Are oil and natural gas going separate ways in the UK?

Cointegration tests with Structural shifts [1]

By

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Abstract

Previous analyses show that British spot market prices for gas follow the same pattern as the global oil price, i.e., we have an integrated market for energy. In recent years there are several developments in the British gas market that may call for a different price relationship. The spot market for gas has become more liquid, and an increasing fraction of gas is used for electricity generation - thus competing against coal and nuclear power. Moreover, there is an increasing LNG import, and there may have been a change in the perception of relative scarcity of oil and natural gas as well as the effectiveness of the OPEC cartel. Analysing more recent data and applying newer analytical tools that allow for endogenous structural shifts, we test whether oil and gas prices in the UK still are cointegrated. We find structural shifts in 2006 and 2007, and after the second structural shift, the evidence for oil and gas markets being cointegrated are much weaker. Specifically the stochastic trend in Brent oil seems less predominant in the movement of NBP gas price.

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1. Introduction

Our knowledge of and our ability to investigate structural breaks for nonstationary data series and cointegration relationships have been rapidly evolving in recent years. It is well documented that the results from unit root tests depend on properly accounting for structural breaks (Bai and Perron, 2008). In a market integration setting it is important that a test is able to distinguish between periods with a cointegration relationship and periods when such a relationship is not present, and to allow for the possibility of more than one structural shift. The only available test fulfilling these requirements is the test suggested by Bai and Perron (2003) that we will utilize in this paper. This is important when investigating the relationship between oil and gas prices as there have been a number of possible structural shifts. This is recognized in the literature, but poorly accounted for econometrically. Asche, Osmundsen and Sandsmark (2006) provide estimates for two sample periods without providing a formal test for a structural break. Panagiotidis and Ruthledge (2007) tests for parameter constancy, but use a test that does not allow a change in the number of cointegration vectors.

The structure of the petroleum part of the energy market has changed substantially during recent decades, a development that has primarily been driven by deregulation of gas markets. This occurred first in the USA (DeVany and Walls, 1993; Doan and Spulber, 1994), and thereafter in Europe; commencing in the UK and then increasingly in continental Europe (Asche, Osmundsen and Tveteras, 2002; Silvertofs et al, 2005; Asche et al., 2006). At the same time, increased capacity for LNG transportation has linked regional market for gas, making the market more liquid and potentially global. Until deregulation there was a link between oil and gas prices due to the pricing formulas in long-term, so called take-or-pay, contracts used for purchases/sales of natural gas.[2] Although it was expected that deregulations

[2] See Section 2.1 below.

should lead to gas-to-gas competition and a separate price determination process for gas (Doane and Spulber, 1994; DeVany and Walls, 1993; Asche et al., 2006), the link between oil and gas has prevailed. This is the case both in the USA (Serletis and Herbert, 1999) and in Europe (Asche et al., 2006; Panagiotidis and Rutledge, 2007). Moreover, the fact that there is a global market for oil (Sauer, 1994; Bachmeier and Griffin, 2006) implies that gas prices in different regions are linked indirectly via the oil price and possibly also directly via LNG transportation. The link between oil and gas prices seems to be due to the fact that oil and gas are close substitutes, so that marginal buyers/consumers have been able to stabilize relative prices by shifting between the two energy sources in a deregulated market.

Asche et al. (2006) analyse data from 1995-1998, and find that oil and gas prices are integrated in the UK. In 1998 the Interconnector, a natural gas pipeline connecting the UK and Continental Europe, physically integrated the liberalized UK natural gas market and the regulated Continental gas markets. The oil-linked Continental gas price became dominant, due both to the large volume of the Continental market and the fact that the significant call options embedded in the complex oil-linked take-or-pay contracts make these contracts the marginal source of supply (Asche, Osmundsen and Tveteras, 2002). However, in an interim period – after deregulation of the UK gas market (1995) and the opening up of the Interconnector (1998) – the UK gas market had neither government price regulation nor a physical Continental gas linkage. Asche et al. (2006) used this period – which for natural gas markets displays an unusual combination of deregulation and autarky – as a natural experiment to explore if decoupling of natural gas prices from prices of other energy commodities, such as oil and electricity, took place. Monthly price data in the period 1995-1998 indicated a highly integrated market where wholesale demand seems to be for energy rather than a specific energy source. Not only were the markets for the energy sources oil and natural gas integrated, but the prices were lead by the oil price, and accordingly by the global oil market.

Despite the fact that deregulation does not seem to significantly affect the long run relationship between oil and natural gas, there are other indications that the stable relative price is under pressure in Europe. During the last decades, demand for natural gas in Europe has more than doubled (Al-Sahkawi; 1989; Asche, Nilsen and Tveterås, 2008). This is largely due to the increased use of gas in the power sector. Combined-cycle gas turbine technology in gas-fired power plants has increased fuel efficiency and has lower capital and operating costs. Moreover, construction times are short, 2-3 years. At the same time tighter sulphur emission limits and targets for CO_2-cuts have made coal less attractive in electricity generation and contributed to a rapid retirement of old coal-fired capacity. In sum this has lead to a substantial increase in the use of natural gas for electricity generation in the UK. Gas-fired power primarily competes against coal and nuclear power, and the increase of the share of UK gas consumption for gas-fired power plants thus potentially contributes to a weaker link towards oil. We have also seen increased gas-to-gas competition and enhanced liquidity of gas spot markets in recent years. These developments further reduce the need for oil linked contracts, thus weakening the direct link between gas and oil.

In this paper our main focus is whether this historically stable relationship between oil and natural gas prices has survived these recent developments. We investigate this question by applying both structural change and cointegration analysis on the relationship between spot Brent oil and NBP natural gas price from 1996 to 2010. As to be demonstrated, our empirical approach suggests a greater decoupling of oil and gas prices in later years. Specifically, from 2007 there is much weaker evidence for cointegration relative to the strong relationship observed in the nineties and early in the current century. Our analysis both confirm the historically strong cointegration relationship established in earlier studies (Asche et al., 2006; Panagiotidis and Rutledge, 2007), in addition to providing some preliminary evidence that this relationship might now start to change.

Since many oil and natural gas companies, as well as other market participants, are involved simultaneously in both natural gas and oil markets, analyzing the nature and stability of the link between natural gas and oil price is important. This is related to both viable risk management and speculation. Finding, for example that, that the oil-gas link has weakened will affect the viability of using oil linked gas contracts.

2. Background

Before proceeding to the empirical analysis of the oil and natural gas price relationship, we discuss some of the factors that determine relative prices of oil and natural gas, and the recent trends in these factors. An understanding of these factors will potentially provide an economic argument for both the recent and historical state of relative prices.

2.1 Take-or-pay contracts

Via the Interconnector, the British gas market is influenced by the Continental gas market, where long-term take-or-pay contracts still dominate. In regulating contracting volumes, the customers and the producers have conflicting interests. These interests are traded off in the contract design. Since gas storage is expensive and may be in limited supply, the customer would often like to have flexibility with respect to volumes, thus being able to adjust to changes in downstream demand. Demand fluctuates, especially over the seasons, with a higher demand in winter than in summer.

The producers of natural gas, on the other hand, may have to sink large irreversible investments in extraction, processing, and transportation facilities. Before doing so, they would like to have assurances that they will be able to sell the gas over a considerable period of time, thus securing a return on their investments. Also, to exploit the extraction, processing and transportation capacity, the seller would prefer to deliver a stable gas stream at maximum capacity utilisation. The producer would – before making large irreversible investments – prefer a specific price, a minimum price, or other types of price guarantees for the entire period of delivery. The customers, on the other hand, would like the gas price to be responsive to the price of substitutes (such as oil products), so that they are able to sell the gas.

The challenging task for gas contract design is to trade off these conflicting interests with respect to volume and price. The exact contents of these contracts are secret, but the general contract structure is common knowledge in the gas industry. The major part of gas export to the Continent is sold on long term take-or-pay contracts (Asche, Osmundsen and Tveteras, 2002). In these contracts, the buyer agrees to receive a certain volume of gas per year or, alternatively, to pay for the part of this gas volume that it does not like to receive. At the same time, the buyer has an option to take out more gas than these minimum annual amounts, thus conveying flexibility. Substantial volume flexibility is also available on a daily basis. The current price on gas delivered according to the long term take-or-pay contracts is determined by a price formula. The formula links the current gas price to the price of relevant energy substitutes, thus continuously securing the buyer competitive terms. The price formula consists of two parts, a constant basis price (fixed term) and an escalation supplement linking the gas price to alternative forms of energy (variable term). Examples of alternative energy commodities used in pricing formulas for natural gas are light fuel oil, coal, and electricity. Usually a combination of alternatives is used for escalation purposes (weighted average).

Each of the alternative energy commodities is assigned a certain weight in the escalation element, reflecting the competitive situation between natural gas and the substitute.

As for recent trends, with the increase in the use of natural gas for electricity, the pricing weight for oil is reduced since the natural gas customers compete against alternative inputs for electricity generation, where oil plays a small and decreasing role. As the gas distribution companies also competes against spot gas, increased gas-to-gas competition also has led to pricing formulas linked to spot gas prices. This applies to new contracts and also via renegotiations for some of the old contracts. The change in pricing formulas contributes to a weaker link between oil and gas prices. Furthermore, if it is possible to make use of existing infrastructure, e.g., existing pipelines, the investment requirements may be lower and the producers may not claim the same price guarantees. With increasing gas consumption, however, this is not likely.

2.2 Liquidity and volatility of the spot gas market

The liquidity of the UK gas market has improved. Lack of liquidity in spot gas markets has been one of the arguments in favour of oil-linked gas sales contracts. It has been argued that the oil link is necessary to instigate large irreversible investments in extraction, processing, and transportation facilities. An increased liquidity of spot gas markets weakens if not eliminates this argument. The larger volatility of gas prices versus oil prices, however, may still entail a larger risk for gas sellers (figure 1).

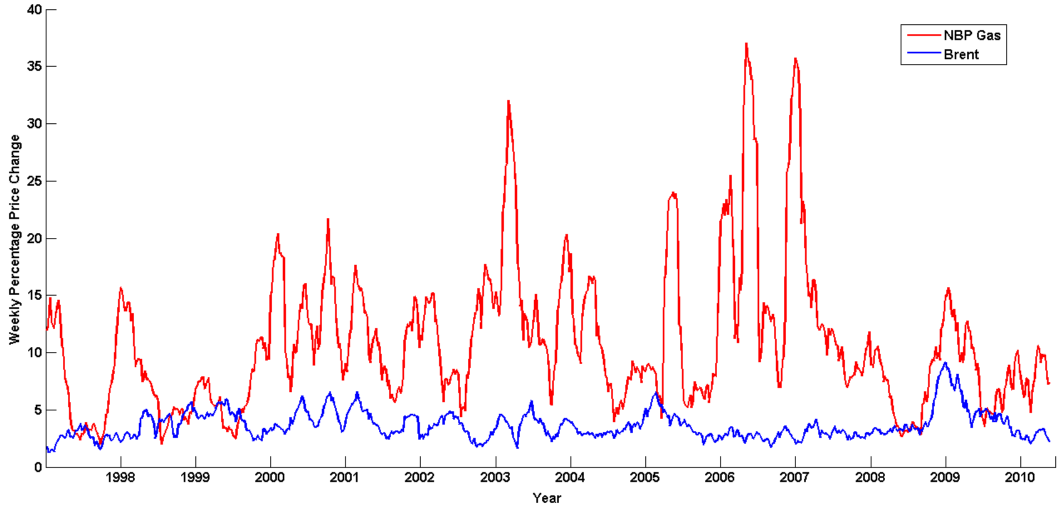

Figure 1. 10 week moving average of percentage price change in Brent Oil and NBP Gas.

However, it is the average income over the year that is relevant to investment decisions for gas fields, and larger seasonal fluctuation in the gas price does not necessarily pose a large problem in this context.

2.3 Change in competitive pattern

The use of combined-cycle gas turbine technology in gas-fired power plants has increased fuel efficiency and has secured lower capital requirement and cut in operating costs. Moreover, construction times are short, 2 to 3 years. At the same time tighter sulphur emission limits and targets for CO_2-cuts have made coal less attractive in electricity generation and contributed to a rapid retirement of old coal-fired capacity. In sum this has lead to a substantial increase in the use of natural gas for electricity generation in the UK. Gas-fired power competes against coal and nuclear power, and the increase of the share of UK gas consumption for gas-fired power plants thus contributes to a weaker link towards oil.

2.4 Increase in LNG supply

We have seen a fairly strong development in global production of liquefied natural gas (LNG), and LNG constitutes an increasing share of UK gas imports. LNG technology enables the utilization of marine transportation for natural gas, and LNG is like oil slowly becoming an internationally traded commodity. However, there is a long way to go, and LNG will never get the same flexibility as oil. The LNG project chain consists of four links (occasionally five); 1) field development, in some cases 2) a pipeline to the coast, 3) the liquefaction facility, 4) tanker transportation, and 5) the receipt/regasification terminal. Each element is highly capital intensive and front-end loaded. Field development will in many cases only represent a quarter of the overall capital expenditure (Emhjellen, Løvås and Osmundsen, 2010). Thus, to make irreversible investments in LNG chains, investors will insist on long-term contracts. The long term contracts in LNG represent a vehicle for sharing the large up-front investment risks that characterise LNG projects. Another necessary assumption for expansion in LNG capacity is that investors must foresee a significant and long lasting price differential between market segments. However, declining costs of delivering LNG have created arbitrage opportunities and price signals are now being transmitted between previously isolated regional gas systems.

According to Jensen (2004), it is not the magnitude of the physical flows between regions that defines the global LNG market, but the fact that small shifts in sources and destinations can provide a basis for international price arbitrage. The Middle East – in particular Qatar – has become a swing (pivot) supplier to both the traditional gas markets in Northeast Asia and the growing markets in the Atlantic Basin, implying that price signals are transmitted between Asia and the Atlantic Basin as well. But because the volumes of LNG in short-term trading are not that large compared to the size of the markets they serve, price arbitration will according to Jensen (2004) have its limits in actually establishing long term price equilibrium among different gas market regions. The fact that LNG contracts are oil-linked will at any rate not cause LNG to change existing pricing patterns.

2.5 Substitution

The price premium of oil relative to natural gas is limited over time due to substitution in consumption. If, e.g., natural gas becomes much cheaper than oil, there is an economic incentive for energy customers to switch to natural gas, and thereby contribute to a movement back to the historic mean relative price. Substitution and the resulting price correction, however, may be time consuming and therefore relative price imbalances may persist for some time. Some types of substitution is quick, e.g., for customers with dual burners. Other types of substitution often require investments. Substitution in such cases takes time. First the energy customers must be convinced that the price deviation will last long enough for them to recoup the investments, thereafter installation of new equipment may take some time. Other types of energy consumption cannot be substituted adequately with existing technology, e.g., oil still has an advantage over gas for transportation purposes. Long lasting price deviation from the historic mean level, however, may lead to R&D that reduces this gap. The cost of gas-to-liquid imposes a cap on the oil-gas price relation, and this technology might be expected to improve in cases of long lasting deviation from relative price mean. Generally, changes in consumption technology that only apply to oil or natural gas may trigger shifts in the price premium.

2.6 Relative scarcity of oil and gas

Inframarginal oil and natural gas receive a resource rent due to the scarcity of the resources. Oil is often perceived to be scarcer than gas, being one of the factors explaining the price premium. The scarcity is evident when comparing proven reserves, as proven reserves has increased with 2.55% pa for natural gas, and only 1.96% pa for oil since 1990 (BP Energy

Review, 2011). The difference is somewhat smaller with the latest reports on proven reserves of oil in Venezuela.

Moreover, the share of proven reserves that is being produced pa is higher for oil compared to natural gas. Total oil production in 2009 was 29.96 thousand million barrels, while the proven reserves at the end of 2009 were 1 376.6 thousand million barrels, meaning that approximately 2.2% of the proven reserves are produced each year. Equivalently, total gas production in 2009 was 3.19 trillion cubic meters, while the proven reserves at the end of 2009 were 186.6 trillion cubic meters, meaning that 1.7% of the proven reserves are produced each year.

Changes in relative scarcity are likely to affect the price premium since scarce commodities tend to generate a price premium. A comparatively higher scarcity of oil, for example, results in a higher price premium compared to natural gas. This gives consumers incentive to shift from oil towards natural gas. Consumption of natural gas has increased with 2.45% on a yearly basis since 1990, with a record increase in 2010 when consumption rose by 7.4%. Oil consumption has increased with 1.4% pa in the same period, but experienced a decrease in both 2008 and 2009. In 2010 oil consumption increased with 3.1%.

The trends in production, consumption and reserves all indicate that the scarcity premium is higher for oil compared to natural gas, and that the differences have increased during the last two decades.

2.7 Market concentration and cartel behaviour

Vital to the price premium is the market power of the OPEC cartel. Unlike oil, OPEC does not have cartel power for natural gas in deciding production levels and price target. Historically, Europe has been dependent on Russian supply of gas, which has an 18.4% share of the global production, and 23.9% of the proven reserves of natural gas. Norwegian gas production has reduced some of the dependency on Russian gas. Algerian gas further supplies some European countries like France, Italy and Spain.

While the Middle East and OPEC provides oil for most of the World, including USA, it only provides natural gas for South Asia, Japan and France. Natural gas in USA is provided by domestic production and production in Canada.

Generally, there is no significant market leader in supply of natural gas like the export region of OPEC for oil. Although there is less interregional trade, the market infrastructure helps avoid monopoly and cartel behavior locally. This reduces the possibilities for cartel behavior and removes the price premium paid to a cartel.

There might be some market power also for natural gas, but not nearly to the same extent as for oil. The cartel stability, and hence market power, of OPEC is shifting over time, and such shifts are likely to affect the price premium.

2.8 Market hypothesis

To sum up, we have two alternative hypotheses with regard to market integration, 1) oil and gas prices remain cointegrated, as has been historically demonstrated, and 2) oil and gas markets are separating, moving away from the historical cointegration relationship. Market characteristics and developments that support a continued oil price link are a) oil-linked gas contracts on the Continent that affects British gas prices via the Interconnector, b) high volatility of spot gas prices makes producers insist on oil-linked contracts, c) the fact that

LNG contracts are oil-linked, d) energy customers will substitute towards the cheaper energy source. Developments that support market separation are a) the pricing weight for oil in gas contracts is reduced since the natural gas customers compete against alternative inputs for electricity generation, b) as the gas distribution companies also competes against spot gas, increased gas-to-gas competition has led to pricing formulas linked to spot gas prices, and c) increased liquidity of the UK spot market for natural gas reduces the need for oil-linked contracts. In the next section we investigate these alternative hypotheses empirically.

3. Data

The crude oil price is weekly observations of Brent blend, i.e. the dominant oil marker containing crude oil originating from the UK and the Norwegian continental shelves. The gas price is the weekly National Balancing Point (NBP) price in the UK, the pricing for Intercontinental Exchange (ICE) – the most liquid gas trading point in Europe. All prices are spot prices. The natural gas is processed of the sellers to satisfy strict requirements with respect to quality. The calorific value of the gas differs, e.g., Norwegian and Russian natural gas in general has a higher calorific value than Dutch gas. Thus, for comparability, contract prices are listed in terms of payment per calorific unit. In our data set prices are listed in USD per million Btu[3], see Figures 2 and 3, which means that the difference in calorific value is accounted for. By applying this energy equivalent to the pricing of oil, we are also able to compare prices of oil and gas deliveries.

[3] Btu = British thermal unit.

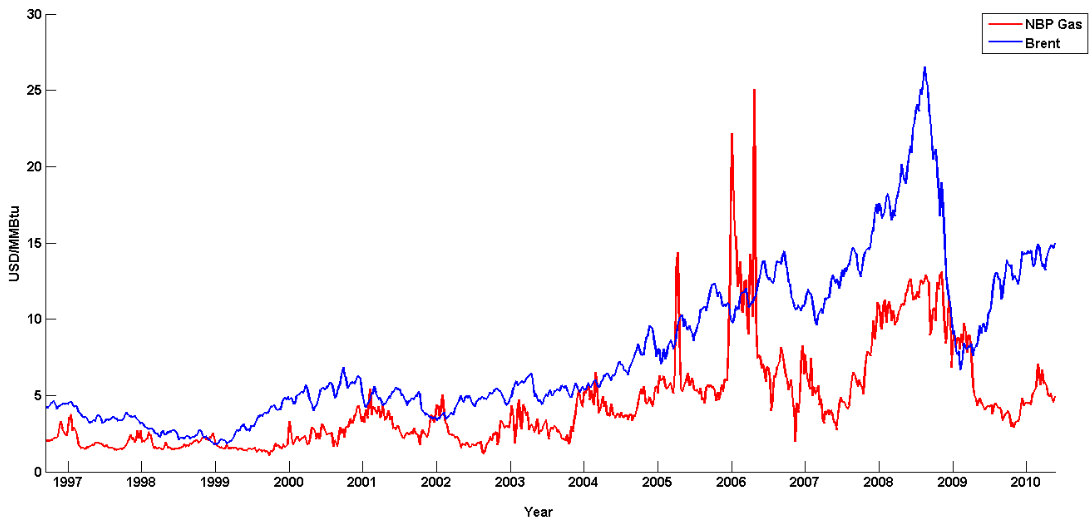

Figure 2. Development in NBP gas price and Brent oil price, September 1996-January 2010.

From Figure 2 we see that the oil price increases strongly from 2006 while at the same time the gas price decreases, creating a large price gap. For relative price evaluations, however, it is the percentage deviation between the two prices that count, and from Figure 2 we see that there were high price differences also in other time periods, e.g., September 1996 and June 2000. To better illustrate relative prices, Figure 3 depicts the oil price divided by the gas price.

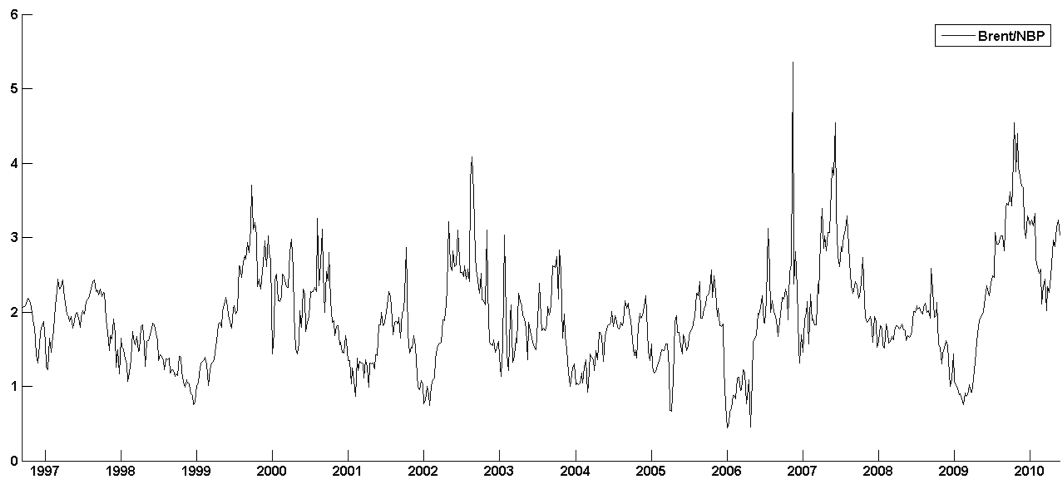

Figure 3. Development in the relative price of NBP gas price and Brent oil price, September 1996-January 2010.

From Figure 3 we see that the relative price seems to fluctuate around a mean price of 1.96, i.e., Brent Blend at average sells at a premium of 96% in our time interval. The price premium of oil has several explanations. Oil can serve many purposes and it is a more flexible means of energy. Transportation costs are also significantly lower for oil, and there is a global oil market. Even if improvements in LNG technology has reduced transportation costs for natural gas over long distances, investments required are much higher than for oil transportation, and LNG can only be delivered to locations with regasification facilities. Consequently, natural gas supplies are to a larger extent locked into regional and segmented markets, implying larger bargaining power of the customers. Oil is also considered scarcer than natural gas, and the oil exporters have more market power due to the OPEC cartel.

4. Empirical Analysis

In this section we seek to analyze the relative price of Brent Oil and NBP gas in order to detect possible structural changes in price relationships. The analysis will proceed in two steps. First we formulate a time series model for relative prices and apply the endogenous structural change model procedure of Bai & Perron (1998, 2003) to identify possible breaks. In the second step we perform unit root tests and cointegration analysis on the subsamples identified by the first step. In this sense we do not impose any structural changes *a priori* on the data, and the identification of structural changes are based solely on the models fit to data. If significant changes have occurred they should be picked up by the analysis, as long as the underlying changes are nested in the original time series model.

4.1 Structural Change Analysis

Sufficiently long economic time series are likely to contain structural changes due to permanent shifts in market fundamentals, such as production technology or governmental policies. This has long been recognized by economists, and a vast amount of work has been related to testing for such changes. In the seminal work of Chow (1960), a test for a single break with known break date was developed. This work has been extended by amongst other the alternative CUSUM and CUSUMSQ tests of Brown, Durbin & Evans (1975), the Nybloms parameter stability test of Nyblom (1989) and Hansens parameter stability tests (Hansen 1992). The testing procedure becomes significantly more difficult when one includes possible unknown break dates and multiple breaks. Contributions toward this problem can be found in Andrews (1993), Hansen (1997), Andrews & Ploberger (1994) Garcia & Perron (1996) and Bai & Perron (1998). Our problem at hand consists of trying to identify possible multiple structural changes with no prior information of break dates. Our procedure follows the method suggested by Bai & Perron (1998, 2003). The procedure is a dynamic programming problem, where optimal break segments are built up from a non-break starting point. Hence, the approach is recursive as it is evaluating improvements in statistical fit as more structural breaks are imposed on the model.

Prior to the analysis several specifications are needed. At first we need to choose an underlying time series. This model should be sufficiently flexible to nest possible structural changes. Since we are interested in changes to mean relative prices, the model should be flexible enough to account for mean shifts. Table 1 below shows some descriptive statistics for the Brent/NBP relative price.

TABLE 1. Descriptive statistics for relative price Brent/NBP.

Mean	1.929	AC(1)	0.882	Normality	73.506**
Std.Dev.	0.677	AC(2)	0.808	Instability Mean	3.640**
Skewness	0.843	AC(6)	0.631	Instability Var.	3.435**
Kurtosis	1.446	AC(12)	0.402	ARCH	362.91**

Note: AC(x) shows autocorrelation at lag x. Normality tests for the null of normality. Instability of the mean test for the null of a stable mean relative price as in Hansen(1992). Instability of variance test for the null of a stable variance as in Hansen(1992). The ARCH test tests for the null of no ARCH effects at lag 1. ** denotes rejection at 1%.

Given the seasonal nature of gas prices, it is not surprising that heteroskedastic effects are present. There is further strong kurtosis in residuals, rejecting a normal distribution. This implies that more observations are located near the mean and in the tails relative to the normal distribution. There is also slight negative skewness in relative prices, arising likely due to higher gas prices in winter. Table 1 also shows that considerable autocorrelation is present in relative prices. Furthermore, normality as well as a stable mean and variance is rejected.

We propose the parsimonious AR(1) process for relative prices in the structural change model. This implies that both the intercept and autoregressive term can change between regimes. We further allow the standard deviations of parameter and errors to vary between segments. The AR(1) model is sufficiently flexible to model structural changes to mean prices, but is possibly not necessarily flexible to account for all ARCH and autocorrelation effects across segments. As suggested by Bai and Perron (1998) residual dynamic effects can be accounted for by applying the heteroskedastic and autocorrelation consistent standard deviation estimators of Newey and West (1987). Hence, our estimates apply the Newey and West (1987) estimators.

Another specification needed is the minimum allowable segment length. In Bai & Perron (2003) this specification is called the trimming parameter, and the authors evaluate trimming parameters between 0.05 and 0.2. A trimming parameter of 0.1 implies that each segment cannot contain less than 10% of total observations. The trimming parameter is important as it changes the statistics in evaluating the structural changes. In our approach we use two trimming parameters 0.1 and 0.15. This means that no less than 71 and 107 observations respectively are allowed in each segment. A trimming parameter of 0.1 allows a maximum of 9 breaks, and a trimming of 0.15 allows a maximum of 5 breaks.

We are now in position to start the structural change analysis. As stated the optimal *r* break point partition is derived in a dynamic programming approach. This means that if $SSR(\{T_{r-1,n}\})$ denotes the sum of squared residuals associated with the optimal partition with *r-1* breaks using the *n* first observations, then the optimal partition containing *r* breaks and the full sample is given by the following minimization:

$$SSR(\{T_{r,T}\}) = \min_{mh \leq j \leq T-h}[SSR(\{T_{r-1,j}\}) + SSR(j+1,T)],$$

where *m* is the minimum allowable segment (defined by the trimming parameter) and $SSR(j+1,T)$is the sum of squared residuals of the segment starting at *j+1* and ending at T. Hence the procedure appends the *rth* segment associated with the lowest sum of squared residuals to the previous optimal *r-1* segment partition. Since increasing the number of break points improves statistical fit even if no breaks are present, we need a test statistic to ensure that adding breaks significantly improves the statistical fit over what we would expect if no breaks where present. Bai & Perron (2003) suggests several procedures to find the optimal number of breaks. One approach is based on a Bayesian Information Criteria evaluating the null of no breaks versus *r* breaks. A test of no breaks against an unknown number of breaks is given some upper bound *M* is also proposed (in the table this is the UD_max statistic). Finally a test of n versus n-1 breaks is evaluated. This final Sup test (Sup F(n|n-1)) can be evaluated sequentially starting at no breaks (n-1), then adding breaks until an additional break finds no statistical support.

TABLE 2. Multiple Structural Break Test

Trimming 0.1				Trimming 0.15			
Breaks	BIC	SSR	F-stat	Breaks	BIC	SSR	F-stat
0	-5.341	3.34205		0	-5.341	3.34205	
1	-5.337	3.29492	20.1885[a]	1	-5.337	3.29492	20.1885[a]
2	-5.360	3.16136	23.4223[a]	2	-5.347	3.20133	19.1837[a]
3	-5.349	3.13709	17.7506[a]	3	-5.336	3.17721	13.6097[a]
4	-5.346	3.08969	15.7737[a]	4	-5.324	3.15863	11.7533[a]
5	-5.333	3.07342	11.4989[a]	5	-5.307	3.154	9.1179[a]
6	-5.330	3.02608	10.0593[a]				
7	-5.310	3.02901	8.3307[a]				
8	-5.287	3.04328	7.0349[a]				
		UD_max	23.4223[a]			UD_max	20.1885[a]
		Sup F(1|0)	17.9147[a]			Sup F(1|0)	17.9147[a]
		Sup F(2|1)	26.2346[a]			Sup F(2|1)	26.2346[a]
		Sup F(3|2)	2.4426			Sup F(3|2)	2.4426

Notes: Subscript *a* mean significance at the 1% level. BIC is Bayesian Information Criteria. F-stat is the Bai-Perron test for k versus zero breaks. UD_max is the Bai-Perron test for significance of M possible breaks against the null of zero breaks. Sup F(|) is the Bai-Perron sequential break test.

Table 2 above reports the results from the structural change analysis. We note that for both trimming parameters we reject the null of no structural breaks in the sample. Further using the sequential Sup test we find that two breaks are sufficient. Adding a third break in either trimming parameter case does not significantly improve the statistical fit. We further note that the Bayesian Information Criteria agrees with the sequential Sup test on two breaks. Two breaks imply three segments. The estimates for each segment, in addition to the estimates of the break dates are reported in table 3 below.

TABLE 3. Structural Change Estimates

Trimming	0.1	
Parameter	Coefficient	HACSE
μ_1	0.022[a]	.0017
μ_2	0.143[a]	.0178
μ_3	0.010	.0061
β_1	0.895[a]	.0072
β_2	0.621[a]	.0491
β_3	0.969[a]	.0199
T_1	06:11	(05:32-06:23)
T_2	07:37	(06:27-08:48)
SSR	3.16	
LB(24)	25.71	
Normality	210.05[a]	
ARCH	16.990[a]	

Trimming	0.15	
Parameter	Coefficient	HACSE
μ_1	0.022[a]	.0018
μ_2	0.108[a]	.0142
μ_3	0.011	.0070
β_1	0.895[a]	.0075
β_2	0.680[a]	.0428
β_3	0.972[a]	.0216
T_1	06:11	(05:40-06:35)
T_2	08:12	(06:03-10:06)
SSR	3.20	
LB(24)	27.96	
Normality	215.56[a]	
ARCH	24.62[a]	

Notes: Subscript *a* mean significance at the 1% level. The LB test is distributed as $\chi(24)$ under the null of no serial correlation. Null for normality is normality, null for ARCH test is no ARCH effects. For estimates of break points the parenthesis show the 95% confidence intervals.

We note that for trimming parameter 0.1 the two breaks are at week 11 in 2006 and week 37 in 2007. For the 0.15 trimming parameter the break dates are week 11 2006 and week 12 2008. Figure 4 below we plot the relative prices and the unconditional means implied by each segment for the 0.1 trimming parameter case. We observe that in the major part of the sample (1997.38-2006.11) little evidence is found of structural change. It is in the latter part of the sample evidence for structural change is found. We observe that in second segment (2006.11 – 2007.37) the mean price increases, suggesting that oil has become more expensive per energy unit than gas. This relationship reverts some in the final segment (2007.37 – 2010.13), however. As we investigate later, there is less evidence that a constant unconditional mean does not exist in this segment, as prices seem to be decoupled.

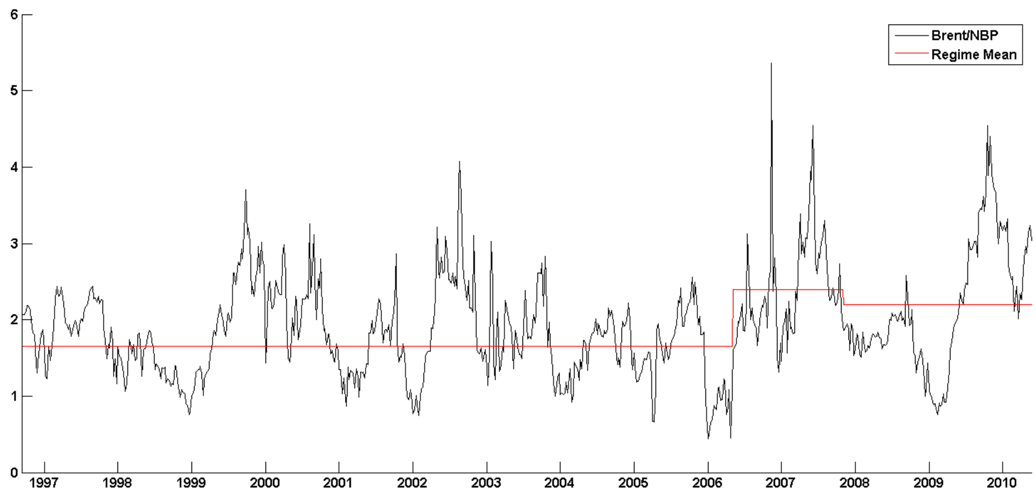

Figure 4. Development in the relative price of NBP gas price and Brent oil price, September 1996-January 2010, with mean and endogenous structural shifts. Plotted for the 0.1 trimming case.

The 0.1 trimming parameter case gives the lowest SSR in addition to the lowest Ljung Box statistic for serial correlation. In addition the 0.1 trimming case is closer to accepting normality and rejecting ARCH effects than the full sample estimate, even though both cases reject normality and homoskedasticity. The reduction in serial correlation and ARCH effects relative to the full sample estimate implies that some of these effects are accounted for by incorporating structural changes. As is known the presence of structural change biases autocorrelation in linear models upward. Of further interest in our analysis is the difference in autoregressive coefficients in each segment. Specifically, in both cases the autoregressive parameters are close to unity in the final segment. This suggests that prices in the latter part of the sample are more decoupled, perhaps moving out of an equilibrium relationship. As stated, previous analysis using less updated data suggests that oil and gas are cointegrated in Europe (Asche et al., 2006; Pangiotides and Ruthledge, 2007). Our results here suggest that perhaps this relationship is breaking down. In the next segment we pursue this hypothesis in more detail.

4.2 Cointegration Analysis

In this section we perform cointegration analysis on the segments implied by the above analysis. For this analysis we use the 0.1 trimming parameter break estimates. The validity of co-integration analysis is conditioned on the series' containing a stochastic trend. If a unit root is present in each series, and a linear combination of the two remove the unit root, the series are said to be co-integrated. Statistically this implies the two series share the same stochastic trend. Economically it suggests that an equilibrium relationship exists between the markets. Either common price driving factors and/or substitution between the commodities ensures that prices are not allowed to diverge in time.

To evaluate unit-roots in the series' we apply the approach suggested by Ng and Perron (2001). Ng and Perron (2001) illustrate that using GLS detrended/demeaned data in collaboration with a modified information criteria (MIC) yield improved size and power properties. The MIC takes into account that the bias in the sum of autoregressive coefficients depends on the truncation lag chosen. In the testing procedure we first apply GLS demeaning or detrending to both series. Next we choose an appropriate lag level using the Modified Akaike Information Criteria (MAIC). We then apply six unit root tests, each for the case of the GLS demeaned and GLS detrended series. The tests are applied on each segment. The specific statistics for the test can be found in Ng and Perron (2001). The five unit root tests are the Augmented Dickey Fuller test (ADF), modified versions of the Phillips (1987) and Phillips-Perron (1988) tests, MZ_{α} and MSB, the Elliot, Rothenberg and Stock (1996) feasible point optimal test P_{GLS}, and the modified version of the feasible point optimal test MP_{GLS}. In addition we apply the KPSS test for the null of stationarity.

TABLE 4. Unit root tests for sub-samples of log Brent and log NBP

	1996:38-2006:11		2006:05-2007:37		2007:37-2010:14	
	Oil Const./Trend	Gas Const./Trend	Oil Const./Trend	Gas Const./Trend	Oil Const./Trend	Gas Const./Trend
Lag	6/6	3/3	1/1	1/1	1/1	2/2
ADF	-2.51/-0.29	-3.32[b]/-1.44	-1.94/-1.90	-4.53[b]/-4.79[b]	-1.15/-1.13	-2.27/-0.85
MZ_a	0.9071/0.907	0.06/0.07	0.53/0.53	0.24/0.24	0.47/0.475	0.22/0.21
MSB	1.628/1.629	0.50/0.51	6.22/6.21	1.58/1.55	3.59/3.58	2.31/2.20
P_{GLS}	24.14/16.39	6.67/6.86	13.59/6.41	16.70/14.85	34.20/9.66	56.47/16.07
MP_{GLS}	567.2/170.8	62.2/20.0	7687/2195	489.1/134.3	2547/724	1027/259.5
KPSS	5.1[a]/0.487[a]	7.89[a]/0.84[a]	678[b]/.652[b]	1.24[a]/ .283[a]	2.12[a]/.803[a]	3.29[a]/0 .49[a]

Notes: Subscript *a* means rejection at the 1% level, *b* significance at the 5% level. The Const. case implies testing on GLS demeaned data. The Trend case means testing on GLS detrended data.

Table 4 above report the unit root test results for the each series and segment. The overall results suggest non-rejection of unit roots in both series and all segments. However, for gas the Augmented Dickey Fuller (ADF) tests reject a unit root at the 5% level using GLS demeaned data for the first segment, and using GLS demeand and GLS detrended data for the middle segment. Considering this is the only divergent test resulter test, and the ADF only weakly rejects, we conclude that both series cannot reject unit roots for all segments.

Having established the series contain unit roots, we now turn to the co-integration analysis. This analysis follows the same procedure as the unit root test, where co-integration tests are performed on each segment. In the cointegration analysis no detrending or demeaning is applied to the data prior to testing. In addition to testing for cointegration, we also test if prices follow the law of one price (LOP). The LOP imply that prices move proportionally. Statistically this means the cointegration vector in the rank 1 case can be represented as $[1, -1\ ]'$. This restriction is tested using a Likelihood Ratio test. In an economic sense the LOP suggests the commodities are perfect substitutes, and either price can be represented by the appropriately scaled price of the other commodity. We also test if either series is weakly exogenous in the co-integration relationship. If one series is found weakly exogenous in this sense, it suggest that only the non-exogenous series corrects to deviations from the cointegration relationship. In this sense it is the movement in the non-exogenous variable that corrects disequilibrium in relative prices, where the non-exogenous variable inherits the stochastic trend in the exogenous variable. Weak exogeneity is tested using a Likelihood Ratio test on the appropriately restricted matrix of adjustment parameters.

In testing for cointegration we apply the Johansen (1988) test. This test allows hypothesis testing on the cointegration and adjustment matrix (Johansen & Juselius, 1990). The Johansen test is based on a vector error correction model (VECM) representation of the data. This representation can be derived from an unrestricted VAR model. In the VECM we allow for short run adjustments to the long run equilibrium implied by the cointegration vectors. Gas and oil prices do not need to adjust instantly to the equilibrium relationship; each series is allowed some independence in moving away from the long run equilibrium in the short run. The cointegration analysis is sensitive to specifications of the short run dynamics. We hence report the cointegration results for each VAR lag. If a significant cointegration relationship is found (95% criteria), we also report the LOP and exogeneity test results. This will allow us to evaluate how sensitive the cointegration results are to dynamic misspecification. To evaluate the short run dynamics we allow the underlying VAR model up to a maximum of 10 lags. Several criteria (LM test for residual autocorrelation using 5 and 10 week lags of residuals, Akaike Information Criteria and Bayesian Information Criteria) are then evaluated in order to find a reasonable representation.

Table 5a below reports the results for estimation on the first segment. As is shown, the cointegration results are unambiguous in this case. All VAR models significantly reject zero rank, and fail to reject rank one for the cointegration matrix. This confirms previous results showing that prices are cointegrated in this sample. We further find evidence that the Law of One Price holds, such that prices move proportionally in this segment. In addition, evidence is found that oil is exogenous, meaning gas adjusts to correct any disequilibrium in relative prices. The price of gas is in this segment suitably represented by the price of oil.

TABLE 5a. Dynamic Specification Tests and Cointegration Analysis for Segment 1996.38-2006.11

	Test Statistics				Cointegration Analysis				
Lag	LM(5)[1]	LM(10)	AIC	BIC	rank=0[2]	rank=1[3]	LOP[4]	Exo.(Oil)[5]	Exo.(Gas)
VAR(1)	0.0000	0.0000	-4.318	-4.267	0.000	0.855	0.7007	0.0735	0.0000
VAR(2)	0.0050	0.0403	-4.374	-4.288*	0.000	0.506	0.5164	0.0459	0.0000
VAR(3)	0.5138	0.4736	-4.403	-4.283	0.005	0.642	0.3514	0.0790	0.0000
VAR(4)	0.8257	0.6999	-4.404*	-4.250	0.008	0.626	0.2282	0.0745	0.0000
VAR(5)	0.8515	0.6028	-4.401	-4.212	0.014	0.796	0.2350	0.1244	0.0000
VAR(6)	0.5880	0.6302	-4.388	-4.165	0.013	0.849	0.2486	0.1650	0.0000
VAR(7)	0.7976	0.6975	-4.386	-4.129	0.014	0.780	0.2452	0.3832	0.0000
VAR(8)	0.4389	0.8661	-4.375	-4.083	0.011	0.859	0.2569	0.4355	0.0000
VAR(9)	0.3742	0.7810	-4.365	-4.039	0.008	0.821	0.2201	0.5697	0.0000
VAR(10)	0.8174	0.8731	-4.353	-3.993	0.005	0.839	0.1699	0.4809	0.0000

Note: [1] The LM test p-value for auxiliary regression of lagged regressors and 5(10) lags of residuals. [2] p-values of test for rank of cointegration matrix r=0, [3] p-values of test for rank of cointegration matrix r=1, [4] p-values for null of LOP. [5] p-values for null of oil(gas) weakly xogenous.

In the second segment (table 5b) the results are less clear. We note that the sample here is relatively small (79 observations), and hence a small sample bias could exist. The volatility of relative prices is also relatively large in this period. We find that for the lags chosen by the information criteria, where further no significant residual autocorrelation is found, the prices are cointegrated. At this lag level the results are in line with the previous segment, where the LOP holds and oil is found to be exogenous. When the VAR lag is increased the evidence for cointegration vanishes, however there is little evidence of misspecification at the lag levels implied by the information criteria. The lack of rejection at the higher lag levels could be the result of a small sample, and a general volatile period in relative prices. We however conclude that evidence supports that prices are still cointegrated in this period.

TABLE 5b. Dynamic Specification Tests and Cointegration Analysis for Segment 2006.11-2007.37

	Test Statistics				Cointegration Analysis				
Lag	LM(5)[1]	LM(10)	AIC	BIC	rank=0[2]	rank=1[3]	LOP[4]	Exo.(Oil)[5]	Exo.(Gas)

VAR(1)	0.3398	0.4803	-4.229	-4.152	0.000	0.253	0.9189	0.0000	0.6797
VAR(2)	0.7205	0.7096	-4.300*	-4.172*	0.017	0.073	0.5794	0.0012	0.5318
VAR(3)	0.9516	0.8755	-4.230	-4.050	0.131	0.049	-	-	-
VAR(4)	0.9551	0.9361	-4.138	-3.907	0.162	0.086	-	-	-
VAR(5)	0.6174	0.8731	-4.073	-3.791	0.122	0.077	-	-	-
VAR(6)	0.8224	0.6883	-4.023	-3.689	0.229	0.111	-	-	-
VAR(7)	0.6157	0.8886	-3.931	-3.545	0.275	0.162	-	-	-
VAR(8)	0.7356	0.8969	-3.906	-3.469	0.233	0.113	-	-	-
VAR(9)	0.8998	0.8340	-3.897	-3.409	0.182	0.024	-	-	-
VAR(10)	0.6789	0.9046	-3.831	-3.292	0.141	0.032	-	-	-

Note: [1] The LM test p-value for auxiliary regression of lagged regressors and 5(10) lags of residuals. [2] p-values of test for rank of cointegration matrix r=0, [3] p-values of test for rank of cointegration matrix r=1, [4] p-values for null of LOP. [5] p-values for null of oil(gas) weakly xogenous.

Table 5c below reports the results for the final segment. The results for this segment are drastically different from the previous segments. What is immediately clear is that the amount of short run deviations and persistence has significantly increased in this period. To satisfactory remove residual autocorrelation a VAR with 9 lags is necessary. Further, using the conservative BIC selection criteria the more parsimonious model rejects cointegration in this period.

TABLE 5c. Dynamic Specification Tests and Cointegration Analysis for Segment 2007.37-2010.14

	Test Statistics				Cointegration Analysis				
Lag	LM(5)[1]	LM(10)	AIC	BIC	rank=0[2]	rank=1[3]	LOP[4]	Exo.(Oil)[5]	Exo.(Gas)
VAR(1)	0.0419	0.0003	-4.715	-4.580*	0.517	0.157	-	-	-
VAR(2)	0.1446	0.0014	-4.724	-4.498	0.500	0.083	-	-	-
VAR(3)	0.2846	0.0049	-4.747	-4.430	0.441	0.069	-	-	-
VAR(4)	0.0483	0.0069	-4.737	-4.330	0.312	0.068	-	-	-
VAR(5)	0.0025	0.0110	-4.694	-4.196	0.312	0.101	-	-	-
VAR(6)	0.0019	0.0214	-4.691	-4.103	0.486	0.171	-	-	-
VAR(7)	0.0066	0.1048	-4.721	-4.042	0.146	0.137	-	-	-
VAR(8)	0.1463	0.4715	-4.792	-4.023	0.010	0.091	0.0207	0.3186	0.0016
VAR(9)	0.7832	0.8094	-4.828*	-3.968	0.022	0.156	0.0195	0.1323	0.0057
VAR(10)	0.6945	0.9181	-4.816	-3.866	0.017	0.201	0.0072	0.0269	0.0152

Note: [1] The LM test p-value for auxiliary regression of lagged regressors and 5(10) lags of residuals. [2] p-values of test for rank of cointegration matrix r=0, [3] p-values of test for rank of cointegration matrix r=1, [4] p-values for null of LOP. [5] p-values for null of oil(gas) weakly xogenous.

However, increasing the lag order to 9 lags there is again evidence of cointegration. Even if cointegration is found the LOP fails in this segment, implying that prices no longer move proportionally. Given that oil is still found to be exogenous, this suggests that the price of gas no longer quickly and unambiguously reverts back to a stable equilibrium relationship. The results from the final segment hence suggest that gas price now to larger degree moves independently of the price of oil, being allowed more persistent deviations from the oil price. Given the unambiguous result for the longest first segment, this suggests that the equilibrium relationship between gas and oil has changed in later years, with gas no longer strongly following the price of oil in Europe.

4.3 Summary and Discussion of Empirical Findings

Analysing relative prices of Brent oil and NBP gas, we identify that two major structural changes in the relationship between prices has occurred in the 1996.36 to 2010.13 sample period. A long period (1996.38 – 2006.11) is found to be relatively stable, with the first structural change being dated to 2006.11-2007.38. In this segment the volatility of relative prices increases. In the final segment, 2007.38-2010.13, we find evidence of larger persistence in relative price movements. Using these implied segments we perform cointegration analysis to examine if the equilibrium relationship between prices has changed. In the first and to a lesser degree second segment we find unambiguous evidence that prices are cointegrated, that the Law of one Price holds and the oil price is weakly exogenous in the price relationship. This finding is consistent with previous studies. In the final segment we find less evidence for a cointegration relationship, with the Law of one Price no longer holding. The last segment is characterized by gas prices moving more independently of oil, with significantly longer periods of deviations from the implied long run equilibrium.

The result that natural gas prices in later years have become more idiosyncratic relative to the Brent oil price is consistent with recent developments in the European gas market, as discussed in section 2. Increased gas to gas competition, gas competing with alternative inputs for electricity generation and increased liquidity of the UK spot market are market factors which supports that natural gas prices might be moving out of the shadow of oil. However, the question arises whether this apparent break-down in the historical long run relationship is permanent or transitory. Considering the break-down occurred in a period with historically very high commodity prices and an economic recession, one might argue that the long-run relationship will establish again when the markets and economy return to a “normal” state. Given a consistently high demand for oil from growth economies like China, and the relative scarcity of oil, it is likely that the price of oil was hit less severe by the economic recession than natural gas prices. Such an argument would point to a transitory divergence in relative prices. None the less, the fact that oil is relatively scarcer than gas, and will most likely increasingly be so, suggests that the relationship between oil and gas markets will not revert to the state observed in the 1990’s.

5. Conclusion

In this paper we investigated the relationship between Brent oil and NBP natural gas prices in light of recent changes in European natural gas markets. This is specifically related to natural gas increasingly being used for power generation, competing against alternative inputs for electricity generation such as coal, and an increased gas-to-gas competition and spot market liquidity reducing the importance of oil-linked contracts. In addition we have seen an increased presence of LNG in Europe, possibly affecting natural gas pricing regimes.

Earlier studies of oil and gas markets in Europe markets have shown the markets to be integrated, following the law of one price, and with Brent oil being weakly exogenous. This relationship has been demonstrated to hold despite deregulations of gas markets in Europe. Using more recent data and newer analytical tools we find statistical evidence that the historical long-run relationship between Brent oil and NBP gas has changed after 2007. Specifically, we find evidence that the price of NBP gas is more idiosyncratic movement and that the law of one price no longer holds. These findings are consistent with recent developments in European petroleum markets. Increasing scarcity of oil relative to natural gas, and different use of the commodities, suggest that relative prices will not revert to the relationship observed in the 90's and early 00's. However, given the break-down occurred in a period with general economic upheaval we cannot rule out that this is a transitory deviation, and that natural gas prices might for some years still be closely related to oil.

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