# Transatlantic Natural Gas Price and Oil Price Relationships - An Empirical Analysis

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Markets for natural gas in industrialized countries have witnessed profound changes in the past two decades. Trade of natural gas at spot markets in North America and Europe expanded and intensified significantly as a direct result of liberalization efforts. We test the relationships of weekly prices for crude oil and natural gas on either side of the Atlantic Basin between 1999 and 2005. Applying cointegration methodology we identify a move toward integration of historically and geographically separated markets for the homogeneous commodity natural gas.

Keywords: market integration, spot markets, natural gas

JEL-Codes: L95, Q49, F15

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# 1 Introduction

This paper analyzes the dynamic integration of international markets for goods and commodities using econometric analysis, applied to the natural gas markets. Markets for natural gas around the world have witnessed profound changes in the past two decades. Restructuring is leading to the emergence of a new "international gas market". Import, distribution and sales monopolies are being unbundled in industrialized countries, third-party access is being developed for natural gas infrastructure to promote further competition following legislative reforms. The introduction of competition implies fundamental changes in commercial and contractual relationships, affecting the formerly limited regional gas markets of Europe, North America and Asia-Pacific. Traditional pricing schemes are being reviewed, moving from long-term, often oil price indexed natural gas prices toward prices based on market mechanisms.

Developments in this new "international gas market" include the following factors. *First,* the liquefied natural gas industry (LNG) has grown steadily for nearly four decades, increasing integration of formerly unconnected regional gas markets. In addition, an active arbitrage has developed in the Atlantic Basin where LNG shipments form Trinidad and Nigeria have been diverted either to the US or Europe depending on spot prices. *Second,* the restructured natural gas industry in Europe and North America features a high proportion of spot trading. Recent gas sales contracts are of a relative short duration compared to traditional long-term contracts. Contract prices are being keyed to a gas market indicator, since oil-linked pricing is a poor indicator in gas-to-gas competitive markets. Trade press reporting for reference points such as the Henry Hub in the US, the NBP in the UK, or Zeebrugge in continental Europe provides transparent information about the market.

Theoretical models predict that in an integrated market, prices on homogenous products from different suppliers should move in the same direction, and price differentials should only represent differences in transportation costs or quality. This hypothesis is tested by exploring the dynamics between major North American and European gas hubs. Furthermore, we analyze the interaction of oil and natural gas prices, since a linkage (though not always formally expressed) to oil is expected due to fundamental and long-run economic factors. The most recent debate aims at expressing the definition of an international gas price rather than questioning its existence.

Following the more general work of cointegration of international long-term import prices by Siliverstovs et al. (2005), we aim at identifying the behavior of spot prices on either side of the Atlantic Basin. Simultaneously, we explore price relations of intra-fuel substitutes. Consequently, the remainder of the paper is structured in the following way: Section 2 provides an overview of existing literature with regard to applications of testing cointegration and convergence relationships in the energy sector. Following this synopsis, developments in natural gas markets on either side of the Atlantic Basin, including the LNG industry, are broadly lined out in Section 3. The data set, applied methodology, and estimation results are introduced in Section 4. Section 5 concludes and identifies further areas of work.

# 2 Related Literature

Restructuring of markets for natural gas and electricity has attracted a variety of empirical investigations. Until recently, related literature has focused on the developments in regional markets. Substantial work on the North American market has been carried out since FERC Order 436 in 1985. During the early 1990s, Serletis (1997), Walls (1994), and De Vany and Walls (1994, 1993) analyzed the relationship of prices for natural gas in several market places, city gates, and wells. Results for tests of cointegration relationships are quite diverse, but applications of Engle-Granger test and correlation analysis to monthly spot prices reveal arbitraging behavior following deregulation. Other econometric tools such as introducing time-varying coefficients, the Johansen test procedure, and applications of impulse response functions to daily spot prices confirm increasing convergence of prices since the late 1990s (King and Cuc, 1996, Cuddington and Wang, 2004). Serletis and Rangel-Ruiz (2004) are the first to investigate shared trends and shared cycles in North American prices for natural gas and oil concluding that there has been uncoupling of these two prices in the time period of 1990 and 2001.Furthermore, they show that prices at Henry Hub determine other North American prices for natural gas.

Since efforts for the creation of a single European market for electricity and natural gas were first implemented in 1998, attention has also been paid to these markets. However, there exists only limited literature focusing on markets for natural gas. The first work by Asche, Osmundsen, and Tveteras (2001, 2002) focus mainly upon monthly long-term import prices from Norway, the Netherlands, and Russia to Germany and France. The authors show that national markets within Europe are highly integrated. However, this result is not surprising since prices under consideration are those agreed upon under extensive long-term contracts generated from the "old world".

The exemption of the UK (having introduced competition some 5 to 8 years in advance of the rest of Europe) with functioning short-term markets for natural gas has served as a pioneer in terms of empirical applications. Panagiotidis and Rutledge (2004) show that there existed a long-run equilibrium of monthly spot wholesale natural gas and oil prices between 1996 and 2003 which has become more volatile over time. Neumann et al. (forthcoming) are the first to investigate price convergence of European spot prices applying Kalman filtering techniques. They conclude that this convergence process is indeed taking place, though it is highly related to the availability of interconnecting capacities; hence price convergence is only taking place between selected trading places.

With LNG becoming more economically and entering the international scene seriously, functioning markets are expected to become integrated. Siliverstovs et al. (2005) test the hypothesis of internationally integrated markets of North America, Europe, and Asia applying Principal Component analysis as well as bi- and multivariate Johansen test procedures to monthly import prices. The hypothesis of cointegration has to be rejected for the transatlantic pair of prices (with importing prices fixed in extensive long-term contracts), but not for the European-Asian relationship. The contribution of this paper is to explore the relationship of transatlantic spot prices for natural gas and interactions with respective oil spot prices which (to the best of the authors' knowledge) has not been visited previously.

# 3 Emergence and Features of Spot Markets for Natural Gas and LNG Trade

## 3.1 Spot Markets in Europe and North America

Efforts to create a single European market for electricity and natural gas date back to the early 1990s. Enforcement of the Second Gas Directive 2003/55/EC emphasizes the European Commission's restructuring ambition in an institutional framework for the natural gas sector.

Along with the breaking up of the monopoly of BG in the UK in 1986, a competitive gas market emerged in Europe. Already in 1994 the National Balancing Point (NBP), a notional trading point on the National Transport System (NTS), was used as an informal market indicator and developed into the primary nexus for spot gas trading activities from 1996. By 1993, total trade has added up to 675 bcm. There has been a steady increase in volume traded both physically and financially, with yet more potential to be explored since LNG experiences a revival in recent times.

Recently, the NBP has served as a reference point for prices in long-term contracts enhancing the worthiness of this trading place. According to the International Energy Agency (IEA, 2004, p. 110) Centrica (BG trading services) has moved away from oil price indexation in most of their contracts, replacing it with gas price indexation. In contrast, the European Regulators Group for Electricity and Gas has criticized the liquidity of the NBP (EPRGEG, 2005).

The opening of the Interconnector system in October 1998 linking Bacton, UK, and Zeebrugge, Belgium paved the way for spot trading in continental Europe. Since its start in 1999, traded volumes have steadily increased to an estimated cumulate volume of 67 bcm including both forward and reverse capacity by 2002. At the end of 2001 and beginning of 2002, HubCo and EuroHub, respectively, launched market places at Bunde and Oude at the Dutch-German border. Trade picked up for the following two years, but the implementation of an entry-exit system on the Dutch high-calorific gas grid brought trade at Bunde/Oude to a sudden end. Instead, trading at the Dutch Title Transfer Facility (TTF) increased and replaced activities in Bunde. According to Heren, prices of Bunde are only indicative these days as very little, if any, trading is done there and it is valued the same as the TTF. By the end of 2004, trade at TTF has doubled to 2.5 bcm. Furthermore, according to operators, trade at Zeebrugge in Belgium[1], Baumgarten in Austria[2], PSV in Italy[3], as well as PEG in France[4], have grown steadily.

Only with deregulation of wellhead prices in 1978 (Natural Gas Policy Act) and opening up access to transport infrastructure (FERC Orders 436 and 636, 1985 and 1992) the way for competition in North America was paved. The development of market centres supported by a dense pipeline infrastructure put Henry Hub in Louisiana ahead of 36 trading places (including Canada). Since 1988, it has become the largest spot market where fourteen pipelines connect and there exists access to three salt storage caverns. Henry Hub serves as delivery and reference point for the New York Mercantile Exchange (NYMEX) gas futures contract and is reference point for all natural gas export contracts to Mexico. Natural gas futures (traded since April 2000) at NYMEX have a depth of five to six years and have been complemented by options since 1992. According to the IEA, the estimated daily trading volume of 20 bcm in 2003 was ten times the amount of natural gas delivered in the United States (IEA, 2004, p. 76 ff.).

It is evident, then, that there is a degree of repetition of history: trade at the TTF is now in its early stages just as Henry Hub was 15 to 20 years ago. The increase in trade intensity at NBP follows the same pattern. There is warranted hope for trade at the TTF to follow preceding developments.

## 3.2 Competition of North American and European markets

With growing demand for natural gas mainly in power generation, this fossil fuel has become a commodity traded on stock exchanges in the world. Limited resources and new discoveries make natural gas a scarce good following price signals and by utilising arbitraging possibilities. Furthermore, the homogeneity of natural gas, technically achievable by blending types, makes it easy for players worldwide to maximise profits by selling on the floor offering a higher price. Arbitraging possibilities emerge in cases when the price differential of a homogeneous commodity exceeds transportation costs. The limited number of companies active in exploration and transporting natural gas from remote areas of drilling to consumption centres (North America and Europe together accounted for 70% of global gas demand in 2004[5]), while aiming to amortize infrastructure investments, will succeed by minimizing transportation costs and yielding high

[1] Huberator (2005).
[2] Central European Gas Hub GmbH (2005).
[3] Snam Rete Gas (2005).
[4] GdF Réseau Transport (2005).
[5] BP (2005).

revenues. Diminishing quantities sold under long-term contracts and additional quantities being demanded on shorter and more flexible terms leads a situation in which buyers and sellers in different markets begin to compete for the same good. Traders and shippers will use futures, options and spot markets simultaneously to maximize profits and manage price risks. Currently, the North American market remains more mature (in terms of volume) and deeper than the still-evolving trading places (mainly in continental Europe), and additionally has no explicit linkage to the price of oil. This pattern is expected to be followed in Europe; hence, true competition of spot prices on either side of the Atlantic Basin has begun to emerge, with Henry Hub evidently acting as leader. The working hypothesis is that European prices will be determined in the North American market and the two trading places will eventually integrate into one market.

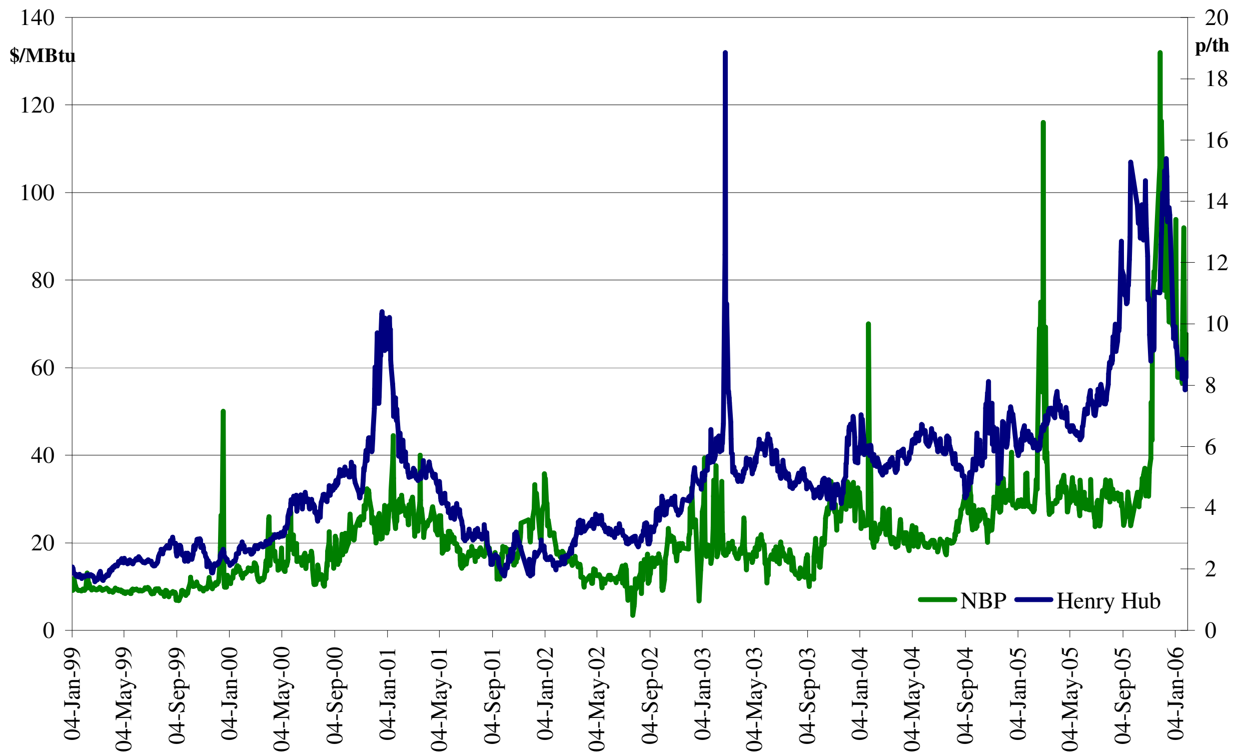
Figure 1 provides a graphical illustration from which it is evident that both prices seem to move closely in particular during the last two years. Arbitraging possibilities frequently arise during summer months, mainly due to the increased use of natural gas in power generation, primarily air conditioning in the United States. Overall, there is an upward trend in British prices, reflecting decreasing indigenous production and thus increasing import dependency coupled with higher (transportation) costs.

Up to now, spot trading has had little effect on the market from which cargoes have been diverted. As swaps avoid cross-shipping, thus substantially reducing transportation costs, they are prone to be exercised more often in the LNG trade. Nigeria already signed a deal with Gaz de France and Enel of Italy under which natural gas between them could be swapped through 2022[6]. An additional example for the internationalisation of LNG trade is represented by the deal signed between GdF and Gazprom. A swap arrangement allows Gazprom to deliver an LNG cargo to Cove Point in the United States by delivering additional pipeline natural gas to France[7].

[6] Gaz de France European Leader in Liquefied Natural Gas (November 2005). GdF Corporate Communications Department.

[7] Press Release : Gaz de France, 23 November 2005 and Alexander's Oil & Gas connection.

**Figure 1: Spot prices for Natural Gas in North America and Europe**




Source: NYMEX and Heren Ltd.

Integration of NBP and Henry Hub via expectations on future prices, coupled with an intensification of trade at the TTF and Zeebrugge, will ensure investment incentives as well as a sound basis for increasing short-term trade. Moreover, implementation of a favourable regulatory environment not only improves planning certainty for industry, but fosters the development of further trading centres, as well.

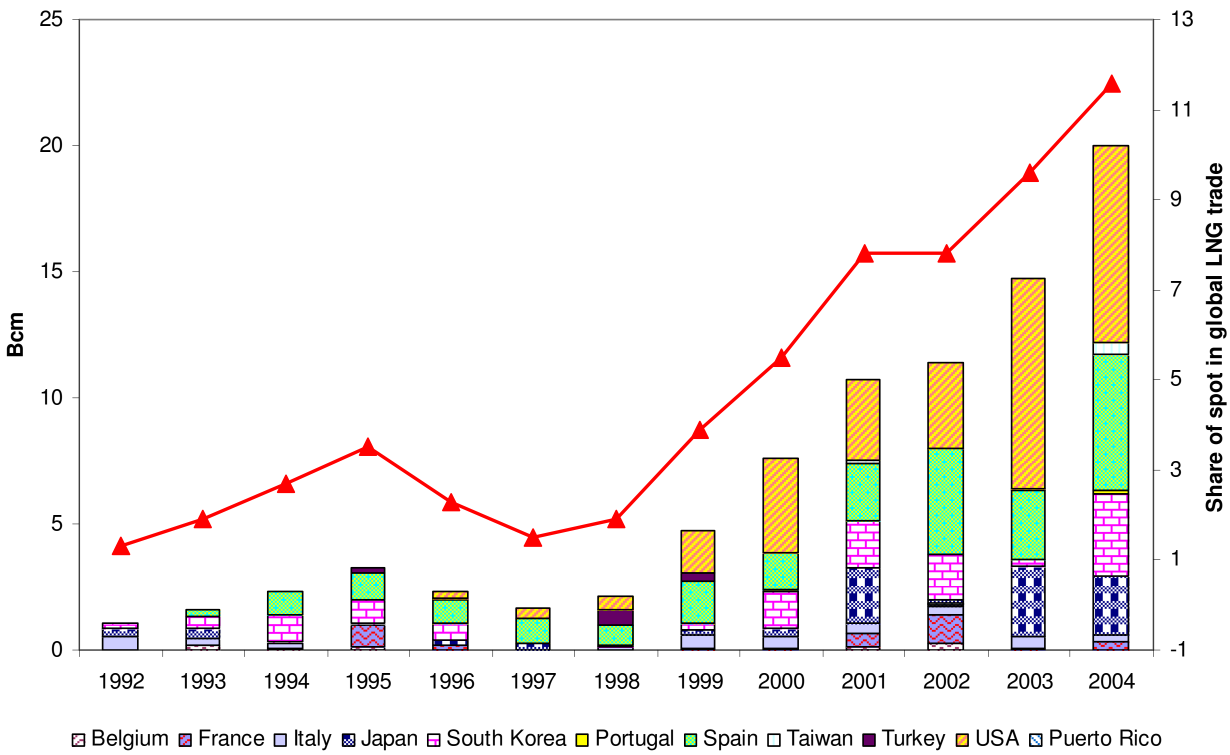
## 3.3 The Role of LNG and arbitrage

Convergence of North American and European prices for natural gas will take place until the difference only reflects transportation costs. With financial instruments at the NBP not offering the same scope as at the NYMEX, a physical interconnection will be crucial for achieving complete convergence. This is expected to be provided by the eminently growing international LNG trade. Prerequisites are fulfilled for completion of mission: increased liquefaction and regasification capacities are in place, supply and demand can be met, and order books for LNG tankers are full. Even projections from Cedigaz in their low-growth scenario anticipate a huge increase in LNG imports (Cedigaz 2004).

A growing share of spot activities in the LNG market, estimated at 20 bcm in 2004 and projected to 15-30% of global LNG trade (Conrnot-Gandolphe, 2005), provides evidence of existing arbitraging possibilities in the Atlantic Basin. However, the impact on market prices remains unclear. Spot trading mainly occurs during cold winter months, providing an ideal opportunity to meet peak demand, and during times of substantial price differences between North America and Europe. Natural gas storage deposits could be filled whilst sustainable low prices prevail, thus incurring strategic redirections of tankers to alternative market places performing at higher prices. A number of ships, in addition to the ones on order, will be freed as long-term contracts for their destination run out and/or come up for renewal.

Recently, high prices in North America had a significant impact in LNG transactions in the Atlantic Basin. In particular, Henry Hub prices have dominated spot transactions last winter and have established the final destination of LNG cargoes. For instance, as much as 44% of total LNG imports was traded on spot basis during 2004. Figure 2 illustrates growing number of LNG spot and swap transactions for the period 1992 until 2004. An increase in the share of LNG supplies to Europe, combined with an increase in demand for natural gas, declining indigenous production, and the changing nature of long-term contracts, exhibit similarities to the US experience. With major LNG exporting companies pegging prices in long-term contracts to different spot market prices, and increasing excess shipping and importing capacities, vertical integrated market participants are bound to explore possible arbitraging profits.

**Figure 2: LNG Spot and Swap Transactions (1992-2004)**




Source: Petrostrategies, GIIGNL

# 4 Model Specification and Results

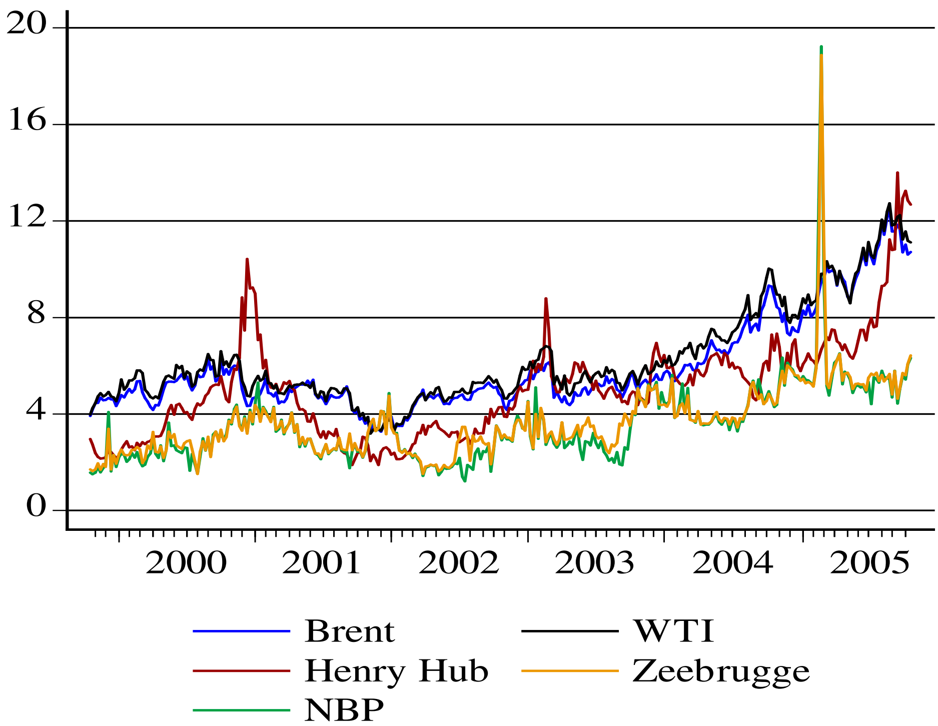
## 4.1 Data

The analysis is based on weekly spot prices for natural gas and crude oil examined for the period spanning October 22, 1999, through October 21, 2005, providing 314 observations. Natural gas spot prices are reported by continental Europe's Zeebrugge trading hub, the United Kingdom's National Balancing Point and, the largest point for natural gas spot and futures trading in the United States, the Henry Hub. We use Platt's quotations for the UK's NBP and Zeebrugge gas markets which are essentially volume-weighted averages of qualifying trades reported to Platt's on the day before contract delivery. The Henry Hub spot prices correspond to the daily midpoint value reported by Platt's for day-ahead deliveries into interstate and intrastate pipelines from the outlet of Henry Hub.

Crude oil spot prices for Europe and for the United States are Brent and West Texas Intermediate (market on close values), reported by the International Petroleum Exchange (IPE) and by the New York Mercantile Exchange (NYMEX), respectively for the nearest delivery month of crude oil. Due to their liquidity and transparency, both prices are used as principal international pricing benchmarks for Europe and the United States. WTI does this through its use on the New York Merchantile Exchange based on a futures contract where trade is equivalent to many hundreds of millions of barrels per day, even though physical WTI production is less than one million barrels per day. Brent offers pricing information based more on the physical trading of oil through spot and forward trading, but also offers futures trading. IPE's physical Brent crude oil represents commingled crude from the Brent and Ninian systems, slated to load at the Sullom Voe terminal.

In Europe, natural gas prices are quoted per kWh, as in Zeebrugge for instance. In the UK, prices are quoted in pence/therm, while the Henry Hub report prices in dollars/MBtu. Finally, crude oil markets are quoted in US dollars per barrel. We have converted all prices into dollars/MBtu in order to allow direct comparison between two fuel prices.[8]

**Figure 3: Natural gas and crude oil prices**




The graph (in logs) of the five series is presented in Figure 2. The figure shows the development in natural gas and crude oil spot markets during the last five "gas years". Natural gas prices in Europe (both Zeebrugge and NBP) move very closely and seem to be correlated with crude oil prices. One explication is that continental Europe gas contracts are indexed against inside petroleum product prices; this is where the link might occur.[9] The explication for the UK's gas prices is less evident.

[8] The MBtu is an internationally accepted unit of volume than the MWh, one MWh = 3.4121MBtu (IEA). We have been not been able to discover a specific calorific value for one barrel of crude oil, but we have taken into account a reasonable approximation: 1 barrel of crude oil = 5.46Mbtu. Natural gas prices for the NBP and Zeebrugge quoted in Euro are converted using daily exchange rates from the US Federal Reserve.

[9] Relationship between oil products pricing and crude oil have been established, for example, in a study by Asche, Gjolberg et Völker (2003) for the price relationship between Brent and refined product prices.

Several studies on the UK's gas market state that the opening of the UK-Belgium Interconnector system in 1998 has established a relationship between the liberalized UK and oil-indexed Continental natural gas markets, which explains the close relationship between NBP and Brent prices[10]. It can, however, also be seen that substantial short-term volatility exists corresponding to short-term tightness in a particular market or to disruption on normal flows of the Interconnector (i.e. non-planned maintenance periods).

It can also be observed that Henry Hub prices seem to be less correlated both with crude oil and natural gas prices in Europe. Prices in North America rose above what was seen as their historical relationship with crude oil prices in 2000, 2002 and 2003; in 2005, they seemed to fall below their historical relationship.

**Table 1: Descriptive statistics**

| Variable | Period | Mean. | Std. Dev. | Max. | Min. | Skew. | Kurt. |
|---|---|---|---|---|---|---|---|
| Brent level | 10:22:99 - 11:3:2005 | 5.93 | 1.99 | 12.40 | 3.24 | 1.42 | 4.22 |
| Logs | | 1.73 | 0.29 | 2.52 | 1.17 | 0.88 | 3.13 |
| WTI level | 10:22:99 - 11:3:2005 | 6.27 | 2.03 | 12.72 | 3.20 | 1.25 | 3.85 |
| Logs | | 1.79 | 0.29 | 2.54 | 1.16 | 0.64 | 2.94 |
| Henry Hub level | 10:22:99 - 11:3:2005 | 5.02 | 2.12 | 14.00 | 1.89 | 1.22 | 5.62 |
| Logs | | 1.53 | 0.41 | 2.64 | 0.63 | -0.05 | 2.63 |
| National Balancing Point | 10:22:99 - 11:3:2005 | 3.54 | 1.67 | 19.24 | 1.21 | 3.47 | 29.55 |
| Logs | | 1.18 | 0.40 | 2.96 | 0.19 | 0.28 | 3.49 |
| Zeebrugge Level | 10:22:99 - 11:3:2005 | 3.65 | 1.55 | 18.87 | 1.51 | 3.74 | 33.22 |
| Logs | | 1.23 | 0.36 | 2.94 | 0.41 | 0.37 | 4.16 |

Table 1 provides further information about underlying relationships between the data under consideration. Prices at Henry Hub exhibit higher values among all natural gas prices series, followed by Zeebrugge and the National Balancing Point. It is also interesting to note that crude oil prices move very closely, as one would expect under the hypothesis of a "global oil market".[11] Furthermore, the coefficients of variation in the data allow us to differentiate between two groups that are in the same range: crude oil and natural gas prices. Indeed, crude oil prices exhibit less volatility than natural gas prices (European and American) both in levels and logs.

## 4.2 Stationary properties of the series

The empirical methodology required to analyze the relationship between two variables must explicitly allow for multiple time series of data which may be non-stationary. Financial series such

[10] A report by ILEX Energy Consulting to the UK government points out that the best explaining factor for rising gas prices through 1999 and 2000 was the opening of the Interconnector between the UK and Belgium. They argue that "the link with oil gas prices on the Continent is the most important factor explaining the rise in UK gas prices through 2000".

[11] Early studies from Adelman (1984), Sauer (1994) and Ripple and Wilamoski (1995) showed that market for crude oil has become highly integrated.

as, i.e. spot prices, are generally accepted to be integrated of order one, denoted as *I(1)* (Pindyck and Rubinfeld, 1998).This implies that the data, when presented in levels, is non-stationary, but is stationary in first differences. In order to test whether the data from natural gas and crude oil markets are consistent with these stylized facts, we performed the Augmented Dickey-Fuller (ADF) unit root test[12], the Phillips Perron (PP) and the Kwiatkowski-Phillips-Schmidt-Shin tests (KPSS) for each variable. Note that ADF and PP tests are based on the null hypothesis of a unit root test, whereas the KPSS test is based on the null of stationarity.

**Table 2: Unit root test**

| | Levels (log) | | | First difference (log) | | |
|---|---|---|---|---|---|---|
| Variable | ADF | PP | KPSS | ADF | PP | KPSS |
| National Balancing Point | -2.02 | -3.65 *** | 1.27 *** | -11.32 *** | -41.22 *** | 0.16 |
| Zeebrugge | -2.24 ** | -3.47 *** | 1.47 *** | -11.43 *** | -40.81 *** | 0.10 |
| Henry Hub | -1.09 | -1.17 | 1.13 *** | -19.11 *** | -19.10 *** | 0.09 |
| West Texas Intermediate | -1.15 | -1.08 | 1.47 *** | -19.08 *** | -19.09 *** | 0.08 |
| Brent | -0.96 | -0.95 | 1.44 *** | -18.58 *** | -18.57 *** | 0.09 |

** denotes significance at a 5% level, *** denotes significance at a 1% level.
All tests are performed using a constant in the model specification, but no time trend for tests in log levels. Test for first differences are performed with neither constant nor time trend for the ADF and PP tests, and with constant for KPSS test.

Results of the ADF, PP and KPSS unit root tests are presented in Table 2. Each of the three series of natural gas and the two crude oil prices are non-stationary and integrated of order one. The first differences of the series are stationary according to the ADF, PP and KPSS tests. By considering these three types of tests, we can conclude that all series in log levels are *I(O)* and *I(1)* in first difference. Having established this, we can proceed investigating the cointegration relationship within natural gas and crude oil spot prices.

## 4.3 Methodology and Model Specification

Studies on the transmission of price signals are founded on concepts related to competitive pricing behaviour.[13] In spatial terms, the classical paradigm of the Law of One Price, as well as the predictions on market integration provided by the standard spatial price determination models (Enke (1951), Samuelson, (1952), and Takayama and Judge (1972)) postulate that price transmission is complete with equilibrium prices of a commodity sold on competitive foreign and domestic markets differing only by transfer costs, when converted to a common currency. These models predict that changes in supply and demand conditions in one market will affect trade and, therefore, prices in other markets as equilibrium is restored through spatial arbitrage.

Most of the existing empirical work utilizes time series econometric analysis techniques that test for the co-movement of prices. The development of these techniques, which include cointegration and error correction models, have become standard tools for analyzing spatial market relationships, replacing earlier empirical tools, such as the bivariate correlation coefficient and regressions.

[12] For the ADF test, lag length was chosen according to the Akaike information criterion. The results in the PP and KPSS tests were obtained using the Newey-West covariance matrix with Parzen kernel and the automatic bandwidth selection.

[13] Fackler and Goodwin (2001) provide a comprehensive review of market integration concepts and of the corresponding economic models of price determination.

Nevertheless, time series analysis has also being criticized as unreliable (Blauch, (1997) and Barrett and Li (2002)), with recent research focussing on switching regime models that incorporate data on prices, volumes traded and transaction costs. The debate on the application methodology for testing for market integration and price transmission has a relatively long history starting with Harris (1979). Blauch (1997) provides a review of the debate and examines the statistical performance of econometric tests for market integration. We argue that, although there is some merit in the above criticisms, time series analysis can provide useful insights into the issue of market integration and price transmission. Cointegration and error correction models provide an analytical tool that can focus beyond the case of market integration or complete price transmission by testing notions such as completeness, speed, and asymmetry of the relationship between prices.

The empirical technique required to analyze the relationship between two variables must explicitly allow for multiple time series of data which may be non-stationary. The theory of cointegration, as developed by Granger (1986) and Engle and Granger (1987), has been used successfully to test for price disparities in financial and geographic product markets when the data are non-stationary. The basic idea of these studies is that even though certain economic variables fluctuate in the short run, deviations from an economic equilibrium must vanish in the long run. For example, natural gas prices in two areas may fluctuate stochastically relative to past prices, but the difference between the two prices must be stable. In this case, the economic equilibrium condition can be written as $| P_i - P_j | \leq T_{i,j}$ where $P_i$ and $P_j$ denote distinct geographic prices and $T_{i,j}$ covers transportation cost between locations $i$ and $j$. If the inequality were violated, natural gas traders could affect spatial arbitrage between the two markets causing the price disparity to vanish.

In a multivariate framework (N>2), the Maximum Likelihood procedure developed by Johansen (1988 and 1995) for investigating causal long-run relationship and common trends is commonly found superior to the Engle-Granger's approach as pointed out by Hamilton (1994). The multivariate Johansen approach can de described as follows: let $P_t$ denote an $n \times 1$ vector of variables, $\Gamma_i$ with $i=1,\ldots k-1$ the short-run coefficients, $\Pi$ a long-run impact matrix summarizing all the long-run information in the $P_t$ process, such rank determines the number of cointegration vectors in the system, $\mu$ a constant term and $\varepsilon_t$ are identically distributed residuals with zero mean and contemporaneous covariance matrix $\Omega$. The VAR(k) system written in the error correction form (ECM) is:

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-1} + \Pi P_{t-1} + \mu + \varepsilon_t \quad (1)$$

When all variable in Equation 1 are $I(1)$, the presence of r linearly independent cointegrating vector implies that the long run impact matrix can be represented as $\Pi = \alpha \beta'$, where both $\alpha$ and $\beta$ are $n \times r$ matrices, and $\beta$ contains the cointegration vectors (the error correcting mechanism in the system) and $\alpha$ the factor loadings or adjustment parameters. Two asymptotically equivalent tests exist in this framework to determine the rank of $\Pi$: the trace and the eigenvalue test.

In this paper, when testing for natural gas market integration, we interpret the presence of cointegration between a pair of prices as evidence of market integration since both prices share a stochastically common trend. Naturally, the absence of cointegration implies that each price is determined by a separate stochastic trend, and therefore, markets are not cointegrated (Goldberg and Knetter, 1997).

As indicated in Hendy and Juselius (2001), the application of the cointegration analysis requires a careful thought about the model specification. In particular, modelling cointegrated series is difficult because of the need to model systems of equations in which one has to specify the deterministic terms and how they enter, determine the lag length, and ensure a congruent representation. Therefore, we have based our lag length selection decision on the outcome of the normality[14], autocorrelation, and heteroscedasticity residual diagnostic as recommended in Kasa (1992) and Hendry and Juselius (2000). In particular, the lag length has been selected as one that corresponds to the most parsimonious model for which these design criteria were fulfilled.

The Johansen procedure allows also hypothesis testing on the coefficients α and β, using likelihood test (Johansen and Juselius, 1990). More specifically, in a bi-variate case where two price series in the $P_t$ vector are cointegrated, the rank of $\Pi = \alpha \beta'$ is equal to one and vectors α and β are $2 \times 1$ vectors. When testing hypothesis with respect to price differences between markets, it is the restrictions on the parameters in the cointegration vector β we test. In our bi-variate case, testing the restriction $\beta'=(1,-1)$ provides the test of constant relative price of the Law of One Price (LOP). The α vector contains information about weak exogeneity. When both elements in the α vector are different form zero, there will be causality in both directions and the two prices should be modelled as a system. However, if one of the elements are zero, there will be no long-run causation towards this variable in this system and then the variable will be weakly exogenous in the system. This implies in our case, when investigating market integration, that this good is a price leader.

## 4.4 Empirical results

Results from cointegration test applied to bivariate models are presented below. The lag length has been chosen according to the likelihhod ratio (LR) statistic criteria in order to whiten the error term. Values of the Lagrange Multiplier (LM) test for autocorrelation up to the 24[th] order and results of the Jarque Bera test of normality are reported in Table 3. Both, the *trace* and the *maxi eigenvalue* tests report cointegration between natural gas prices in Europe, but provide no evidence of cointegration between European and American natural gas prices since we can not reject the null hypothesis of no cointegration between NBP and Zeebrugge prices with respect to Henry Hub prices. This result confirms a split into two regional markets, despite increasing international trade and arbitraging opportunities in the Atlantic basin, confirming the results of Siliverstovs et al (2005).

As for European prices for natural gas, the bivariate cointegration test between NBP and Zeebrugge provides strong evidence of regional market integration between continental Europe and UK natural gas prices under scrutiny. We argue that the UK's deregulated market is tightly bound to the European gas market, since the opening of the Interconnector, physically linking these two markets, had a significant impact on the level of both trade and fundamentals of natural gas price formation in the UK.

It is also interesting to note that we can reject the hypothesis of no cointegration relations between natural gas prices in the UK and continental Europe, and Brent crude oil prices at a 5% significance level. This perfect co-movement between the series underlines the surprising dominance of oil-indexation pricing mechanisms even in a competitive market environment, as, for instance, in the UK gas market. Another explanation can refer to long-term substitution fundamentals since natural gas and refined petroleum products have been close substitutes in European industry and electric power generation. Electric power generators can switch back and forth between natural gas and residual fuel oil, opting to use whichever energy source is less expensive at a given time. Consequently, we can expect movements of natural gas prices to track those of crude oil.

[14] Since the period under analysis contains extraordinary natural gas and crude oil market price changes, caused, for example, by such events as the Californian energy crisis and September 11 terrorist attacks, transitory blip dummies for the VEC – which correspond to an impulse effect on prices – are used in order to achieve normality of the residuals. The transitory blip dummies is D*xxyy* unity for t=20*xx:yy*, -1 to t=20*xx,yy*+1 and zero otherwise.

**Table 3: Bi-variate cointegration test**

| Variables | Ho : rank = p | Trace test | | Max Eigenvalue test | | Misspecification tests | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Autocorrelation | | Normality | |
| **Natural Gas** | | | | | | | | | |
| Henry Hub and | p == 0 | 15.32 | . | 12.43 | . | 0.94 | | 6.92 | ** |
| National Balancing Point | p <= 1 | 2.89 | . | 2.89 | . | 1.28 | | 1.77 | |
| Henry Hub and | p == 0 | 15.96 | . | 12.27 | . | 0.90 | | 3.38 | |
| Zeebrugge | p <= 1 | 3.69 | . | 3.69 | . | 2.27 | *** | 10.78 | *** |
| National Balancing Point and | p == 0 | **24.16** | ** | **21.15** | *** | 1.63 | * | 0.19 | |
| Zeebrugge | p <= 1 | 3.01 | . | 3.01 | . | 3.27 | *** | 7.68 | * |
| **Oil** | | | | | | | | | |
| West Texas Intermediate and | p == 0 | **15.43** | ** | **13.55** | ** | 1.41 | | 6.51 | * |
| Brent | p <= 1 | 1.88 | . | 1.88 | . | 1.48 | | 7.95 | * |
| **Natural Gas and Oil** | | | | | | | | | |
| National Balancing Point and | p == 0 | **19.63** | * | **17.85** | ** | 2.60 | ** | 3.23 | |
| Brent | p <= 1 | 1.78 | . | 1.78 | . | 1.32 | | 7.55 | ** |
| National Balancing Point and | p == 0 | 14.92 | . | 12.89 | . | 1.62 | * | 7.60 | ** |
| West Texas Intermediate | p <= 1 | 2.03 | . | 2.03 | . | 1.16 | | 8.60 | ** |
| Zeebrugge and | p == 0 | **12.83** | ** | 10.16 | . | 1.80 | * | 7.62 | |
| West Texas Intermediate | p <= 1 | 2.67 | . | 2.67 | . | 0.94 | | 2.97 | |
| Zeebrugge and | p == 0 | **22.32** | ** | **19.80** | *** | 1.61 | | 9.12 | * |
| Brent | p <= 1 | 2.52 | . | 2.52 | . | 1.14 | | 8.88 | * |
| Henry Hub and | p == 0 | 9.48 | . | 7.92 | . | 1.18 | | 1.51 | |
| West Texas Intermediate | p <= 1 | 1.55 | . | 1.55 | . | 1.36 | | 3.35 | |
| Henry Hub and | p == 0 | 8.41 | . | 6.59 | . | 0.94 | | 1.32 | |
| Brent | p <= 1 | 1.82 | . | 1.82 | . | 1.50 | | 8.42 | ** |

*** indicates significance at a 1% level, ** indicates significance at a 5% level and * indicates significance at a 10% level

Autocorrelation test reports Lagrange multiplier (LM) test for autoregressive conditional heteroskedasticity (ARCH up to the 24th order; that is asymptotically distributed $\chi^2$ (24,257)

Normality test report Jarque Bera statistics that has a $\chi^2$ distribution with two degrees of freedom

Our results confirm also that North American natural gas prices do not share a common stochastic trend, neither with Brent nor WTI crude oil prices. This finding proves that the opening of the North American natural gas market and regulatory policies over the past 25 years have led to a very integrated and mature market for natural gas, confirming the results of Serletis and Herbert (1999) and King and Cuc (1996). Henry Hub gas prices are determined then by market forces and gas to gas competition. The long-term relationship between natural gas and crude oil in North America has declined since inter-fuel substitution between natural gas and residual fuel oil for industry and power generation in the US has weakened with a diminishing number of facilities able to switch between natural gas and residual fuel oil.[15] In the most recent five years, natural gas prices seemed

[15] U.S. Natural Gas Prices Heat Up. Southwest Economy. Issue 5, September/October 2003. Federal Reserve Bank of Dallas.

to move independently of oil prices, resulting in an independent market for the commodity natural gas.

When testing the Law of One Price (LOP), we cannot reject that this holds valid for each of the cointegrated bivariate models shown below. Results confirm the strong relationship between European natural gas prices with respect to Brent crude oil prices; however, we can only accept that the LOP holds for Zeebrugge and West Texas Intermediate prices at a 10% significance.

The test for weak exogeneity provides more information as to whether any of the products are price leaders. As discussed before, imposing restrictions on the α vector will determine if any of the variables can be considered as weakly exogenous in the system. The test is performed under the null hypothesis that a particular row associated to a variable contains zeros; this is tested with a Likelihood ratio.

**Table 4: Law of One Price and Weak Exogeneity test**

| | **Cointegration equation**† | **LOP**‡ | **Probability** | **Weak Exogenity test statistic** | **Probability** |
|---|---|---|---|---|---|
| National Balancing Point and | **1 , -1.06** | 0.541 | 0.462 | 15.010 | 0.000 |
| Zeebrugge | (0.07) | | | 4.564 | 0.033 |
| West Texas Intermediate and | **1 , -0.39** | 0.008 | 0.931 | 12.221 | 0.000 |
| Brent | (0.03) | | | 0.005 | 0.945 |
| Brent | **1 , -0.88** | 0.348 | 0.555 | 13.950 | 0.077 |
| National Balancing Point and | (0.15) | | | 3.133 | 0.000 |
| Zeebrugge and | **1 , -1.40** | 5.846 | 0.016 | 6.877 | 0.009 |
| West Texas Intermediate | (0.07) | | | 0.664 | 0.415 |
| Zeebrugge and | **1 , -1.06** | 0.104 | 0.747 | 18.011 | 0.000 |
| Brent | (0.16) | | | 1.537 | 0.215 |

† Reports unrestricted estimate of the cointegration vector β, normalized at the row variable with standard error in parentheses

‡ Report the likelihood ratio test statistic of the Law of One price, β=(1,-1)', that has an asymptotic $\chi^2$ (1) distribution

Results are presented in Table 4 and point out that weak exogeneity for Brent crude oil prices is accepted with respect to WTI, NBP and Zeebrugge prices. These results suggest that Brent crude oil is the driving force determining the relationship between variables. For instance, we cannot reject strong exogeneity of Brent prices with respect to Zeebrugge prices, confirming that continental European prices follow crude oil evolutions in the long term. The oil driving force is also established by the fact that weak exogeneity is strongly accepted for WTI prices with regard to Zeebrugge natural gas prices. Since previous results on Brent and WTI crude oil anticipate integration between these markets, we can affirm that natural gas prices move accordingly to the developments in the "global crude oil market".

It is also interesting to note that we can only conclude weak exogeneity of Brent in respect to NBP prices at a 5% significance level, but not at 1%. Results illustrate that the UK's natural gas market is somewhat more independent from oil linkage than the continental European market. Testing the relationship between NBP and Zeebrugge led us to conclude weak exogeneity of Zeebrugge at a 10% significance level, but not at a 5%. This surprising result may indicate how the oil linkage is passed from continental European onto natural gas prices in the UK.

# 5 Conclusion

This paper empirically analyzes the relationship of changing market conditions for natural gas. On the one hand we have shed light on recent developments on spot markets for natural gas in North America and Europe. Following, technology of transporting and receiving natural gas in the form of LNG was identified the missing link of a global gas market. However, we have pointed out several factors likely to contribute to the fostering of a truly international market for natural gas. Using weekly data on spot prices for the regional trading markers in North America and Europe allowed a quantitative examination. The empirical analysis of spot prices for natural gas and crude oil shows that the split of regional markets prevails up to this day. However, taking into account several factors such as forecasts of future demand for natural gas, delivery books of Asian shipyards for LNG tankers and recently signed agreements of major gas companies allowing swaps to Europe and the US internationalization of natural gas trade seems to be only a step away. However, further research should concentrate in quantifying the pricing relationship of oil and natural gas prices in order to eliminate possible fluctuations in currently politically driven trends of oil prices from developments in international markets for natural gas.

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