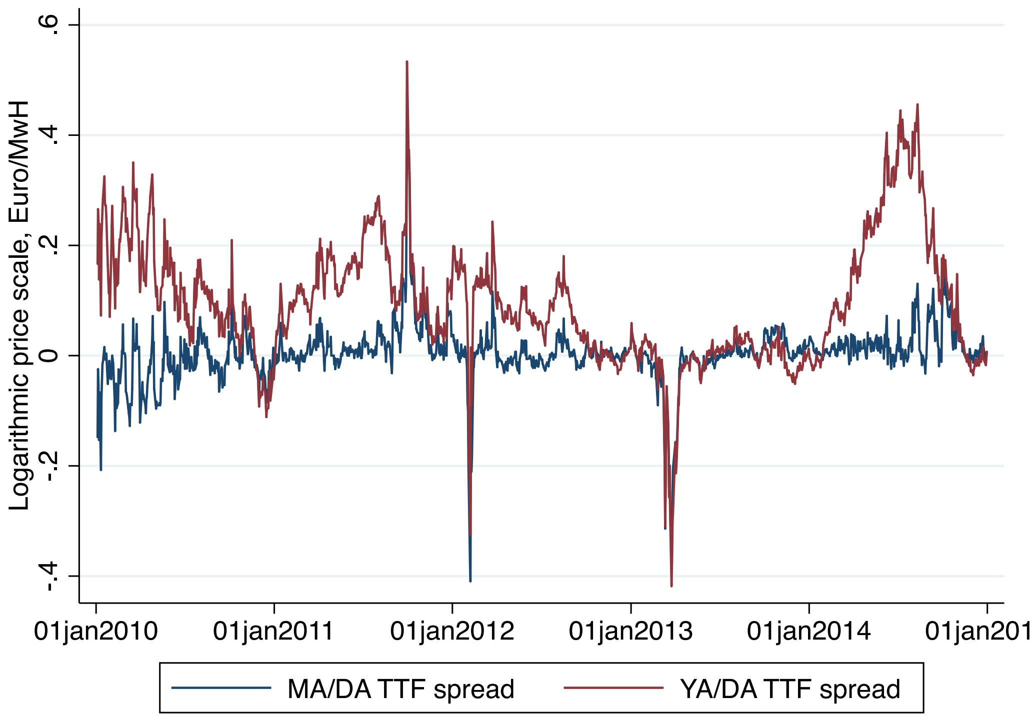

Figure 11, month-ahead and year-ahead spreads for the TTF hub, DA stands for day-ahead, MA for month-ahead while YA stands for year-ahead. (Source: ICIS Heren, own calculations)

The explanatory variables are the interest rate and inventory levels. The inventory data is extracted from the Cedigaz Underground Gas Storage Database, Gas Infrastructure Europe and GasTerra. Inventory data is only available as a percentage filling degree. This variable is therefore first multiplied by the maximum amount of working gas available per country, as indicated by the Cedigaz Underground Gas Storage Database to obtain inventory data in million cubic metres (MMcM). Inventory data in MMcM is then multiplied by one million followed by a multiplication by 0,01044[9] to result in inventory data in MwH. As a result we obtain a variable that indicates the amount of natural gas that is present in the storage facility, measured in MwH.

The second explanatory variable is the interest rate, for which data is extracted from De Nederlandsche Bank (DNB). As an indicator for the risk-free interest rate, Euribor data is chosen. Euribor is the rate at which primary banks present within the Economic and Monetary Union (EMU) can lend and borrow to each other. Although Euribor data contains some degree of credit risk, it is the most risk free data that was available. Other possibilities that

[9] * 1 m3 contains the average of h gas: 11,1111111 and l gas 9,7694444 = 10,44 kwh/m3 or 0,01044 MwH/m3.

were reviewed were EONIA and the German Bund. However, EONIA data is only available for a limited time period, whereas data concerning the yield on the German Bund was only available for very long maturity periods.

7.3 Econometric tests and summary statistics

Before actually estimating the several models it is important to test for some common problems in time-series analysis. When dealing with time series, especially over longer time-periods, non-stationary is often an issue that could lead to biased results. Table A1 in appendix A presents Augmented Dickey-Fuller (ADF) unit root test for stationary for the first model. All variables are stationary according to the ADF-test. Table A2 present the results for the Breusch-Godfrey Lagrange Multiplier test. Weak evidence of autocorrelation is found for the Dutch estimations, strong evidence for German estimations while there is no evidence of autocorrelation for British estimates. Additionally the Breusch-Pagan test identifies a significant amount of heteroskedasticity. To deal with both problems Newey and West (1987) suggest autocorrelation and heteroskedasticity (HAC) consistent standard errors. This approach is followed and all regressions are executed using these standard errors. Finally it might be suspected that the oil price and the storage differential are actually functions of the natural gas price itself. Table A4 presents the results for the Wu-Hausman test for exogeneity. We find some evidence of endogeneity of the oil price in The Netherlands and the United Kingdom for the specification with the year-ahead futures price. Ordinary Least Squares (OLS) estimates lead to inconsistent results and we therefore estimate these two regressions using the instrumental variables (IV) approach. The lagged natural logarithm of the Brent oil price is used as instrument for the daily change in the logarithm of the Brent oil price. Furthermore, the Wu-Hausman results indicate that the daily change in the storage differential is exogenous. Tables A5 and A6 provide descriptive statistics and a correlation matrix

Table B1 in appendix B reports the test results of the Augmented Dickey-Fuller test results for the second model. Intertemporal price spreads are found to be stationary variables whereas storage data and Euribor data is assumed to be non-stationary. Visual inspection of figure 7 suggests that this result might be questioned. A mean reverting process with a rather constant trend of seasonality is observed. Furthermore, the data are bounded by fixed capacity limitations. However to take into account the possibility of non-stationarity of the storage level we chose to estimate two sets of regressions, one including the first differences of inventory and one including inventory in levels. Tables B2, B3, B4 and B5 indicate serious forms of autocorrelation and heteroskedasticity at the highest significance level for nearly all specifications. HAC consistent standard errors are used in the regressions that follow. Finally, a Wu-Hausman test for exogeneity of storage in levels is performed because it might be suspected that this variable is endogenous, presented in table B6 and B7. All specifications reject the null hypotheses that the storage variable is exogenous. Therefore an IV regression using the lagged inventory level as an instrument for the inventory level is performed. Tables B8 and B9 provide some descriptive statistics and a correlation matrix

8. Results

The following three tables present the results of the regressions for The Netherlands, Germany and the United Kingdom for the first model, more specifically equation (2). In each table specification [1] and [2] are estimated by OLS and measure the effect of the explanatory variables on the natural logarithm of daily changes in the spot and month-ahead price of natural gas. For The Netherlands and the United Kingdom, specification [3] is an IV regression of the year-ahead estimation for which the first-order lag of the natural logarithm of the Brent oil price is used as instrument for daily changes in the natural logarithm of the Brent oil price. For Germany, specification [3] is an OLS regression estimating the effect on daily changes in the year-ahead price of natural gas.

Table 4 reports the results of the regressions for The Netherlands. Results for changes in the storage differential differ in sign between the three specifications and are insignificant. We find strong evidence that daily changes in the Brent oil price positively affect daily changes in the natural gas spot and month-ahead price. An increase in the daily change of the Brent oil price by 1% results in an increase in the daily change of the natural gas price of 0,21% in the first specification and 0,23% in the second specification. IV estimation leads to insignificant results for the lagged Brent oil price. A similar result is found for the changes in the natural logarithm of the coal price, where the coefficients range between 0,19 and 0,26. Increases in the daily change in heating degree days have a positive and significant effect in the first specification, albeit at very limited size. We observe a positive coefficient for the daily change in the HHI index, which is significant in the second specification. This positive coefficient indicates that as competition decreases, daily changes in the gas price increase. We find a negative relation between changes in the EONIA rate and changes in the natural gas price. An increase in the EONIA rate means that prices are more heavily discounted resulting in a negative effect on daily changes in the natural gas price. We find a positive and significant effect for the dummy capturing the effects of the natural gas dispute between Ukraine and Russia. The coefficient decreases in size as the time horizon increases, meaning that the effect on the price change is higher in the short run than in the long run. The market is able to smooth out the effect of the disruptions in the market over a longer time period. Finally the season dummy, which equals 1 in the depletion season, has a positive and significant effect on changes in the spot natural gas price.

Table 4
Estimation results for the daily change in natural gas prices, The Netherlands

	[1]	[2]	[3]
Constant	-0,00196*	-0,00023	0,00011
	(0,00117)	(0,00071)	(0,00035)
Storage differential	-0,00258	0,00032	0,00080
	(0,00285)	(0,00313)	(0,00158)
ln(Brent)	0,21491***	0,23019***	0,40349
	(0,07038)	(0,03321)	(0,36106)
ln(coal)	0,19651*	0,26415***	0,20888***
	(0,10411)	(0,06521)	(0,03538)
HDD NL	0,00043**	0,00002	-0,00006
	(0,00018)	(0,00009)	(0,00005)
HHI	0,02015	0,06065*	0,02394
	(0,05012)	(0,03543)	(0,01599)
EONIA	-0,00135***	-0,00153***	-0,00034
	(0,00042)	(0,00042)	(0,00021)
Industry	-0,00849	0,00633	0,00264
	(0,01317)	(0,00827)	(0,00343)
Ukraine	0,05656***	0,02159***	0,00622***
	(0,00203)	(0,00108)	(0,00200)
Season dummy	0,00363*	0,00070	0,00016
	(0,00198)	(0,00106)	(0,00052)
R^2	0,0282	0,0888	0,2021
N	973	973	973

*Note: specification [1] and [2] estimate the effect of the explanatory variables on the natural logarithm of daily changes in the spot and month-ahead price of natural gas. Specification [3] is an IV regression of the year-ahead estimation for which the first-order lag of the natural logarithm of the Brent oil price is used as instrument for daily changes in the natural logarithm of the Brent oil price. All variables are daily changes except for the dummy variables. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively.*

Table 5 reports the results of the regressions for the German natural gas hub. We find weak evidence that daily changes in the storage differential have a negative effect on daily changes in the natural gas price. An increase in the storage differential by 1% results in a decrease of price changes by -0,00144%. Changes in the natural gas prices are negatively affected when inventory levels are above their seasonal norm. We find strong evidence that that daily changes in the oil price positively affect changes in the natural gas price, albeit only in the first and second estimation. Similar results are obtained for changes in the coal price.

Table 5
Estimation results for the daily change in natural gas prices, Germany

	[1]	[2]	[3]
Constant	-0,00213*	-0,01008***	0,13151***
	(0,00115)	(0,00201)	(0,00581)
Storage differential	-0,00144**	0,00048	0,00038
	(0,00064)	(0,00098)	(0,00161)
ln(Brent)	0,22269***	0,30350**	0,19939
	(0,06381)	(0,13411)	(0,22932)
ln(coal)	0,25976**	0,11703***	-0,03722
	(0,10223)	(0,16126)	(0,34272)
HDD GER	0,00043***	0,00024	0,00048
	(0,00015)	(0,00018)	(0,00052)
HHI	0,00605	0,00382	0,04267
	(0,05033)	(0,08277)	(0,18760)
EONIA	-0,00192***	-0,00263***	-0,00240
	(0,00029)	(0,00042)	(0,00190)
Industry	-0,00531	0,01703	0,05514
	(0,01230)	(0,02377)	(0,04209)
Ukraine dummy	0,07028***	0,45230***	0,38395***
	(0,00198)	(0,00361)	(0,00517)
Season dummy	0,00368*	0,00453	0,09378***
	(0,00199)	(0,00356)	(0,00685)
R^2	0,0438	0,0851	0,1813
N	972	972	972

*Note: specification [1], [2] and [3] estimate the effect of the explanatory variables on the natural logarithm of daily changes in the spot, month-ahead and year-ahead price of natural gas. All variables are daily changes except for the dummy variables. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively.*

Changes in heating degree days are positive and significant only in the short run. Changes in the EONIA rate have a negative and significant effect in the first and second specification. An increase in the daily change of the EONIA rate by 1% results in decrease in the change in the natural gas price by approximately -0,002%. Remarkably the effect of the dummy capturing the effects of the Ukraine/Russia natural gas dispute increases when we compare the first with the second and third specification. Finally the season dummy has a positive and significant effect in two of the three specifications (1 and 3) meaning that daily changes in natural gas prices are higher during the depletion season.

Table 6 reports the results of the regressions for the British natural gas market. The effects of the storage differential differ in sign and are insignificant. We find a positive relation between changes in the oil price and changes in the natural gas price. The magnitude of the coefficient ranges between 0,22 and 0,26. IV estimation leads to insignificant results for the lagged Brent oil price. Changes in coal prices have a positive and significant effect on changes in natural gas prices in all three specifications. Effects of changes in heating degree days are only significant in the short run, however the signs under the other specifications are as expected. Changes in the EONIA rate do have the signs as hypothesized. A negative relation between changes in this rate and changes in the natural gas price is observed. The dummy capturing the effects of the gas dispute between Ukraine and Russia is positive and significant. The size of the coefficient is decreasing as the time horizon increases. Similar to the results obtained before we find that price changes are bigger in the depletion season than in the injection season.

Table 6
Estimation results for the daily change in natural gas prices, United Kingdom

	[1]	[2]	[3]
Constant	-0,00196	-0,00034	0,00006
	(0,00123)	(0,00085)	(0,00042)
Storage differential	0,00003	0,00001	-0,00002
	(0,00004)	(0,00002)	(0,00004)
ln(Brent)	0,25967***	0,21748***	0,41231
	(0,07270)	(0,03894)	(0,37778)
ln(coal)	0,31042***	0,29326***	0,19895***
	(0,10101)	(0,03891)	(0,04078)
HDD UK	0,00064***	0,00014	-0,00004
	(0,00018)	(0,00013)	(0,00010)
HHI	-0,03585	0,05700	0,02121
	(0,04740)	(0,03872)	(0,01724)
EONIA	-0,00123***	-0,00110**	-0,00040
	(0,00020)	(0,00045)	(0,00025)
Industry	0,00162	0,00911	0,00264
	(0,01190)	(0,00882)	(0,00379)
Ukraine dummy	0,12780***	0,04288***	0,01035***
	(0,00191)	(0,00121)	(0,00217)
Season dummy	0,00341*	0,00089	0,00030
	(0,00195)	(0,00122)	(0,00058)
R^2	0,0549	0,0669	0,1575
N	973	973	973

*Note: specification [1] and [2] estimate the effect of the explanatory variables on the natural logarithm of daily changes in the spot and month-ahead price of natural gas. Specification [3] is an IV regression of the year-ahead estimation for which the first-order lag of the natural logarithm of the Brent oil price is used as instrument for daily changes in the natural logarithm of the Brent oil price. All variables are daily changes except for the dummy variables. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively.*

The next eight tables present regression results for the second model, more specifically equation (6) for the Dutch, German and British natural gas price spreads. In each table specifications [1], [2], [3] and [4] estimate the effect of the independent variables on the spread between the month-ahead price and the spot price or between the year-ahead price and the spot price of natural gas. The specifications differ in time horizon in terms of the risk-free Euribor rate. The time horizon increases from one-month to three-months, six-months and twelve-months for specification [1], [2], [3] and [4] respectively. We estimate by means of OLS using first differences of the inventory level to account for possible non-stationarity of this variable. We estimate the same four specifications using IV to account for endogeneity of the storage variable in levels. We use the first order lag of the inventory level as instrument for the inventory level.

Table 7 presents the regressions results for the spread between month-ahead and spot natural gas prices for the Dutch natural gas market. In line with economic theory we find positive and significant estimates of the storage variable in both OLS and IV regressions. Differences in natural gas storage levels positive influence price spreads. IV estimates indicate that increases in the levels of natural gas storages result in bigger price spreads. Higher inventory levels result in higher storage costs and a decreased convenience yield, leading to a bigger spread. A higher level of inventory leads to lower scarcity on the natural gas market and subsequently a lower spot price. This can be explained by the fact that when inventory levels increase, storage costs increase while the convenience yield is lower. As a result, net storage costs are higher. We find negative and significant estimates for the interest rate, which is also as expected. Differences in the natural logarithm of the interest rate negatively affect price spreads. A higher interest rate makes future discounting more expensive resulting in a lower month-ahead price and smaller price spreads.

Table 7

Estimation results for the spread between month-ahead and spot natural gas prices, The Netherlands				
	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,00566***	0,00533***	0,00543***	0,00555***
	(0,00161)	(0,00163)	(0,00165)	(0,00164)
d.Storage level	0,04265***	0,04210***	0,04257***	0,04258***
	(0,00708)	(0,00710)	(0,00710)	(0,00711)
d.ln(Euribor)	-0,05213**	-0,20427***	-0,22442*	-0,20370
	(0,02305)	(0,06932)	(0,11543)	(0,16872)
R^2	0,0466	0,0471	0,0456	0,0446
N	989	991	989	989
Instrumental Variable (IV)				
Constant	-0,05669***	-0,05604***	-0,05689***	-0,05698***
	(0,00620)	(0,00615)	(0,00623)	(0,00624)
Storage level	0,00165***	0,00163***	0,00166***	0,00166***
	(0,00016)	(0,00016)	(0,00016)	(0,00016)
d.ln(Euribor)	-0,04055**	-0,0527	0,04643	0,12837
	(0,01877)	(0,06948)	(0,14088)	(0,17609)
R^2	0,1936	0,1913	0,1920	0,1922
N	989	991	989	989

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on month-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

We find positive and significant estimates for first differences in the storage level for the price spread between year-ahead and spot natural gas prices, presented in table 8. IV estimation leads to insignificant results for storage levels but do have the correct sign. Additionally we find negative and significant estimates for differences in the Euribor rate both under OLS and IV estimation. Furthermore the coefficients increased in magnitude, especially for the Euribor rate. Sizes of the coefficients for the Euribor rate increase from a range between -0,04 and -0,20 to a range between -0,20 and -0,77 indicating that the future is more heavily discounted (in case of the Euribor rate). Furthermore differences in the storage level have a bigger impact on the price spread between year-ahead and spot prices than on the price spread between month-ahead and spot prices.

Table 8
Estimation results for the spread between year-ahead and spot natural gas prices, The Netherlands

	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,09805***	0,09676***	0,09733***	0,09770***
	(0,00344)	(0,00345)	(0,00347)	(0,00346)
d.Storage level	0,11470***	0,11241***	0,11448***	0,11449***
	(0,011890	(0,01187)	(0,01188)	(0,01191)
d.ln(Euribor)	-0,19584***	-0,75021**	-0,74983**	-0,71746*
	(0,05902)	(0,30797)	(0,31105)	(0,42023)
R^2	0,0810	0,0817	0,0767	0,0742
N	989	991	989	989
Instrumental Variable (IV)				
Constant	0,07791***	0,07840***	0,07899***	0,07849***
	(0,01243)	(0,01238)	(0,01255)	(0,01257)
Storage level	0,00045	0,00041	0,00041	0,00043
	(0,00031)	(0,00031)	(0,00031)	(0,00031)
d.ln(Euribor)	-0,19801***	-0,77201**	-0,74236**	-0,74195*
	(0,06262)	(0,32496)	(0,31487)	(0,40310)
R^2	0,0136	0,0165	0,0088	0,0067
N	989	991	989	989

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on year-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

Table 9 provide the results of the regression for the spread between month-ahead and spot natural gas prices for the German NCG hub. When we estimate by OLS we find a negative and significant effect of differences in the Euribor rate under all four specifications. The magnitude of this effect increases as the time horizon of the Euribor rate increases. We find insignificant results for first differences of the storage variable, however the correct sign is found. Under IV we find a positive and significant effect of storage levels on the price spread. The magnitude of this effect is rather constant over time. We find evidence of a negative and significant effect of differences in the Euribor rate with a coefficient that varies between -0,05 and -0,12.

Table 9
Estimation results for the spread between month-ahead and spot natural gas prices, Germany

	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,0035**	0,00315**	0,00317**	0,00328**
	(0,00158)	(0,00159)	(0,00162)	(0,00160)
d.Storage level	0,00512	0,00510	0,00515	0,00517
	(0,00353)	(0,00351)	(0,00353)	(0,00354)
d.ln(Euribor)	-0,05883***	-0,26131***	-0,32788***	-0,35984**
	(0,02203)	(0,07406)	(0,10567)	(0,15027)
R^2	0,0293	0,0319	0,0298	0,0282
N	986	988	986	986
Instrumental Variable (IV)				
Constant	-0,06694***	-0,06602***	-0,06683***	-0,06697***
	(0,00636)	(0,00631)	(0,00637)	(0,00639)
Storage level	0,00480***	0,00047***	0,00047***	0,00047***
	(0,00004)	(0,00004)	(0,00004)	(0,00004)
d.ln(Euribor)	-0,05095***	-0,12883**	-0,09945	-0,06617
	(0,01552)	(0,05204)	(0,09711)	(0,13876)
R^2	0,1864	0,1841	0,1836	0,1833
N	986	988	986	986

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on month-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

Estimates for the price spread between year-ahead and spot prices in Germany are presented in table 10. OLS estimation leads to positive and significant effects of differences in the storage level. These coefficients are approximately 0,014 under all four specifications. We observe negative and significant estimates for differences in the natural logarithm of the Euribor rate. Similarly to the observations in The Netherlands, we find that the coefficients differ a lot between specifications between the month-ahead and spot price spread and the between the year-ahead and spot price spread. Under IV estimation we obtain negative and significant estimates for changes in the Euribor rate, as theory predicts. The coefficients differ between estimations with one-month time to maturity Euribor data versus estimations with three, six and twelve month estimations.

Table 10
Estimation results for the spread between year-ahead and spot natural gas prices, Germany

	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,0924***	0,09109***	0,09155***	0,09187***
	(0,00346)	(0,00346)	(0,00348)	(0,00348)
d.Storage level	0,01390***	0,01381***	0,01401***	0,014106***
	(0,00529)	(0,00523)	(0,00532)	(0,00534)
d.ln(Euribor)	-0,19874***	-0,82282**	-0,86447**	-0,92517**
	(0,05965)	(0,33371)	(0,32681)	(0,41128)
R^2	0,0476	0,0513	0,0444	0,0419
N	986	988	986	986
Instrumental Variable (IV)				
Constant	0,07221***	0,07291***	0,07369***	0,07303***
	(0,01379)	(0,01371)	(0,01390)	(0,01393)
Storage level	0,00013	0,00012	0,00012	0,00012
	(0,00009)	(0,00009)	(0,00009)	(0,00009)
d.ln(Euribor)	-0,20229***	-0,80915**	-0,81160**	-0,82652**
	(0,01379)	(0,33052)	(0,32096)	(0,40831)
R^2	0,0140	0,0177	0,0096	0,0071
N	986	988	986	986

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on year-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

Estimates for the natural gas price spread between month-ahead and spot prices for the United Kingdom are presented in table 11. OLS estimation leads to insignificant estimates for differences in storage levels as well as for differences in the Euribor rate. However, the coefficients do have the expected sign. Under IV estimation we find a positive and significant relation between the storage level and natural gas price spreads under all specifications. Euribor estimates differ in sign and are insignificant.

Table 11
Estimation results for the spread between month-ahead and spot natural gas prices, United Kingdom

	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,00354	0,00329	0,00339	0,00361*
	(0,00038)	(0,00218)	(0,00221)	(0,00219)
d.Storage level	0,01880	0,01878	0,01883	0,01882
	(0,01240)	(0,01238)	(0,01241)	(0,01242)
d.ln(Euribor)	-0,03135	-0,15041*	-0,13965	-0,00378
	(0,02423)	(0,01238)	(0,14355)	(0,20567)
R^2	0,0323	0,0329	0,0321	0,0316
N	989	991	989	989
Instrumental Variable (IV)				
Constant	-0,07156***	-0,07119***	-0,07188***	-0,07219***
	(0,00694)	(0,00687)	(0,00692)	(0,00694)
Storage level	0,00219***	0,00218***	0,00220***	0,00222***
	(0,00019)	(0,00019)	(0,00019)	(0,00019)
d.ln(Euribor)	-0,01930	0,02591	0,16501	0,42933*
	(0,01625)	(0,08455)	(0,16479)	(0,22474)
R^2	0,1916	0,1908	0,1921	0,1941
N	989	991	989	989

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on month-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

Table 12 presents regression results for the United Kingdom using the price spread between year-ahead and spot natural gas prices. We find positive estimates for differences in storage levels, under OLS estimation. Under IV estimation, we again observe positive values for storage in levels. However both estimates for the storage variables are insignificant. Estimation by OLS results in negative and significant estimates for changes in the natural logarithm of the Euribor rate. Again we identify a big difference in magnitude between the first and other specifications. The IV estimates are similar to that of the results obtained using OLS.

Table 12
Estimation results for the spread between year-ahead and spot natural gas prices, United Kingdom

	(1)	(2)	(3)	(4)
Ordinary Least Squares (OLS)				
Constant	0,11195***	0,11073***	0,11120***	0,11162***
	(0,00436)	(0,00438)	(0,00441)	(0,00439)
d.Storage level	0,04049	0,04045	0,04068	0,04075
	(0,02617)	(0,02606)	(0,02625)	(0,02628)
d.ln(Euribor)	-0,20197***	-0,81037**	-0,78665**	-0,72894*
	(0,06924)	(0,36312)	(0,36079)	(0,43970)
R^2	0,0451	0,0475	0,0416	0,0393
N	989	991	989	989
Instrumental Variable (IV)				
Constant	0,09592***	0,09669***	0,09679***	0,09639***
	(0,01378)	(0,01368)	(0,01383)	(0,01389)
Storage level	0,00041	0,00035	0,00036	0,00039
	(0,00038)	(0,00038)	(0,00038)	(0,00038)
d.ln(Euribor)	-0,20368***	-0,79342**	-0,73467**	-0,62921
	(0,06987)	(0,35621)	(0,35737)	(0,04477)
R^2	0,0104	0,0124	0,0061	0,0040
N	989	991	989	989

*Note: specifications [1], [2], [3] and [4] estimate the effect of the independent variables on year-ahead/spot natural gas price spreads. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively. We use the first order lag of the storage level as instrument for the storage level in the IV regressions. Standard deviations are reported in parentheses while *, ** and *** refers to 10%, 5% and 1% significance level respectively. All storage data is multiplied by 1 million for ease of interpretation.*

9. Discussion

The aim in this paper was to measure the impact of natural gas storage on natural gas prices. We asses this impact using two techniques, one in which we measure the effect on daily changes in the natural gas price and one in which we examine intertemporal price spreads.

The results obtained from the first model are rather similar across The Netherlands, Germany and the United Kingdom. We find strong evidence of a positive relation between changes in oil prices and changes in natural gas prices, with coefficients ranging between 0,20 and 0,30, which is in line with previous work by Asche et al. (2006). This means that oil prices and natural gas prices are still correlated, but significantly less than before the liberalisation of the natural gas market. Changes in coal prices also significantly explain differences in natural gas prices. Natural gas and coal are subject to inter-fuel competition, especially in the demand area of power generation as was earlier found by Hintermann (2010). As analysed in section 3.1, natural gas demand in this area is expected to increase significantly in the coming two decades (WEO, 2010). As a result, the relation between natural gas and coal prices probably strengthens. We do not find a relation between changes in the storage differential on changes in natural gas prices. This is somewhat contradictory since existing literature like that of Brown and Yücel (2008) finds a price depressing effect of deviations from the seasonal norm on the natural gas price. Evidence of influences of the weather is only significant when we analyse spot price changes. Changes in the EONIA rate do seem to imply that daily changes in the natural gas price can be explained by a more heavily discounted future. Another implication of this result might be that daily changes in natural gas price do take into account some form of inflation. However it might also be that the costs of carrying inventory from one-period to another are reflected by this variable, as was found by Mu (2007). The gas dispute had a positive and significant effect on changes in the natural gas price. The magnitude of this effect decreases over time in The Netherlands and the United Kingdom. In the German gas market, the effect becomes stronger as the time horizon decreases, which is contradictory. Possibly, the shock of the dispute is reflected in German month-ahead and year-ahead prices due to lower indigenous production in Germany compared to The Netherlands and the United Kingdom. (BP, 2015). As a result the market reacts more heavily leading to a stronger size of the coefficient. From a policy makers' point of view these results indicate that natural gas prices do not have completely decoupled from oil prices. Additional steps need to be taken to further increase the share of hub based trading towards a perfectly competitive natural gas market.

For the second model we find that differences in storage levels have a positive and significant effect on intertemporal price spreads in The Netherlands and Germany, while in the United Kingdom these results do have the correct sign but are insignificant. IV estimations indicate that storage in levels only leads to significant results when we take the spread between month-ahead and spot prices as the dependent variable. Higher inventory levels result in a lower scarcity of natural gas and therefore push spot prices down. Both in differences and in levels the intertemporal price spreads increase. Another way to explain the increase in the intertemporal price spread is that as inventory levels increase, storage costs increase while the convenience yield becomes lower. This results in a positive effect of inventory levels on the price spread. Furthermore, We find that the size of the coefficients for the Euribor rate increases when we move from the month-ahead specification to the year-ahead specification, indicating that the future is more heavily discounted. Uncertainty about future market circumstances as well as future natural gas prices might also explain the increased size of this coefficient as time horizons increase. Furthermore, this value might imply that storage users do not optimally make use of arbitrage opportunities. This hints to a not perfectly competitive natural gas market, which was already observed in previous work. However, both results are in line with existing literature like that of Fama and French (1987) and more recently Modjtahedi and Movassagh (2005). The theory of storage is thus valid for the TTF, NCG and NBP hub.

Limitations of this study are mainly related to the data sample. While most of the data is available on a daily basis, natural gas market prices are not available in the weekend due to the fact the trading only occurs during weekdays. As a result, we only focus on analysis with weekday data for all variables. However, differences between Friday and Monday data in explanatory variables might exist. Interpolating all these observations might be an option but leads to biased results. Unidentified extreme outliers or underlying factors causing disruptions might also lead to biased results. Although we have constructed a large dataset including daily observations, the time period in this paper might be an in-between period. The period 2010-2014 can be seen as a period of transition from an oil-indexed market to a hub-based market. Due to these changing circumstances, markets might respond differently in the transition period than before this period (oil-indexation) or after this period (hub-based). Estimating this model when a more mature, hub-based natural gas market has evolved might lead to different results. Another limitation of this study is the transparency of the data. Whereas all prices are perfectly transparent, storage and production data might be less transparent. Owner and operators of natural gas storage facilities do not always report the correct amount of storage being stored or produced, due to i.e. constraints in the maximum amount that can be withdrawn daily. Heated political discussions, such as most recently in The Netherlands concerning the Groningen field, only enhance the lack of transparency.

Further research that might be conducted as a result of this paper should aim at identifying more variables that are able to influence daily changes in natural gas spot, month-ahead and year-ahead prices. Additionally the second model is rather limited as the intertemporal price spread is explained only by two variables. Important variables seem to be missing out in the current model specification and identifying these variables is an important topic for future research. Furthermore, additional research should aim at collecting data for a longer time period, hereby creating a more complete picture of the natural gas market.

10. Conclusion

The liberalisation of the natural gas market in Europe since the 1990's has led to increased market integration and the creation of physical gas trading hubs such as the TTF in the Netherlands, NCG in Germany and the NBP in the United Kingdom. Historically natural gas was traded using long-term contracts that were often oil-indexed. Hub based trading is based on supply and demand factors, amongst which natural gas storage serves as an important factor to meet seasonal gas demand. With lower indigenous production in the future dependence on natural gas storages will increase, leading to a higher amount of natural gas storage facilities. This paper tries to answer the research question 'What is the effect of natural gas storage on natural gas prices in the Dutch, German and British natural gas market?' Using two approaches we tried to assess the role that natural gas storages play in the natural gas markets in The Netherlands, Germany and the United Kingdom. The first approach examining daily changes in the natural gas price tries to answer the sub question 'What are the main factors influencing daily changes in natural gas spot, month-ahead and year-ahead prices?' The second technique examines the influences of inventory levels of natural gas storages on intertemporal price spreads and possibly answers: 'What is the influence of inventory levels of natural gas storage facilities on intertemporal price spreads?'

We used a dataset including daily observations of variables affecting demand and supply of natural gas from 2010-2014. Amongst these variables are the oil price, the coal price, a weather indicator, a competition variable, the interest rate, a productivity indicator and dummies capturing specific events. We do not find evidence of a stabilising effect of changes in a storage differential on changes in the spot natural gas price in the three markets of interest. However, we find a strong relation between changes in oil and coal prices and changes in natural gas prices meaning that energy commodities generally follow the same trend, which is in line with work by Mu (2007). Moreover we find evidence that the EONIA rate has a negative effect on daily natural gas price changes and we find weak evidence that the temperature has a positive effect on natural gas price changes. This is in line with existing work by, amongst others, Asche et al. (2008). The first sub question can be answered by stating that daily changes in the natural gas price are mainly influenced by the price of other energy commodities like oil and coal. The second model estimated the effects of inventory levels on natural gas price spreads. In line with existing literature that concentrates on the theory of storage, like Fama and French (1987) and more recently Modjtahedi and Movassagh (2005), we find a positive relation between inventory levels and natural gas price spreads. Increased inventory levels result in lower scarcity in the natural gas market that leads to a positive net storage effect or a lower spot natural gas price. These effects lead to a bigger spread between futures prices of natural gas and the spot price of natural gas. The second sub question can be answered by that inventory levels positively influence intertemporal price spreads. Our findings suggest that the theory of storage is valid for the natural gas markets in The Netherlands, Germany and the United Kingdom.

Answering our research question we find that the effect of natural gas storage facilities on the gas price is ambiguous. We do not find a stabilising effect of natural gas storage facilities on the natural gas price, which is not in line with existing literature. However, the positive effect of the storage model seem to imply that natural gas storage facilities are able to decrease spot prices by maintaining a sufficiently high amount of natural gas in their facilities. However, the results that were obtained in both models are relatively similar across the three different markets that were analysed, which might be an indication of a highly integrated market and price convergence. Although we do not find evidence of a stabilising effect of natural gas storage facilities, future developments in the natural gas markets in The Netherlands, Germany and the United Kingdom indicate that indigenous production will decrease in the coming decades. Therefore, additional storage facilities need to be constructed to meet flexible natural gas demand as well as securing natural gas supply in the future.

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12. Appendices

A. Econometric tests and summary statistics for the first model.

Table A1
Augmented Dickey-Fuller unit root test

	Levels
Natural logarithm of daily Dutch spot price change	-19,148***
Natural logarithm of daily Dutch month-ahead price change	-32,677***
Natural logarithm of daily Dutch year-ahead price change	-29,341***
Natural logarithm of daily German spot price change	-24,892***
Natural logarithm of daily German month-ahead price change	-6,987***
Natural logarithm of daily German year-ahead price change	-3,269**
Natural logarithm of daily British spot price change	-24,197***
Natural logarithm of daily British month-ahead price change	-32,660***
Natural logarithm of daily British year-ahead price change	-29,894***
Daily change in the Dutch storage differential	-12,923***
Daily change in the German storage differential	-12,913***
Daily change in the British storage differential	-31,562***
Natural logarithm of daily Brent oil price change	-30,583***
Natural logarithm of daily coal price change	-20,452***
Daily change in Dutch Heating Degree Days	-32,493***
Daily change in German Heating Degree Days	-32,725***
Daily change in British Heating Degree Days	-32,995***
Monthly change in Industrial index	-5,863***
Daily change in the HHI index	-17,358***
Daily change in the EONIA rate	-31,965***

*Note: *** and ** refers to 1% and 5% significance level respectively.*

Table A2
Breusch-Godfrey Lagrange Multiplier test for serial correlation

	[1]	[2]	[3]
The Netherlands	6,493**	4,158**	0,007
	(0,011)	(0,041)	(0,935)
Germany	12,080***	631,341***	896,724***
	(0,001)	(0,000)	(0,000)
United Kingdom	0,911	2,215	0,289
	(0,340)	(0,137)	(0,591)

*Note: *** and ** refers to 1% and 5% significance level respectively, p-value in parentheses. Specifications [1], [2] and [3] represent the specifications concerning daily changes in spot, month-ahead and year-ahead prices of natural gas respectively.*

Table A3
Breusch-Pagan test for heteroskedasticity

	[1]	[2]	[3]
The Netherlands	127,63***	117,48***	36,48***
	(0,000)	(0,000)	(0,000)
Germany	896,724***	140,42***	37,57***
	(0,000)	(0,000)	(0,000)
United Kingdom	137,04***	116,81***	97,52***
	(0,000)	(0,000)	(0,000)

*Note: *** refers to 1% significance level respectively, p-value in parentheses. Specifications [1], [2] and [3] represent the specifications concerning daily changes in spot, month-ahead and year-ahead prices of natural gas respectively.*

Table A4
Wu-Hausman test for exogeneity

	[1]	[2]	[3]
The Netherlands			
Oil price	0,000	0,275	3,537*
	(0,99)	(0,601)	(0,060)
Storage	0,327	0,208	1,881
	(0,568)	(0,648)	(0,171)
Germany			
Oil price	0,051	0,607	0,127
	(0,821)	(0,801)	(0,722)
Storage	0,192	0,473	0,106
	(0,661)	(0,492)	(0,745)
United Kingdom			
Oil price	0,021	0,270	2,799*
	(0,886)	(0,604)	(0,095)
Storage	0,035	0,018	0,175
	(0,853)	(0,894)	(0,6760

*Note: * refers to 10% significance level respectively, p-value in parentheses. Specifications [1], [2] and [3] represent the specifications concerning daily changes in spot, month-ahead and year-ahead prices of natural gas respectively.*

Table A5
Descriptive statistics

	Mean	Standard deviation
Natural logarithm of daily Dutch spot price change	-0,00011	0,03097
Natural logarithm of daily Dutch month-ahead price change	-0,00009	0,01682
Natural logarithm of daily Dutch year-ahead price change	-0,00012	0,00882
Natural logarithm of daily German spot price change	-0,00008	0,03048
Natural logarithm of daily German month-ahead price change	-0,00740	0,05494
Natural logarithm of daily German year-ahead price change	-0,08441	0,11460
Natural logarithm of daily British spot price change	-0,00010	0,03032
Natural logarithm of daily British month-ahead price change	-0,00007	0,01898
Natural logarithm of daily British year-ahead price change	-0,00011	0,00977
Daily change in the Dutch storage differential	-0,00095	0,25402
Daily change in the German storage differential	0,00275	0,91229
Daily change in the British storage differential	0,04974	2,06040
Natural logarithm of daily Brent oil price change	-0,00044	0,01368
Natural logarithm of daily coal price change	-0,00068	0,00959
Daily change in Dutch Heating Degree Days	0,71006	4,10585
Daily change in German Heating Degree Days	1,07787	5,57540
Daily change in British Heating Degree Days	0,64032	3,43430
Monthly change in Industrial index	0,00643	0,08152
Daily change in the HHI index	0,00031	0,01801
Daily change in the EONIA rate	0,03475	1,67887

Table A6
Correlation matrix

	$\ln(S/S_{-1})$ NL	$\ln(M/M_{-1})$ NL	$\ln(Y/Y_{-1})$ NL	$\ln(S/S_{-1})$ Ger	$\ln(M/M_{-1})$ Ger
$\ln(S/S_{-1})$ NL	1,0000				
$\ln(M/M_{-1})$ NL	0,5544	1,0000			
$\ln(Y/Y_{-1})$ NL	0,3506	0,6357	1,0000		
$\ln(S/S_{-1})$ Ger	0,9031	0,5307	0,3502	1,0000	
$\ln(M/M_{-1})$ Ger	0,3388	0,2666	0,2128	0,3470	1,0000
$\ln(Y/Y_{-1})$ Ger	0,1316	0,0632	0,0548	0,1391	0,5495
$\ln(S/S_{-1})$ UK	0,7497	0,5586	0,4088	0,7075	0,2632
$\ln(M/M_{-1})$ UK	0,5312	0,9344	0,5945	0,5071	0,2308
$\ln(Y/Y_{-1})$ UK	0,3468	0,6041	0,9526	0,3399	0,2105
SD/SD_{-1} NL	-0,0121	0,0256	0,0395	0,0248	0,0088
SD/SD_{-1} Ger	-0,0462	-0,0166	-0,0272	-0,0409	0,0079
SD/SD_{-1} UK	0,0138	-0,0114	-0,0278	0,0073	-0,0008
$\ln(P/P_{-1})$	0,0977	0,1904	0,4270	0,1064	0,0805
$\ln(C/C_{-1})$	0,0601	0,1492	0,2278	0,0781	0,0162
HDD/HDD_{-1} NL	0,0518	0,0107	-0,0153	0,0507	-0,0076
HDD/HDD_{-1} Ger	0,0611	0,0887	0,0297	0,0708	0,0196
HDD/HDD_{-1} UK	0,0089	0,0205	0,0166	0,0392	-0,0699
Ind/Ind_{-1}	-0,0212	0,0270	0,0138	-0,0132	0,0276
HHI/HHI_{-1}	0,0062	0,0610	0,0310	0,0008	0,0033
R/R_{-1}	-0,0741	-0,1582	-0,0862	-0,1089	-0,0807

	$\ln(Y/Y_{-1})$ Ger	$\ln(S/S_{-1})$ UK	$\ln(M/M_{-1})$ UK	$\ln(Y/Y_{-1})$ UK	SD/SD_{-1} NL
$\ln(Y/Y_{-1})$ Ger	1,0000				
$\ln(S/S_{-1})$ UK	0,0961	1,0000			
$\ln(M/M_{-1})$ UK	0,0483	0,5690	1,0000		
$\ln(Y/Y_{-1})$ UK	0,0569	0,4000	0,5915	1,0000	
SD/SD_{-1} NL	0,0314	-0,0035	0,0325	0,0336	1,0000
SD/SD_{-1} Ger	0,0065	-0,0508	-0,0364	-0,0386	0,0072
SD/SD_{-1} UK	0,0139	0,0061	-0,0085	-0,0389	0,0049
$\ln(P/P_{-1})$	0,0213	0,1240	0,1604	0,3865	-0,0279
$\ln(C/C_{-1})$	-0,0155	0,0933	0,1442	0,1947	0,1394
HDD/HDD_{-1} NL	-0,0640	0,0400	0,0120	-0,0070	-0,0063
HDD/HDD_{-1} Ger	-0,0461	0,0561	0,0841	0,0343	-0,0010
HDD/HDD_{-1} UK	-0,0775	0,0728	0,0306	0,0106	-0,0119
Ind/Ind_{-1}	0,0603	0,0045	0,0384	0,0131	-0,0309
HHI/HHI_{-1}	0,0037	-0,0242	0,0509	0,0217	0,0275
R/R_{-1}	-0,0204	-0,0729	-0,1022	-0,0867	-0,0301

	SD/SD_{-1} Ger	SD/SD_{-1} UK	$\ln(P/P_{-1})$	$\ln(C/C_{-1})$	HDD/HDD_{-1} NL
SD/SD_{-1} Ger	1,0000				
SD/SD_{-1} UK	-0,0161	1,0000			
$\ln(P/P_{-1})$	-0,0208	-0,0605	1,0000		
$\ln(C/C_{-1})$	0,0676	0,0573	0,0049	1,0000	
HDD/HDD_{-1} NL	-0,0387	-0,0032	-0,0099	0,0940	1,0000
HDD/HDD_{-1} Ger	0,0123	0,0088	0,0195	0,0437	0,5226
HDD/HDD_{-1} UK	0,0231	0,0008	0,0454	-0,0140	0,2189
Ind/Ind_{-1}	0,0517	-0,0267	-0,0178	0,0058	0,0029
HHI/HHI_{-1}	-0,0209	0,0040	-0,0316	-0,0075	-0,0298
R/R_{-1}	0,0111	0,0042	-0,0330	-0,0007	0,0104

	HDD/HDD_{-1} Ger	HDD/HDD_{-1} UK	Ind/Ind_{-1}	HHI/HHI_{-1}	R/R_{-1}
HDD/HDD_{-1} Ger	1,0000				
HDD/HDD_{-1} UK	0,1709	1,0000			
Ind/Ind_{-1}	0,0486	0,0144	1,0000		
HHI/HHI_{-1}	-0,0106	-0,0143	0,0339	1,0000	
R/R_{-1}	-0,0117	-0,0436	0,0285	-0,0093	1,0000

Note: S is the spot price, M is the month-ahead price, Y is the year-ahead price, SD stands for storage differential, P stands for the oil price, C stands for the coal price, Ind stands for industry index, R stands for the EONIA rate.

B. Econometric tests and summary statistics for the second model.

Table B1
Augmented Dickey-Fuller unit root test

	Levels	First-difference
Spread between year-ahead and day-ahead prices in NL	-3,799***	
Spread between month-ahead and day-ahead prices in NL	-8,767***	
Spread between year-ahead and day-ahead prices in Germany	-3,806***	
Spread between month-ahead and day-ahead prices in Germany	-8,487***	
Spread between year-ahead and day-ahead prices in the UK	-3,231**	
Spread between month-ahead and day-ahead prices in the UK	-7,750***	
Storage level in the Netherlands	-1,736	-5,179***
Storage level in the United Kingdom	-1,995	-6,243***
Storage level in Germany	-0,761	-19,251***
Natural logarithm of the 1 month Euribor rate	-0,761	-16,170***
Natural logarithm of the 3 month Euribor rate	0,925	-4,813***
Natural logarithm of the 6 month Euribor rate	0,982	-5,561***
Natural logarithm of the 12 month Euribor rate	1,446	-6,918***

*Note: *** and ** refers to 1% and 5% significance level respectively, p-value in parentheses.*

Table B2
Breusch Godfrey Lagrange Multiplier test for serial correlation, spread between month-ahead and spot prices

	[1]	[2]	[3]	[4]
The Netherlands	455,845***	459,910***	457,145***	456,774***
	(0,000)	(0,000)	(0,000)	(0,000)
Germany	425,539***	429,473***	428,412***	428,116***
	(0,000)	(0,000)	(0,000)	(0,000)
United Kingdom	563,010***	565,637***	562,835***	561,927***
	(0,000)	(0,000)	(0,000)	(0,000)

*Note: *** refers to 1% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B3
Breusch Godfrey Lagrange Multiplier test for serial correlation, spread between year-ahead and spot prices

	[1]	[2]	[3]	[4]
The Netherlands	661,814***	665,981***	666,747***	667,497***
	(0,000)	(0,000)	(0,000)	(0,000)
Germany	662,953***	666,831***	667,583***	668,371***
	(0,000)	(0,000)	(0,000)	(0,000)
United Kingdom	689,026***	691,734***	693,060***	693,957***
	(0,000)	(0,000)	(0,000)	(0,000)

*Note: *** refers to 1% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B4
Breusch-Pagan test for heteroskedasticity, spread between month-ahead and spot prices

	[1]	[2]	[3]	[4]
The Netherlands	15,62***	14,24***	14,96***	15,87***
	(0,000)	(0,001)	(0,001)	(0,000)
Germany	17,51***	15,15***	16,72***	15,04***
	(0,000)	(0,001)	(0,000)	(0,001)
United Kingdom	25,80***	26,35***	29,90***	26,46***
	(0,000)	(0,000)	(0,000)	(0,000)

*Note: *** refers to 1% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B5
Breusch-Pagan test for heteroskedasticity, spread between year-ahead and spot prices

	[1]	[2]	[3]	[4]
The Netherlands	24,37***	28,38***	22,47***	24,37***
	(0,000)	(0,000)	(0,000)	(0,000)
Germany	5,93*	10,37***	3,21	4,37
	(0,052)	(0,006)	(0,200)	(0,113)
United Kingdom	10,08***	9,96***	6,89***	7,44**
	(0,007)	(0,007)	(0,032)	(0,024)

*Note: ***, ** and * refers to 1%, 5% and 10% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B6
Wu-Hausman test for exogeneity, spread between month-ahead and spot prices

Month-ahead	[1]	[2]	[3]	[4]
The Netherlands				
Storage	52,36***	52,99***	52,62***	52,86***
	(0,000)	(0,000)	(0,000)	(0,000)
Germany				
Storage	29,66***	29,96***	29,91***	29,95***
	(0,000)	(0,000)	(0,000)	(0,000)
United Kingdom				
Storage	36,40***	40,58***	40,45***	40,36***
	(0,000)	(0,000)	(0,000)	(0,000)

*Note: *** refers to 1% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B7
Wu-Hausman test for exogeneity, spread between year-ahead and spot prices

	[1]	[2]	[3]	[4]
The Netherlands				
Storage	76,05***	73,50***	75,44***	75,25***
	(0,000)	(0,000)	(0,000	(0,000)
Germany				
Storage	38,22***	37,92***	38,68***	38,85***
	(0,000)	(0,000)	(0,000)	(0,000)
United Kingdom				
Storage	38,34***	38,40***	38,54***	38,56***
	(0,000)	(0,000)	(0,000)	(0,000)

*Note: *** to 1% significance level respectively, p-value in parentheses. Time-to-maturities of the Euribor rate differ from one-month, three-month, six-month and twelve-month for specification [1], [2], [3] and [4] respectively*

Table B8
Descriptive statistics

	Mean	Standard deviation
Spread between year-ahead and day-ahead prices in NL	0,09410	0,11255
Spread between month-ahead and day-ahead prices in NL	0,00397	0,05445
Spread between year-ahead and day-ahead prices in Germany	0,09138	0,11088
Spread between month-ahead and day-ahead prices in Germany	0,00279	0,05100
Spread between year-ahead and day-ahead prices in the UK	0,10999	0,12735
Spread between month-ahead and day-ahead prices in the UK	0,00261	0,06551
Storage level in the Netherlands	36,9663	14,1133
Storage level in the United Kingdom	33,7749	12,5815
Storage level in Germany	147,533	44,3812
Natural logarithm of the 1 month Euribor rate	-1,3077	1,23430
Natural logarithm of the 3 month Euribor rate	-0,7755	0,86723
Natural logarithm of the 6 month Euribor rate	-0,4119	0,72152
Natural logarithm of the 12 month Euribor rate	-0,0727	0,59377

Note: storage data is divided by 1 million to avoid extremely large numbers

Table B9
Correlation Matrix

	Spread NL Y	Spread NL M	Spread Ger Y	Spread Ger M	Spread UK Y	Spread UK M
Spread NL Y	1,0000					
Spread NL M	0,4617	1,0000				
Spread Ger Y	0,9369	0,4289	1,0000			
Spread Ger M	0,3209	0,8312	0,4473	1,0000		
Spread UK Y	0,9919	0,4247	0,9356	0,2979	1,0000	
Spread UK M	0,4621	0,9666	0,4470	0,8202	0,4554	1,0000
Storage NL	0,0659	0,4319	0,0686	0,4320	0,0585	0,4264
Storage Ger	0,0400	0,4272	0,0523	0,3202	0,0355	0,4302
Storage UK	0,0626	0,4162	0,0620	0,4152	0,0639	0,4252
ln(Euribor-1)	0,1906	-0,0103	0,1990	-0,0327	0,1925	-0,0191
ln(Euribor-3)	0,2468	0,0342	0,2479	-0,0017	0,2470	0,0199
ln(Euribor-6)	0,2391	0,0278	0,2356	-0,0084	0,2397	0,0127
ln(Euribor-12)	0,2294	0,0304	0,2243	-0,0049	0,2298	0,0142

	Storage NL	Storage Ger	Storage UK	ln(Euribor-1)	ln(Euribor-3)	ln(Euribor-6)
Storage NL	1,0000					
Storage Ger	0,9579	1,0000				
Storage UK	0,9374	0,9473	1,0000			
ln(Euribor-1)	-0,0885	-0,2474	-0,1799	1,0000		
ln(Euribor-3)	-0,0354	-0,1899	-0,1396	0,9621	1,0000	
ln(Euribor-6)	-0,0125	-0,1771	-0,1283	0,9324	0,9920	1,0000
ln(Euribor-12)	-0,0078	-0,1745	-0,1247	0,9193	0,9854	0,9979