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**Working Paper**

## Theory of storage: an empirical assessment of the European natural gas market

DIW Discussion Papers, No. 821

**Provided in Cooperation with:**

German Institute for Economic Research (DIW Berlin)

*Suggested Citation:* Stronzik, Marcus; Rammerstorfer, Margarethe; Neumann, Anne (2008) : Theory of storage: an empirical assessment of the European natural gas market, DIW Discussion Papers, No. 821, Deutsches Institut für Wirtschaftsforschung (DIW), Berlin

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# Discussion Papers

# 821

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Anne Neumann

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Berlin, September 2008

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## IMPRESSUM

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ISSN print edition 1433-0210  
ISSN electronic edition 1619-4535

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# **Theory of Storage – An Empirical Assessment of the European Natural Gas Market**

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**and Anne Neumann<sup>3</sup>**

## **Abstract**

We analyze the relation between European natural gas storage facilities and price patterns at major trading points, considering the theory of storage to derive a testable hypothesis imposed by the non-arbitrage condition. To model the efficiency of the natural gas market, we apply two indirect tests absent the scarcity of European inventory data. We find that operators of storage facilities realize seasonal arbitrage profits, and that market performance overall is substantially distinct from the competitive benchmark.

**Keywords:** storage, energy commodity, natural gas, convenience yield

**JEL-Codes:** Q 40, L95, G 13

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## **1 Point of Inception**

The need for a competitive, efficient European natural gas market has been clearly expressed in the European Commission's (EC) draft of the forthcoming legislative package (EC, 2007). Whereas the past decade focussed on the development of a level playing level field for operators mainly in (long-distance) transportation and liquefied natural gas (LNG) imports, other parts of the value chain remained untouched. Now policy makers are looking at the market for storage, an integral part of the gas value chain. Evidence from the US, where a futures market for inventories exists at the New York Mercantile Exchange (NYMEX), shows that the days when gas storage was considered solely as backup inventory or as a seasonal supply source are gone forever (Hirschhausen, 2008). In today's uncertain times natural gas has become a highly traded commodity and a profitable asset in risk management.

The EC's draft Directive acknowledges the significance of natural gas storage facilities. In addition, the public debate about securing energy supplies for Europe underscores the fundamental importance of using storage to counteract supply disruptions, balance the system and provide additional flexibility.

Approximately one third of Europe's total natural gas consumption is used in power generation (IEA, 2007). Other demand is characterized by seasonal usage and heating/cooling. Storage that is sited near or adjacent to electricity dispatch and balancing facilities will provide optimum flexibility to meet seasonal peaks.

The draft of the Third Directive also emphasizes the necessity for independent storage operators and an increase in transparency of available capacities to third parties as necessary conditions for efficient market operations. Moreover, non-discriminatory access contributes to the European Union's goal of creating a truly competitive market.

Competitive markets are characterized by the law of one price, i.e. they do not provide arbitrage opportunities (in a temporal or spatial context). The starting point for our analysis is the interdependency of natural gas spot and futures market prices directly linked to the use of storage. The theory of storage says that price signals influence the operation of storage facilities and infrastructure investments as long as a competitive market environment exists, and that development of natural gas storage capacities and efficient adjacent markets will reduce volatile spot prices. The theory also shows that the return from purchasing the commodity today and selling it for delivery later (the so-called basis) equals the interest forgone by storing the commodity plus marginal storage cost less marginal convenience yield from an additional unit of inventory. The convenience yield is defined as the value from

inventory and is negatively correlated with inventories, i.e. the higher the level of stored goods the less value is gained from storing an additional unit.

This paper investigates the predictions of the theory of storage as applied to the European gas market using two indirect tests developed by Fama and French (1987, 1988), since there is limited availability of inventory data for Europe. Whereas the indirect test in Fama and French (1988) is based on the relative variation of spot and futures prices, they used seasonal dummies instead of inventory data to capture variations in the marginal convenience yield (Fama and French, 1987). We use their second approach because it allows us to: study the overall market performance by analyzing whether the basis varies with nominal interest rates corresponding to different maturities of various futures contracts; and to verify the existence of seasonality in the basis. If the hypotheses cannot be rejected, it follows that the European market for natural gas storage does not presently function in a purely merchant fashion. We use market data for spot and futures prices from the British National Balancing Point (NBP), from Zeebrugge (Belgium) and the Title Transfer Facility (TTF) in the Netherlands to distinguish the regions.

The remainder of the paper is organized as follows. In the next section we present the fundamental theoretical background on the theory of storage accompanied by a brief literature overview of its empirical applications for natural gas markets. Section 3 describes the data set. The testable hypotheses are derived in Section 4 which also introduces the two indirect approaches. Empirical results and their interpretation are presented in Section 5, and summaries and conclusions appear in Section 6.

## **2 Literature Overview**

Increasing international trade and the development of global markets have put commodity price determination back on the agenda. The theory of storage (Working, 1949) says that filling quantities are determined by the equivalence of marginal storage cost and the intertemporal price spread.<sup>4</sup> Brennan (1958) reworks the theory to include the convenience yield given that spot prices can exceed futures prices.<sup>5</sup> The benefits for consumers from

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<sup>4</sup> The intertemporal price spread is the difference in spot and futures prices. This only holds as long as futures prices do not fall below spot prices, which cannot be assured when considering natural gas markets.

<sup>5</sup> Consumers of a commodity (such as natural gas) receive an implicit stream of benefits from holding inventory - the convenience yield (Kaldor, 1939).

holding inventories arise because the stored product depicts an input for the production of other commodities as well as the ability of a user to meet unexpected future demand.

Natural gas is often used to produce heat together with electricity in combined heat and power stations. Heat demand correlates with changes in temperature, itself highly stochastic, leading to the expectation that gas demand is also driven by temperature and should therefore follow a similar stochastic. The theory of storage displays these dependencies, showing that commodity futures and spot prices differ by the cost of storage and interest costs of holding inventory less convenience yield. Normalizing this relation to spot prices yields:

$$\frac{F(t,T) - S(t)}{S(t)} = r(t,T) + \frac{W(t,T) - C(t,T)}{S(t)} \quad (1).$$

Let  $F(t,T)$  be the futures price at time  $t$  for delivery of the commodity at  $T$  and  $S(t)$  the spot price at  $t$ . The left side of the equation (1) is the return from purchasing the commodity at  $t$  and selling it for delivery at a later date  $T$  (the basis). The difference between futures and spot prices should equal the interest forgone ( $r(t,T)$ ) plus marginal warehousing costs ( $W(t,T)$ ) less the marginal convenience yield<sup>6</sup> from an additional unit of inventory ( $C(t,T)$ ).

The value of marginal convenience yield should then decline as the aggregate level of inventory increases. Convexity of the slope implies that an additional unit of inventory leads to a larger reduction in marginal convenience yield if the current level of inventory is low. French (1986) and Fama and French (1987, 1988) derive implications of a convex marginal convenience yield in terms of futures and spot price variances and correlations. They illustrate that for a high level of inventory, contemporaneous spot and forward prices should have similar variances and therefore high correlation. Lower inventory levels imply that the variance of spot prices exceeds the variance of future prices, consequently leading to a lower correlation between both prices. More recently, Cho and McDougall (1990), and Ng and Pirrong (1994) provide evidence for this theory showing that the convenience yield is inversely related to the level of inventory.

Applying the theory of storage to the natural gas industry, most recent empirical studies have only analyzed the US market. Susmel and Thompson (1997) analyze the relationship between commodity price volatility and investment in US storage facilities during gas market deregulation. A switching ARCH model with two states and two autoregressive terms shows that investments in additional storage facilities follow an increase in volatility. Wei and Zhu

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<sup>6</sup> The marginal convenience yield is defined as the additional flow of benefits accrued from holding an extra unit of inventory.



(2006) use a bivariate GARCH model to estimate different risk premiums for the US market. While the dependence of estimated convenience yields on other explanatory variables confirm the theory of storage, it does not hold for all resulting risk premiums. Dincerler, Khokher and Simin (2005) and Khan, Khokher and Simin (2005) provide additional evidence on the dependency of commodity futures prices upon inventory levels with a special focus on mean-reverting behavior for various commodity markets in the US, including natural gas. The predictions of the theory of storage are confirmed for the North American natural gas market between 1990 and 2002 by Serletis and Shahmoradi (2006). However, Modjtahedi and Movassagh (2005) find only partial support to the cost-of-carry theory of the basis determination by analyzing US data from 1993 through 2004.

In a first application to the European market, Haff et al. (2008) find similar results for the UK natural gas market with a non-linear effect of storage on the relationship between spot and futures prices. While Modjtahedi and Movassagh (2005) detect a negative risk premium for the US, Haff et al. (2008) show the opposite for the UK.

We believe that this paper presents the first comparative analysis of major European trading points applying the theory of storage and using the two indirect tests developed by Fama and French (1987, 1988). With the limited availability of inventory data for natural gas storage in the emerging European market, we note that the two approaches provide market insights.

### **3 Data**

We use daily data for spot and futures prices from the National Balancing Point in the UK (NBP), the Dutch Title Transfer Facility (TTF), and Zeebrugge in Belgium (ZEE) as provided by Heren.<sup>7</sup> The data is collected for the period of October 2005 to September 2007 thus covering two “gas years”.<sup>8</sup> We focus on the analysis of six- and twelve-month maturities of futures contracts. Corresponding risk-free interest rates are provided by daily EURIBOR (Belgium and the Netherlands) and LIBOR (UK) rates from Bloomberg for six-month and one-year maturities.

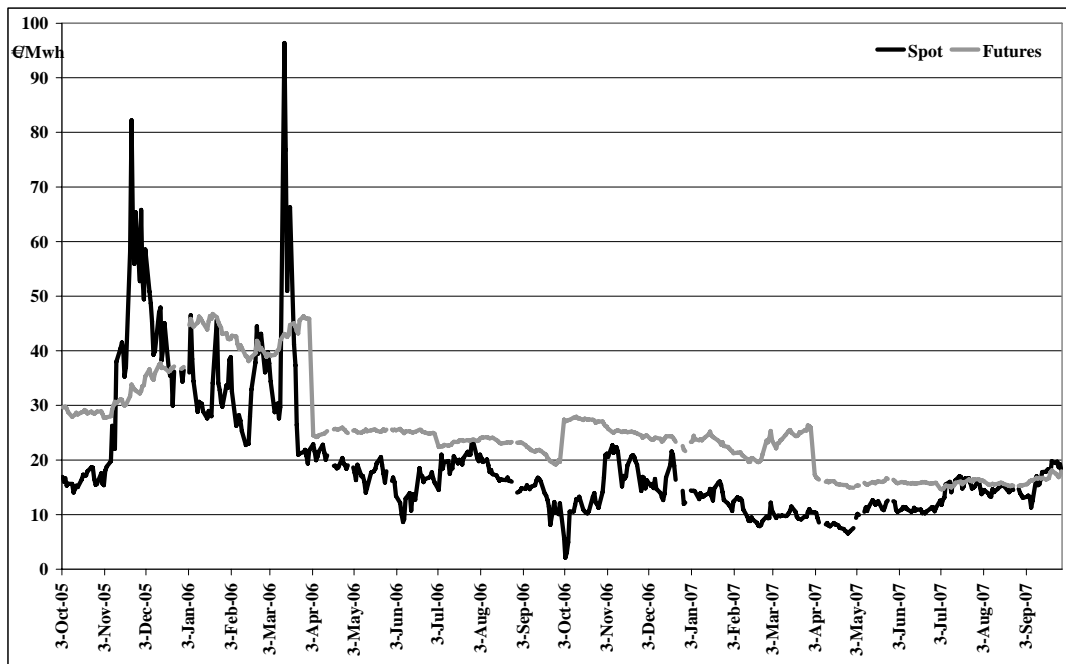
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<sup>7</sup> A futures contract is an agreement determining the delivery of a certain commodity at a pre-specified future date. Futures are marked to market (“mark to market” is the shorthand term) implying cash settlement at each trading day. Zeebrugge and NBP price data (p/Therm) is converted into €/MWh using daily exchange rates and 1 therm = 29.3071 kWh.

<sup>8</sup> A “gas year” starts on October 1 and is divided into winter (Oct.-Mar.) and summer seasons (Apr.-Sept.). Natural gas is usually withdrawn from storage during winter when demand and prices are high and injected during summer when supply exceeds actual demand.

Figure 1, illustrating spot and futures prices for the NBP on a twelve-month basis, shows that the futures prices are regularly well above spot prices. Market situations with strong backwardation are observed in winter 2005/2006.<sup>9</sup> The two peaks in spot prices were caused by shortages in production in Norwegian natural gas fields accompanied by relatively low temperatures across Europe. Lower prices are observed during the summer season of a “gas year”.

**Figure 1: Spot and Futures Prices for Delivery at NBP (12-month maturity)**



The differences between futures and spot prices relative to the spot price determine the spread (the left side of eq. (1)) and is called basis. For further study we restrict our analysis to futures with six- and twelve-month maturities. Therefore, we calculate the different basis for the respective maturities.

Figure 2 highlights the price differences between *basis12* for TTF and Zeebrugge with respect to NBP. While Zeebrugge closely tracks NBP, TTF deviates significantly during the first half of the considered period with a tendency to converge since the end of 2006.<sup>10</sup> Whereas Zeebrugge is directly linked to the UK system via the Interconnector since 1998, the connection between TTF and NBP was established only recently, when the Balgzand-Bacton-Pipeline began operations at the end of 2006.

<sup>9</sup> When spot prices exceed futures prices it is called backwardation; contango signals the opposite.

<sup>10</sup> Neumann et al. (2006) confirm these results.

Figure 2: *Basis12-Differences* (TTF and Zeebrugge compared to NBP)

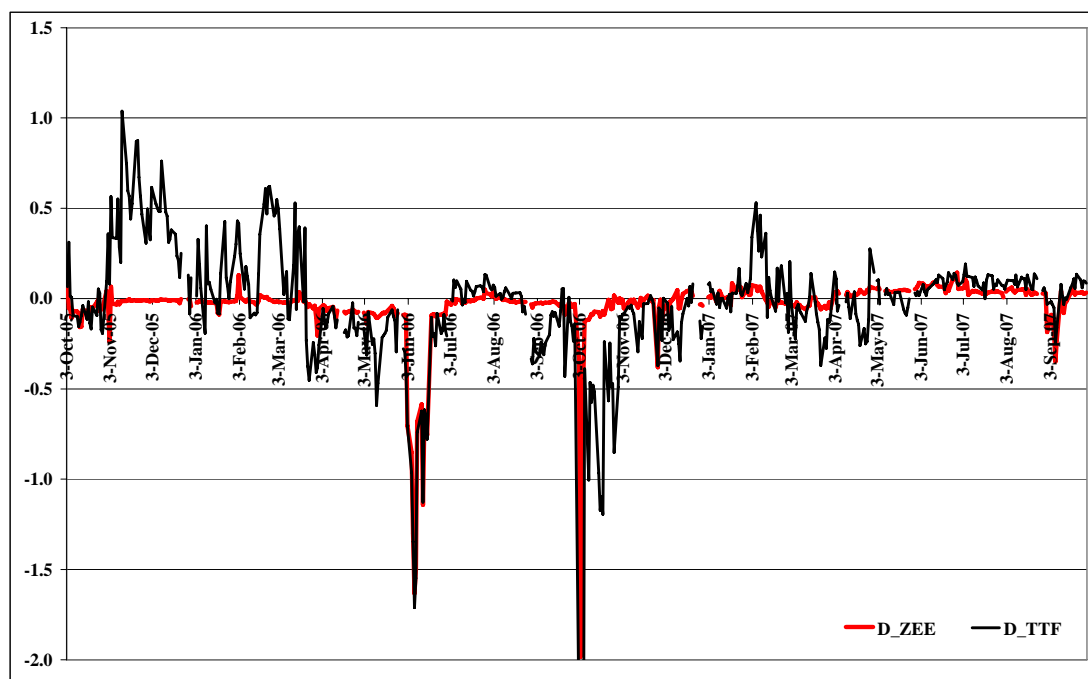


Table 1 highlights the explanatory power of the evolution in *basis6* or *basis12* for NBP for the development of the six- or twelve-month basis of TTF and ZEE.

The coefficients and the R-squared show that price developments at Zeebrugge are closer to NBP than at TTF.

**Table 1: Basis12-Differences (TTF and Zeebrugge compared to NBP)**

	Variable	Coefficient	Std. Error	t-Statistic	Prob.	R-squared
BASIS6	TTF	0.5836	0.0119	4.898.558	0.0000	0.7093
BASIS6	ZEE	0.8613	0.0083	1.034.879	0.0000	0.9365
BASIS12	TTF	0.5979	0.0156	3.822.437	0.0000	0.4339
BASIS12	ZEE	0.88139	0.0071	1.235.788	0.0000	0.9521

Interdependencies of the three Northwest European trading places are shown in Table 2. In particular, there are high correlations between NBP and ZEE spot prices and NBP and ZEE futures prices. The relation between NBP and TTF is similar, but at a much lower level when considering spot prices. The high level of correlation indicates that prices are either driven by each other by an exogenous third factor that affects each time series separately but in an equal manner.

**Table 2: Correlation for the price series**

Spot prices	NBP	TTF	ZEE
NBP	1.000000	0.785989	0.993631
TTF		1.000000	0.801595
ZEE			1.000000
Futures Prices	NBP	TTF	ZEE
NBP	1.000000	0.985636	0.999840
TTF		1.000000	0.985098
ZEE			1.000000

Following Granger (1969) and Johansen (1988), Table 3 provides the results for the considered price series.<sup>11</sup> Except for NBP and TTF spot prices, there is no evidence for futures or for spot prices that one time series drives the other. This confirms the impression from Figure 2 and the connection via the Interconnector indicating that NBP and ZEE prices evolve similarly over time. The opposite holds for NBP and TTF spot prices. Hence, we expect similar results when testing the trading platforms NBP and ZEE for validity of the theory of storage in contrast to the Dutch hub.

<sup>11</sup> This exemplarily shows the results for the 6-month maturity.

**Table 3: Granger causality**

Null Hypothesis	Probability
FUTURES_TTF does not Granger Cause FUTURES_NBP	0.60749
FUTURES_NBP does not Granger Cause FUTURES_TTF	0.84929
FUTURES_ZEE does not Granger Cause FUTURES_NBP	0.63195
FUTURES_NBP does not Granger Cause FUTURES_ZEE	0.71167
SPOT_TTF does not Granger Cause SPOT_NBP	0.02155
SPOT_NBP does not Granger Cause SPOT_TTF	0.00386
SPOT_ZEE does not Granger Cause SPOT_NBP	0.54176
SPOT_NBP does not Granger Cause SPOT_ZEE	0.98979

## 4 Method

We test the performance of the European natural gas market with storage facilities based on the condition of an arbitrage-free market. The validity of equation (1) for the European natural gas market is evaluated first by following Fama and French (1988), and Serletis and Shahmoradi (2006) (analyzing how spot and futures prices behave in different states of storage activity) and Second, following Fama and French (1987), investigating overall market performance. Both approaches are indirect as neither requires inventory data.

### 4.1 Test of Pricing Behavior

Rearranging equation (1) implies that the left side stands for the interest-adjusted basis and equals the difference of warehousing costs and convenience yield relative to spot prices such that:

$$\frac{F(t,T) - S(t)}{S(t)} - r(t,T) = \frac{W(t,T) - C(t,T)}{S(t)} \quad (2)$$

The signs of the interest-adjusted basis become predictors for the level of inventory. Low inventory implies a negative sign and vice versa. Changes in spot and futures prices should be approximately of equal magnitude. If the theory of storage holds, a low inventory level, i.e. a negative sign of the adjusted basis, should imply higher variability in the adjusted basis.

## 4.2 Test of Overall Market Performance

To obtain a second indirect test of the theory of storage absent inventory data, we follow Fama and French (1987) and use the following general regression formula:

$$\frac{F(t,T) - S(t)}{S(t)} = \beta_1 r(t,T) + \beta_2 Q_{2,t} + \beta_3 Q_{3,t} + u_t \quad (3)$$

where quarterly dummies  $Q_{i,t}$  equal 1 if the corresponding futures contract matures in that period.<sup>12</sup> The regression coefficients are given by  $\beta_i$  and the residuals are modeled as an AR(1)-process. Using seasonal dummies in equation (3) approximately controls for seasonalities in the marginal convenience yield.<sup>13</sup> We test two hypotheses:

- $H_1$  (significance of predictors): The estimated seasonal dummy coefficients  $\beta_2$  and  $\beta_3$  should have significant explanatory power. High winter and low summer demand both create an arbitrage potential which will be exploited by market participants in an efficient market.
- $H_2$  (market performance): The slope coefficient  $\beta_1$  should vary one-for-one with the nominal interest rate ( $\beta_1=1$ ). Disregarding other conceivable reasons for market imperfections (e.g., market power at the wholesale level), a  $\beta_1$  far from one implies that storage users do not fully exploit arbitrage opportunities.

## 5 Results and Interpretation

Results for the test of the pricing behavior are shown in Table 4. Reported are the number of observations, average values, and volatilities of the risk-adjusted basis for the considered trading points ordered by the sign of the risk-adjusted basis.

Contrary to Serletis and Shahmoradi (2006) who report a more or less equal share for the US, we observe a dominance of a positive-adjusted basis at all hubs in Europe. This translates into a relatively low value attached to natural gas in storage by market participants (convenience yield). Standard deviations are higher when the interest-adjusted basis is positive, thereby contradicting economic reasoning. Demand shocks in competitive markets of storable

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<sup>12</sup> We use quarterly dummies to map seasonality as they fit best.  $Q_{2,t}$  and  $Q_{3,t}$  represent the summer season of a gas year. E.g.,  $Q_{2,t}$  indicates that the futures contract matures during the second quarter of the year (April to June). The other two quarters are omitted in equation (3) and in the remainder of this paper since they have no explanatory power.

<sup>13</sup> In fact we control for  $W(t,T) - C(t,T)$ .

commodities create more independent variations of spot and futures prices leading to higher changes in the basis when inventory is low.

**Table 4: Summary Statistics for daily interest-adjusted bases**

Basis	TTF			Zeebrugge			NBP		
	Observations			Observations			Observations		
	+	-	All	+	-	All	+	-	All
<b>6</b>	347	155	502	346	156	502	325	178	503
<b>12</b>	480	23	503	429	73	502	425	78	503
	Average values			Average values			Average values		
<b>6</b>	0.591	-0.139	0.355	0.746	-0.268	0.409	0.869	-0.271	0.440
<b>12</b>	0.473	-0.079	0.439	0.525	-0.183	0.414	0.614	-0.178	0.491
	Standard deviation			Standard deviation			Standard deviation		
<b>6</b>	0.207	0.061*	0.176	0.275	0.069*	0.232	0.348	0.067*	0.282
<b>12</b>	0.224	0.174*	0.222	0.306	0.145*	0.288	0.379	0.118*	0.352

Notes: \* indicates rejection of the null hypothesis of equal variances at the one percent level.

In the European context, there are two conceivable explanations for this phenomenon. First, a low convenience yield might indicate a higher level of inventory than required under pure economical operation of storage facilities. Second, accounting for the limited availability of storage capacities across Europe and the non-existent secondary market, participants with no access to storage facilities might disregard this trading opportunity. If incumbents used their facility as a strategic tool, they would attach a lower value to natural gas on hand than they would do under effective competition.<sup>14</sup> *Therefore, both observations provide a first indication of a malfunctioning natural gas market in Europe.*

Second, we note that the data for the three trading points is best explained by the chosen model specification for the six-month maturity of futures contracts (*basis6*) (Tables 5 and 6). The best fit is achieved for Zeebrugge. Our model specification seemingly provides a good approximation of the data compared to Fama and French (1987) who report goodness of fit of less than 20% in many cases. Nonetheless, the relatively low values of R-squared in some cases indicate important omitted variables, i.e. storage levels. When this information is made

<sup>14</sup> In this case, storage has a strategic rather than an operational value for its owner.

publicly available for all major European facilities, we suggest including it in the model to test whether the results can be improved.<sup>15</sup>

**Table 5: Estimation results for 6-month bases**

	<b>TTF</b>	<b>Zeebrugge</b>	<b>NBP</b>
<b>r</b>	22.064* (1.496)	19.249* (2.672)	16.519* (2.053)
<b>Q2</b>	-0.523* (0.1059)	-0.122 (0.493)	-0.366 (0.509)
<b>Q3</b>	-0.709* (0.142)	-0.799* (0.080)	-0.956* (0.099)
<b>R<sup>2</sup></b>	0.790	0.822	0.799

\* indicates significance at the 1%-level.

Number in brackets report standard errors.

**Table 6: Estimation results for 12-month bases**

	<b>TTF</b>	<b>Zeebrugge</b>	<b>NBP</b>
<b>r</b>	20.627* (2.101)	28.091* (1.868)	19.019* (6.234)
<b>Q2</b>	-0.418* (0.089)	-0.827** (0.343)	-0.689*** (0.354)
<b>Q3</b>	-0.563* (0.103)	-1.245** (-0.595)	-1.097*** (0.564)
<b>R<sup>2</sup></b>	0.574	0.706	0.666

\*, \*\*, \*\*\* indicates significance at the 1, 5 and 10 %-level.

Number in brackets report standard errors.

The three European trading points show that the interest rates are significant at a one-percent level. The picture is less clear concerning seasonal dummies. The bases at TTF reveal a clearer seasonal pattern than NBP or ZEE. For *basis6*, the second quarter does not have significant explanatory power, mainly due to high volatility observed during winter

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<sup>15</sup> For the UK, Haff et al. (2008) show that even after incorporating inventory levels the no-arbitrage condition has to be rejected.



2005/2006 that mirrors the lowering effect of the first summer dummy. Given the seasonal influence at NBP and Zeebrugge, although lower than at TTF, our first hypothesis of the indirect performance test can be confirmed, i.e. storage facilities realize seasonal arbitrage but may reveal problems regarding short-term arbitrage.<sup>16</sup>

The negative signs of the dummy coefficients in the case of *basis6* were expected since winter spot prices are compared with futures prices, reflecting market expectations of the upcoming summer season. Since scarcity is usually higher during winter, the seasonal dummies tend to have a reducing effect on the basis. We also observe a negative sign of these coefficients in the case of *basis12*. We see no obvious explanation. The lowering effect of summer dummies on the basis indicate, compared to the winter cycle, a higher convenience yield during the second and third quarter of a year implying lower stocks. Due to the arbitrage-free condition and assuming an unchanged interest rate this leads to a convergence of spot and futures prices.

The major finding of evaluating the overall market performance is the magnitude of the interest rate coefficient far away from one, the value expected from theoretical considerations. We observe a  $\beta_I$  of around 20 at all hubs, hinting at huge arbitrage potentials that are not exploited by market players. Hence, we can reject our second hypothesis, again indicating a malfunctioning natural gas storage market reflected at the three European trading points

## 6 Conclusions

This paper contributes to the ongoing discussion concerning the role of storage in fostering a truly competitive European market for natural gas. To assess the performance of natural gas storage, the observed market outcome must be tested against a competitive benchmark, the intertemporal no-arbitrage condition. Our analysis is based on the indirect tests of Fama and French (1987, 1988) and allows us to study the performance of the three major European trading points in relation to storage absent inventory data. First, we use the risk-adjusted basis as a proxy for inventory, testing whether the basis, i.e. the difference between futures and spot prices, varies more during periods of low storage levels. We find the results less intuitive, contradicting our expectations. Second, we introduce seasonal dummies to map storage levels controlling for seasonality in the convenience yield and for a one-for-one relation between the

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<sup>16</sup> It should be noted that we abstract from any bottlenecks in the network. Nevertheless, a service-oriented operation of storage and the introduction of derivative products (virtual storage) should partially overcome these problems.

basis and the risk-free interest rate. Estimations using seasonal dummies lead to interest rate coefficients far away from one. Surprisingly, though NBP is much more developed than the two other trading points, we observe no significant differences across markets.

The indirect tests indicate a fairly high arbitrage potential that is not being exploited by market participants and hints at market imperfections. Given the limited availability of storage capacity and the missing secondary market for these products across Europe, the results could be explained by the strategic behaviors of some storage owners. The storage capacity constraint is also mentioned by Haff et al. (2008) as being a possible problem in the UK market. Following this same line of reasoning, we observe that the results may be driven by the lack of transparency. Finally, the market outcome could be influenced by the technical orientation operations of storage facilities that still predominate in the market. To move towards the competitive benchmark, these hurdles must be overcome, which will likely lead to more service-oriented operations of gas storage facilities.

In conclusion we suggest that additional research will provide a more complete picture through incorporating direct information about storage levels and price data spanning longer time periods. To date, our analysis considers a theoretical optimal usage of facilities, neglecting other factors. In particular, the availability of future natural gas supplies for Europe may substantially influence the relationship in the forward-looking context.

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