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OIL AND GAS MARKETS IN THE UK:
EVIDENCE FOR FROM A COINTEGRATING APPROACH

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Abstract

The paper examines the relationship between UK wholesale gas prices and the Brent oil price over the period 1996-2003 in order to investigate whether oil and gas prices 'decoupled' during this period as orthodox gas market liberalisation theory suggests. Tests for Unit Roots and Cointegration are carried out and it is discovered that a long run equilibrium relationship between UK gas and oil prices exists. Moreover, this relationship predates the opening of the UK-Mainland Europe Inter-connector. Following a recursive methodology (Hansen & Johansen 1999), it was found that the cointegrating relationship is present throughout the sample period. However, the long run solutions seem to be more volatile. Evidence is provided that the short run relationship is linear and impulse response functions are used to examine the effects that a shock in oil would have on gas. These findings do not support the assumption that gas prices and oil prices 'decouple'.

Keywords: oil price, gas price, cointegration, nonparametric cointegration, recursive trace test, error correction, impulse response
JEL: C22, C52, O13, Q43

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1. INTRODUCTION

A fundamental assumption of those who strongly support the liberalisation of natural gas markets (structural reforms leading to the emergence of full gas-on-gas competition) is that under a fully liberalised regime gas and oil prices 'decouple'. It is also generally assumed that after such 'decoupling', gas prices fall significantly with consequent welfare benefits to consumers. The pre-liberalisation regime of gas prices 'coupled' to oil prices reflects (so it is argued) the market power of state or private sector gas monopolies to extract rent from gas consumers for whom oil and its products are the only alternative fuels in many domestic and industrial uses.

A classic statement of this proposition is that of Barton and Vermeire (1999) who argue that in a liberalised gas market "*the linkage with oil prices is now much less transparent*". They argue that after liberalisation, gas prices fluctuate between two bounds, the higher one set by interfuel competition in industries where gas and oil are close substitutes and the lower bound determined by the marginal cost of extracting gas from the reservoir. Since 1994 the UK gas market has become progressively liberalised and by 2003 was probably the most highly liberalised gas industry in the World.[1]

In a similar vein Heren (1999) argued that since liberalisation, UK gas prices diverged from those on the Continent because they were no longer influenced by

[1] The UK gas market exhibits all the key features of a highly liberalised market. Wholesale gas trading takes place on liquid spot and futures markets. Consumers – right down to the individual domestic customer – can choose their gas supplier. Competing gas suppliers have third party access to the country's gas transportation system. The gas transportation system is supervised by a regulatory authority guaranteeing non-discriminatory access and tariffs. At present the UK is the only gas market in the world which exhibits all these features. In comparison, a liberalised gas market in Continental Europe can be said to barely exist. Most gas is still sold on long-term contracts with prices determined in advance and frequently linked to the crude oil or heavy fuel price. In the USA gas markets are liberalised to a considerable degree but, unlike the UK, final domestic consumers do not, in general, have a choice of individual gas supplier.

the oil price. The latter also argues that UK gas prices had benefited from the development of spot pricing which had accompanied the deregulation of industrial gas markets and stated that "*The British spot price is now widely accepted as the measure of the commodity's value in the British market, and the benefits of lower prices have in general been passed through to the consumer. European border prices, on the other hand, owe nothing to the actual market conditions in the gas industry, and everything to the oil price*" (Heren 1999, p7). Before the liberalisation of the UK gas market it was certainly the case that UK gas prices closely followed the pre-liberalisation 'Barton and Vermeire paradigm'. In evidence to the Monopolies and Mergers Commission (MMC) in 1988, British Gas made it quite clear that it indexed gas prices in the un-regulated so-called 'contract' market (the market for industrial and large commercial consumers) to the prices of crude oil and petroleum products (MMC, 1988). British Gas was also accused of price discrimination and restricting third party access to its pipeline system. Following this, and a further Monopolies and Mergers Commission investigation in 1993, British Gas was required to introduce a number of reforms including the internal unbundling of its supply and transportation functions and the release of part of its portfolio of upstream gas supplies to competitors. While the price of gas to domestic consumers was not fully deregulated until 2002, the competitive sector of the market - 'contract' sales – witnessed a substantial fall in prices between 1994 and 1998, seemingly confirming the views of those that supported the general liberalisation thesis (International Energy Agency, IEA, 1998).

However, between mid-1999 and the end of 2000, UK wholesale natural gas prices, which had remained at very low levels since the spot and futures markets were first established in 1995-1996, increased very substantially, with prices almost doubling. This rapid increase in the price of gas was concomitant with that occurring in the international oil market, where the price of Brent Crude oil increased by more than one hundred per cent during 1999. Between 2001 and

2003 UK gas prices continued to experience much greater volatility than previously and, by late 2002, the rising oil price was again accompanied by rising gas prices. More recently, the surge in oil prices since 2003 was once again associated with UK gas prices reaching record levels.

As a result of the initial unexpected increase in gas prices during 1999-2000, the UK Government commissioned a report that concluded that UK gas prices had risen because the oil-gas price linkage had become re-established (ILEX 2001). They argued that the main factor explaining the rise in the gas price through 1999-2000 was the physical link that had recently been established between the UK and oil-indexed Continental gas markets as a result of the opening of the UK-Belgium Interconnector gas pipeline at the end of 1998. This established a relationship between two gas markets which had previously been quite independent of one another. It concluded that *"the link with oil indexed gas prices on the Continent is the most important factor in explaining the rise in UK gas prices through 2000"* (ILEX 2001, p.3).

The Interconnector pipeline between Bacton in Norfolk and Zeebrugge in Belgium was originally built to allow UK gas to be supplied to Continental markets where reserves and gas production are much lower than in the UK. However, the flow of gas can be reversed (albeit at a smaller rate than the flow from the UK to the Continent). After the opening of the Interconnector in October 1998, initially gas began to flow in this 'reverse' direction, from the Continent to the UK. However, with Continental gas prices rising sharply in 1999, it became clear to UK gas traders that arbitrage profits were available, selling UK gas, via the Interconnector, into the higher-priced Continental markets where gas prices are indexed to the price of oil (either crude or fuel oil) in long-term contracts. These arbitrage activities between the UK and

Continental gas markets which led to price convergence between the two markets therefore also indirectly linked UK gas prices to the rising price of oil.

The question of the relationship between oil and gas prices in liberalised and unliberalised gas markets is of considerable importance. If it is correct that after liberalisation gas and oil prices do indeed 'decouple' then the current efforts of the European Commission to compel European countries to follow the UK route leading to full liberalisation may produce considerable welfare benefits for both European and UK citizens. However, if the fundamental assumption about 'decoupling' is incorrect – if there exists some fundamental factors underlying the historically close relationship between oil and gas prices which cannot easily be dispelled by the type of measures currently being contemplated by the European Commission – then clearly the mandatory liberalisation of European gas industries may turn out to be a futile exercise. In this context, Wright (2006) has argued that liberalisation of the European gas industries along UK lines could actually result in higher and certainly more volatile gas prices.

To provide a more rigorous definition of both 'coupling' and 'decoupling' it will be useful to employ the following expression:

$$\ell n\, p_{1t} = \alpha + \beta \; \ell n\, p_{2t} \qquad (1)$$

where p_{1t} and p_{2t} are the prices of gas and oil respectively, *ln* is the natural logarithm, α is a constant term (the log of a proportionality coefficient that captures differences in the levels of the prices) and β gives the relationship between the prices. If $\beta = 0$ there is no relationship between the prices i.e. they are completely 'decoupled'; if $\beta = 1$ the prices are proportional.

In this paper we intend to use cointegration analysis to answer the following questions.

(i) Is there a cointegrating (long-run) relationship between UK gas prices and oil prices in the period since liberalisation commenced (c1994) or did oil and gas prices permanently de-couple' at this time as Barton and Vermeire (1999) suggest?

(ii) If cointegration is shown to be present, did this occur *only* after the Interconnector was opened (as suggested in ILEX 2001) or did it pre-date the opening?

The rest of the paper is organised as follows. The recent literature is reviewed in section 2. Section 3 provides more information about the data set, describing the different gas price series that were available to us at the time of writing. Unit root and cointegration tests are considered in Section 4. The error correction models are given in Section 5. The discussion of the empirical analysis and the impulse response function analysis is provided in Sections 6 and 7 respectively. Finally, Section 8 concludes.

2. RELEVANT LITERATURE

There is a small but growing volume of literature examining the statistical relationship between different energy prices some of which is directly relevant to our own investigation. De Vany and Walls (1999), used cointegration methods to model regional US electricity markets and to assess price integration between these markets. Using a vector error correction model, the authors provided strong evidence of cointegration between eleven regional electricity markets in the US. Hendry and Juselius (2000, 2001) discussed extensively the cointegrating relations between weekly gasoline prices at different locations.

In a univariate framework, Robinson (2000) analysed the behaviour of electricity prices in England and Wales since the creation of their spot market in 1990. It was argued that the process is nonlinear and a logistic smooth transition model (LSTAR) was fitted. Electricity and gas markets are similar in the sense that these commodities have been deregulated over the last decade in many countries. Since deregulation, prices for these commodities have become more volatile. However, Huisman and Mahieu (2001) demonstrated that electricity prices have been much more volatile than gas prices, partly due to the non-storability of electricity.

Serletis and Herbert (1999) examined the long term trends between different energy prices in North America. They found cointegration between the price of natural gas and fuel oil, indicating effective arbitraging mechanisms between those markets, but no such relationship was found with the price of electricity. They used univariate and bivariate models to make inferences about the time series relations between energy prices. However, the authors use data of a short time span – only one year – in their analysis and they admit that an approach based on the use of higher-dimensional VARs and impulse response functions would be more robust. This study does employ these techniques in analysising the relationship between the UK gas price and oil prices (see sections 5 and 6). More recently, Narayan and Smith (2005) in a single equation framework, have employed the bounds testing approach to cointegration to model residential demand for electricity in Australia.

Contrasting with the argument presented by ILEX (2001), which posits a link between gas and oil prices which is fundamentally dependent upon the existence of contractual terms linking oil and gas prices in a non-liberalised gas market, Barcella (1999) discovered a relationship between oil and gas prices in the liberalised US gas market which, she argued, was based on more fundamental and long-run economic factors. It was found that crude oil and natural gas prices were highly correlated in the US, *"yearly trends in crude oil and natural gas prices …are highly correlated, with a coefficient of 0.916. The weekly gas and fuel oil prices… are less highly correlated, but are cointegrated"* (Barcella, 1999, p.12). It is argued that the close relationship between natural gas and oil prices (both crude and fuel oil) reflected the underlying economic fact that the fuels were substitutes for one another in a large number of industrial processes. In particular the study refers to "*the significant inter-fuel competition in the electric power sector*."

However, recently Bachmeier and Griffin (2006) find evidence of weak integration between crude oil, natural gas and coal markets in the USA. Testing for a cointegrating relationship between oil and gas prices they find that these are "*cointegrated in the long run and exhibit stronger evidence of market integration. Nevertheless the relationship is weak compared to the market integration we observe among [regionally different] crude oils or Western coals"*. In accounting for the rather weak cointegration between oil and gas prices, in contrast to Barcella (1999), they argue that it is only in certain limited industrial processes, such as residential and commercial heating, that there is direct competition and substitutability between oil and natural gas. In the most important sector of the oil market – motor vehicle transportation –there is almost no substitutability with natural gas. Asche et al (2002) provide a discussion of the structure of the take-or-pay contracts and evidence that the continental market for gas is integrated. Gjølber and Johnsen (1999) investigate the link between crude oil and several refined products like fuel oil, finding this to be high and accordingly increasing the likelihood of finding evidence of market integration between crude oil and natural gas.

Finally, a recent paper by Asche et al. (2006) has a particular relevance for our study since it raises similar questions. But (i) is methodologically different, (ii) provides different results and (iii) draws different conclusions. They look at the decoupling of gas, oil and electricity prices and claim that the opening of the Interconnector leads to the liberalized UK natural gas market and the regulated Continental gas markets becoming physically integrated and the '*the Continental gas price [becoming] dominant*.' However they also note that in an interim period – after liberalisation of the UK gas market and the opening up of the Interconnector – the UK gas market '*had neither government price regulation nor a physical Continental gas linkage*.' They use this period (1995-1998), which they describe as '*an unusual combination of deregulation and autarky*' to explore if decoupling of natural gas prices from prices of other energy commodities – oil and electricity – took place.[2]

Using cointegration methods (Johansen) Asche et al. (2006) found evidence of an integrated UK energy market in the period when the gas market was liberalised but not yet linked to the Continent (1995-1998) and conclude that this supports their theory of a single UK energy market where energy prices are determined in the global market with the world oil price operating as an exogenous determining variable. The authors also test the period after the opening of the Interconnector between 1998 and 2002, but find no evidence of cointegration between UK natural gas, Brent oil and electricity prices in this period. These results are indeed interesting because they are precisely the opposite of what we would have expected (i.e. cointegration after 1998, no cointegration between 1995 and 1998, see also ILEX, 2001).

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[2] Throughout, the authors use the term 'deregulation' rather than liberalisation. In our opinion use of the term 'deregulation' is misleading. The UK gas market was not 'deregulated' in the period to which they refer. The unbundled transportation network remained tightly regulated as did the domestic sector of the supply business which was not fully deregulated until 2002. However the system as a whole was certainly 'liberalised' after the implementation of many of the recommendations of the 1993 Monopolies and

This study conducts a more thorough analysis of the possibility of structural breaks compared with Asche et al. (2006)[3]. We mitigate the potential limitations of the relatively short span of data by employing three different methodological approaches. In addition it provides a recursive framework to identify potential structural breaks, focuses on the nature of the relationship in the short-run and whether it is linear or not, and finally uses impulse response function to trace the results of shocks to the system.

Economic theory suggests that past changes in the oil price cause current changes in the price of UK gas but not vice versa. Apart from the fact that Continental gas prices are indexed to the price of oil and not vice-versa, it seems unlikely that the gas price would be able to influence the oil price. The size of the contract market and volumes traded for oil are vastly greater than for the gas market[4]. The Brent crude oil price is an international price determined in large part by the world supply and demand for oil, whereas the UK gas market is, by definition, only a national one. However, it is possible that expectations of an oil-gas relationship could cause gas prices to feed back onto oil prices. Therefore to investigate these possibilities, we employ a Vector Error Correction Model (VECM) specification to model the UK gas price on the one hand and impulse response functions (IRF) are generated on the other to examine the consequences of a shock introduced in the oil price.

Mergers Commission Report in 1993 and the industrial and commercial market segments became fully competitive (i.e. liberalised) at the same time.

[3] Differences in results with Asche et al (2006) could stem from the inclusion of the electricity price.

[4] Volumes for the Brent oil futures contract market at the IPE per day were 1,639,041 in February 2002 compared to only 43,560 for the natural gas futures contract market.

3. DATA SOURCES

The price of wholesale natural gas in the UK is determined in several markets, the Over-the-Counter (OTC) or 'spot' market, the On the Day Commodity Market (OCM) used primarily for gas balancing purposes, and the IPE gas futures market. Price data is available for all three markets which we will use in our empirical analysis.

The most liquid market is the OTC market. Total annual volumes traded at the National Balancing Point (NBP) (both physical and 'paper' trades) amount to around 6 times the throughput of the UK gas pipeline system (Wright 2006, p.69). Dealing on the OTC market is usually through bi-lateral trade or through a broker and consequently price data is confidential, or only available through commercial energy consultancies. PH Heren Ltd, produces a monthly series – the 'Heren Index' – which is a volume-weighted average of OTC transaction prices reported during the month in pence/therm. The series commences April 1995 and PH Heren Ltd has kindly made this data available to the authors.

Another source of wholesale gas price data is the On-the-Day Commodity Market (OCM) operated, during the period covered in our study, by EnMO. This market was established on 1st October 1999 replacing the original 'Flexibility Mechanism' operated by the UK pipeline company BG Transco which had been originally introduced to provide a mechanism for daily gas balancing on the UK pipeline system. EnMO published cash-out price data as a daily series and the System Average Price (SAP) is broadly an average trading price for wholesale gas measured in pence per kilowatt hour (p/kWh) on a particular day. Although the OCM is a relatively small market[5] and exhibits a high degree of volatility

[5] OCM volumes are only about 10 percent of total UK pipeline throughput (Wright 2006, p.69).

there is evidence to suggest that OCM cash-out prices (SAP) are strongly correlated with the OTC (spot) prices (OFGEM, 2000, p.25), and can therefore be used as a good proxy for the daily spot price in our econometric analysis.

The final source of UK wholesale natural gas price data we shall be employing in our analysis is from the International Petroleum Exchange (IPE which is the main exchange for trading gas futures contracts in the UK. This futures price series began in January 1997 and was established to manage the risk in the underlying physical gas market, i.e., the OTC market. The IPE provides daily a one month forward price for wholesale natural gas prices for physical delivery within the UK natural gas grid at the NBP. As this data series is a one month forward price – although it is closely related to the spot price – it experiences less volatility than the spot or OCM price data

In Europe and throughout most of the world, gas prices are quoted per KWh. In the UK natural gas is usually priced in pence per therm, while in the international crude oil markets, oil is priced in US dollars per barrel. We have converted both into pence per kilowatt-hour (p/kWh) in order to allow direct comparison between the two fuel prices[6].

European Gas contracts are mainly indexed against inland German heating and fuel oil, and this is where the link with the oil price occurs. Crude oil is benchmarked against a variety of blends; in the UK and Europe the benchmark blend is Brent. The spot price of Brent crude oil is available from several commercial energy agencies and the monthly series is obtained from *DataStream*.

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[6] The KWh is a more internationally accepted unit of volume than the therm, one therm = 29.3 kilowatts an hour. One barrel of Brent crude oil is taken to be equal to 1597 KWh: we have been unable to discover a precise calorific definition for Brent, but we believe this is a reasonable approximation. Oil in US$ barrel is converted using daily or monthly exchange rates (depending on the frequency of the gas data it is being compared to); the oil price in £/barrel can then be converted into pence by multiplying by 100 and finally to pence/kWh by dividing by 1597.

4. UNIT ROOT AND COINTEGRATION TESTS

We consider three unit root tests: the Augmented Dickey Fuller (ADF), the Breitung (2001) and Breitung and Taylor (2003) and one proposed by Saikkonen and Lutkepohl (2002) and Lanne, Lutkepohl and Saikkonen (2002) (unit root test with structural break)[7]. The first is well known in the literature. Breitung (2002) and Breitung and Taylor (2003) propose a nonparametric unit root test which is robust to structural breaks. Saikkonen and Lutkepohl (2002) and Lanne, Lutkepohl and Saikkonen (2002) have proposed a test for processes with level shift. Shift functions could be i) a simple shift dummy, ii) based on the exponential distribution function and iii) a rational function in the lag operator applied to the shift dummy. The break data is chosen based on simulation results and the AR order on the relevant information criteria. The unit root tests for each series are presented in Table 1. Each of the three data series for wholesale natural gas, i.e., IPE, OCM's SAP and the Heren Index series exhibit unit roots and are integrated of order one, as does the price of Brent crude oil, (see Table 1). All tests suggest that the first differences of the series are stationary.

Having established that the wholesale natural gas data and oil price series each contain a unit root we can proceed to investigate the existence of a cointegrating relationship between the two commodity prices. As explained in the previous section we expect the two variables to be cointegrated after the opening of the Inter-connector. However the possibility of a cointegrating relationship predating that will also be investigated.

[7] The Phillips-Perron (PP) was also carried out. The results were similar to ADF and are available upon request.

Two distinct methodologies are used to test for cointegration; the trace test developed by Johansen (1995), and the nonparametric test for cointegration proposed by Breitung (2002).

In Johansen's (1988, 1995) notation, we write a p-dimensional Vector Error Correction Model (VECM) as:

$$\Delta y_t = \sum_{i=1}^{k-1} \Gamma_i \Delta y_{t-i} + \Pi y_{t-1} + \mu + \varepsilon_t, t = 1, \ldots, T \tag{2}$$

where Δ is the first difference operator, y_t is the set of $I(1)$ variables discussed above, $\varepsilon_t \sim niid(0, \Sigma)$, μ is a drift parameter, and Π is a (p x p) matrix of the form $\Pi = \alpha\beta'$, where α and β are (p x r) matrices of full rank, with β containing the r cointegrating vectors and α carrying the corresponding loadings in each of the r vectors. In our approach, we set y_t = [*Brent, Heren*]′ and ε_t = [ε_{Bt}, ε_{Ht}][8].

The Johansen procedure, like many others, requires estimation of various structural and nuisance parameters. For example, a vector autoregressive (VAR) lag order must be specified and the lag parameters estimated (for the lag order specification see section 5). To get around this problem we employ the recently developed nonparametric test for cointegration due to Breitung (2002). No lag structure or deterministic terms need to be estimated. As Breitung (2002) notes: "*there are a number of situations where the nonparametric approach may be attractive. Since the short-run component does not affect the asymptotic null distribution of the test statistic, the test is robust against deviations from the usual assumption of linear short-run dynamics*".

[8] The analysis was carried out for SAP and IPE as well and provided similar results. We report Heren since this is the longest series. The other two cases are available upon request.

Both the Johansen and Breitung tests reject the null of zero cointegrating vectors between crude oil and the three different proxies for gas. Using the logs of the series, the outcome was further confirmed. The results for both the parametric (Johansen) and the nonparametric (Breitung) method are presented in table 2[9]. However, relationships between economic variables do not necessary remain the same throughout time and various factors, such as political crises , technology, innovation, as well as investment in infrastructure (such as the building of the inter connector) can influence and alter the nature of the relationship.

To test the stability of the results presented in Table 2 on the one hand and examine potential changes in the relationship between the two variables over time, we employ a recently developed econometric methodology. Following Hansen & Johansen (1999) we consider the parameter constancy in the cointegrated VAR model. This is very useful since we would like to examine whether the opening of the UK-Mainland Europe inter-connector has affected the relationship between oil and gas. The adopted methodology recursively estimates the trace test (see Johansen 1995 and Hansen & Johansen 1999) and uses the time paths of the estimated parameters as a diagnostic tool in evaluating the parameter constancy. Figures 3 and 5 present the results. We calculate the trace test statistic for each additional observation using an expanding window and then divide the test statistic by the critical value. If this fraction is greater than one then the two series are cointegrated and there is a long-run relationship. If it is below one the two series are not cointegrated. As it is obvious from both graphs the ratio is above unity throughout our sample for both the levels and the logs of the prices. The latter allows us to conclude firstly, that the prices were cointegrated for the whole period 1996-2003 and that the Interconnector did not

[9] The bounds test for cointegration proposed by Pesaran et al (2001) was also estimated confirming the conclusions of table 2. The results are available upon request.

change that relationship, and secondly, that the (potential) outliers did not alter this relationship at any point in time.

The long-run solution estimates for all the series are presented in Table 3. The estimates vary from 0.38 (2) to 0.855 (4). The coefficients for IPE and Heren are very close (around 0.5 for the levels and 0.8 for the logs). The long-run coefficient for SAP is the smallest in both cases (equations (2) and (5)). The next step was to investigate whether there were considerable changes in magnitudes of these coefficients throughout the period and especially whether the Interconnector has affected the relationship. In other words we ask 'how long-run is our long-run solution?' We proceed with estimating the recursive βs together with their standard errors (see equation 3 in the next section), using an expanding window. Each point in the graph corresponds to what an investigator at the time would have found (see Figures 4 and 6). In 1999 we observe a reduction in the Brent long-run coefficient which suggests a smaller dependency during that year and up to mid 2000. This seems to be reverted from mid 2001 up to the end of our sample (see Figure 4). The same picture emerges from the log analysis (see Figure 6). In both cases little variation appears after 2001. Note here that the last point in Figure 6 corresponds to the long-run solutions presented in Table 3 (0.855 and (-1)* -0.542 respectively).

To sum-up, both methodologies support the existence of a cointegrating relationship between UK gas prices and the oil price in the period prior to the opening of the Bacton - Zeebrugge gas Interconnector[10]. These results provide support for the theory that an equilibrium relationship between UK gas prices and the oil price existed before the opening of the gas Interconnector. The long run coefficients decrease in the first 15 months of the operation but quickly

[10] Two periods when the Interconnector was shut were not included in the data analysis – 16-26 July 2000 and 17-27 September 2001.

moved upwards after that. Our initial findings, therefore, indicate the presence of a long-run equilibrium relationship but does not imply a linear short-run specification.

5. ERROR CORRECTION MODELS AND LINEARITY TESTING

Linearity is an underlying assumption of the VECM model (2). However, many aspects of economic behaviour may not be linear (see the discussion in Campbell et al 1997). In this part we investigate potential deviations from linearity. Many tests for neglected non-linearity have been proposed in the literature. Instead of using a single statistical test, for the purposes of this paper, four different tests are considered; McLeod & Li (1983), Engle LM (1982), Tsay (1986) and the Brock et al (BDS) (1996). All these tests share the principle that once any (linear or non-linear) structure is removed from the data, any remaining structure should be due to an (unknown) non-linear data generating mechanism. All the procedures embody the null hypothesis that the series under consideration is an *i.i.d.* process.

The McLeod & Li test looks at the autocorrelation function of the squares of the prewhitened data and tests whether corr (e_t^2, e_{t-k}^2) is non-zero for some k and can be considered as an LM statistic against ARCH effects (see Granger & Terasvirta 1993; Patterson & Ashley 2000). The test suggested by Engle (1982) is an LM test, which should have considerable power against GARCH alternatives (see Granger & Terasvirta 1993; Bollerslev, 1986). The Tsay (1986) test explicitly looks for quadratic serial dependence in the data and has proven to be powerful against a TAR (Threshold Autoregressive) process. The BDS test is a nonparametric test for serial independence based on the correlation integral of the scalar series, $\{e_t\}$ (see Brock, Hsieh & LeBaron 1991 and Granger & Terasvirta 1993). This is a general linearity test where the alternative to linearity can be considered to be a stochastic non-linear model (Granger & Terasvirta 1993). The reader is also referred to the detailed discussion of these tests in the technical appendix and the simulations in Patterson & Ashley (2000).

6. EMPIRICAL ANALYSIS

A general-to-specific approach is followed where each VECM was estimated for *i= 0* to 6 and lag order was selected using the Akaike Information Criterion (AIC) and the Hannan-Quin Information criterion (HQ). The results for both the raw data and the logs are presented in Tables 4 and 5. The error correction term is significant in both models 2 and 3 for the Heren equation[11] and the lagged values of both variables are found to be significant..

The residuals of these models were saved and the four tests for linearity were estimated. These tests could provide us with information about any neglected non-linearity present in the VECM on the one hand and on the other guide us into the nature of this (potential) non-linearity (McLeod & Li for ARCH, Engle for GARCH, Tsay for TAR and BDS as general linearity test). Table 6 reports the tests for residuals of models 1 and 2. The employed tests are, like most econometric procedures, only asymptotically justified. Given the limited sample available, the tests are estimated using both the asymptotic theory and the bootstrap. The values under 'asymptotic theory' are based on the large sample distributions of the relevant test statistics. For the 'Bootstrap' results, 1000 new samples are independently drawn from the empirical distribution of the pre-whitened data. Each new sample is used to calculate a value for the test statistic under the null hypothesis of serial independence. The obtained fraction of the 1000 test statistics, which exceeds the sample value of the test statistic from the original data, is then reported as the significance level at which the null

[11] We are interested in the equation where (L)Heren is the dependent variable as Brent is affected by other factors.

hypothesis can be rejected (for a detailed discussion on the sample size, the asymptotic theory and the bootstrap see Patterson and Ashley 2000).

Throughout the battery of the tests we can accept the null hypothesis that the residuals of the second equation in both cases are *i.i.d* (we are not interested in the residuals of the Brent equation since this is affected by other factors).

To summarise the results, we have used a vector error correction specification to capture the short run dynamics of the relationship between oil and gas prices in the light of the completion of the Interconnector pipeline which connects the oil-indexed continental gas markets with the UK. We have found evidence that this mechanism is linear using four different test statistics which conclude that the employed VECM can satisfactory explain the dynamics of the series.

7. IMPULSE RESPONSE FUNCTIONS

Using the VECM system that has been estimated in the previous section, we extend the analysis and generate impulse response functions. A shock to the *i*th variable not only directly affects the *i*th variable but it is also transmitted to all the other endogenous variables through the dynamic (lag) structure of the VECM. An impulse response function (IRF) traces the effect of a one-time shock to one of the innovations on current and future values of the endogenous variables. If the innovations ε_t are contemporaneously uncorrelated, the interpretation of the impulse response is straightforward. The *i*th innovation $\varepsilon_{i,t}$ is simply a shock to the *i*th endogenous variable y_{it}.

The generalised IRF (GIRF) can be defined as

$$GIRF(n, \varepsilon_t, \omega_{t-1}) = E[y_{t+n} | \varepsilon_{j,t}, \omega_{t-1}] - E[y_{t+n} | \varpi_{t-1}] \qquad (3)$$

where y_t is a random vector, ε_{t+i} is a random shock, ϖ_{t-1} a specific realisation of the information set Ω_{t-1} and n is the forecast horizon. The GIRF is a random variable given by the difference between two conditional expectations which are themselves random variables. We estimate the generalized impulses (GIRF) following Pesaran and Shin (1998). They construct an orthogonal set of innovations that does not depend on the VAR ordering. The generalized impulse responses from an innovation to the *j*th variable are derived by applying a variable specific Cholesky factor computed with the *j*th variable at the top of the Cholesky ordering [for more details see Pesaran and Shin (1998)].

It would be useful to point out that that IRF analysis can be viewed as a 'conceptual experiment'. We are interested in investigating the consequences of introducing a shock to the oil price. Figures 7 and 8 present the results of our IRF analysis. Introducing a positive shock to the oil price, we observe a negative response from gas price which dies out after 7 periods (response standard errors were calculated using 1000 Monte Carlo repetitions). However this response is not statistically different from zero. In the second graph the shock is introduced to the log prices (Model 3). Again a negative response from Gas price is observed which dies out much quicker (after four periods) but still is not significant.

8. CONCLUSIONS

It has been frequently argued that in liberalised gas markets like the UK, the link with oil prices, typically witnessed in pre-liberalised markets, disappears, or at least becomes considerably less pronounced. However between 1999 and the end of 2000 the link between oil and gas prices in the UK appears to be strong. The sharp increase in UK wholesale natural gas prices during this period was attributed by ILEX (2001) to the opening of the UK-Belgium gas pipeline, the argument being that this gave opportunities to both the UK and Continental gas traders for arbitrage profits thereby indirectly linking UK gas prices to World oil prices. The important point to emphasise here is that such a consequence of the physical linkage to European gas markets is still perfectly consistent with the 'orthodox' liberalisation argument; i.e. it suggests that had the physical integration *not* taken place, UK gas prices would have remained 'decoupled' – a property of the UK gas market which orthodox liberalisation theory attributes to the structural changes in the industry which took place c.1994.

This paper provides evidence that the UK gas prices are cointegrated with oil prices using the Johansen methodology and the recently developed Breitung nonparametric procedure. However, using recursive techniques it has also been demonstrated that cointegration is accepted *throughout the whole sample period 1996-2003* and that this relationship was not affected by the opening of the Interconnector. The existence of a cointegrating relationship prior to the inauguration of the Interconnector indicates that despite the highly liberalized nature of the UK gas market, gas prices and oil prices are moving together in the long-run. This casts doubts in the efforts of the European Commission to liberalize the gas markets

In the same framework, the long run coefficients reduced considerably (from 1 to 0.2) for the first 15 months but seem to converge to a 0.5 (or 0.8 for the logs) long run value. We employed a VECM specification to capture the short-run dynamics. Three tests for neglected non-linearity were calculated: the McLeod-Li and Engle test for (G)ARCH effects and the BDS test statistic as general test for linearity. Bootstrap values as well as asymptotic are presented. Strong evidence emerges to support the argument that the relationship between oil and gas is a linear one. Finally, we generated impulse response functions to investigate the response of Gas price as a result of a shock introduced in the price of oil. Negative responses from gas seem to die out quickly.

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Figure 1

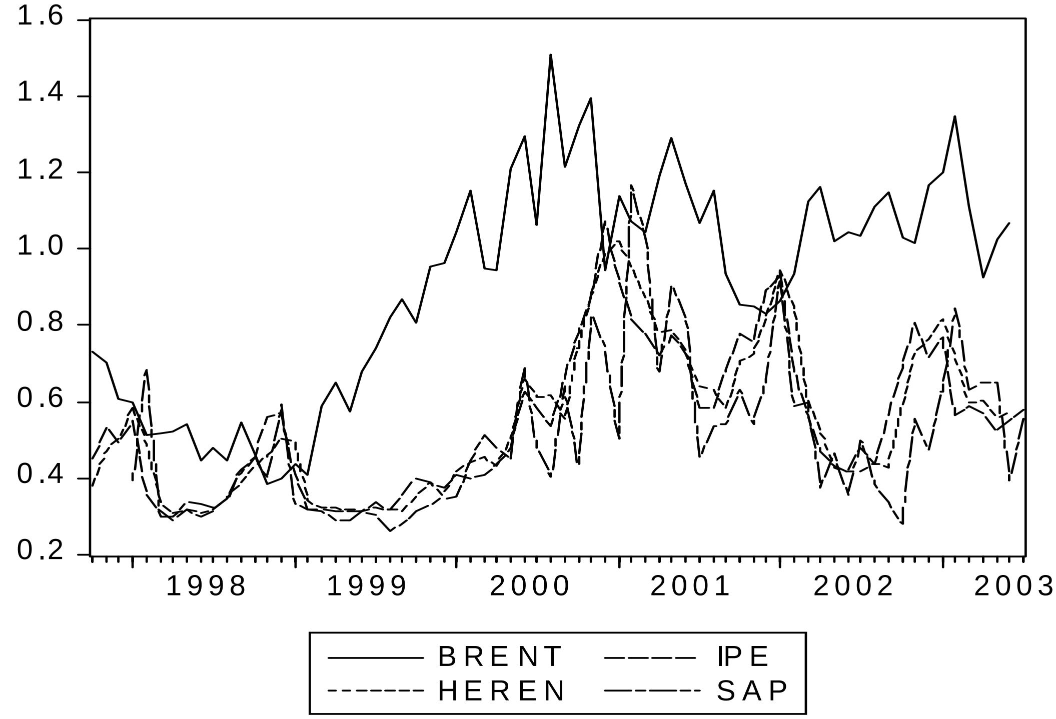
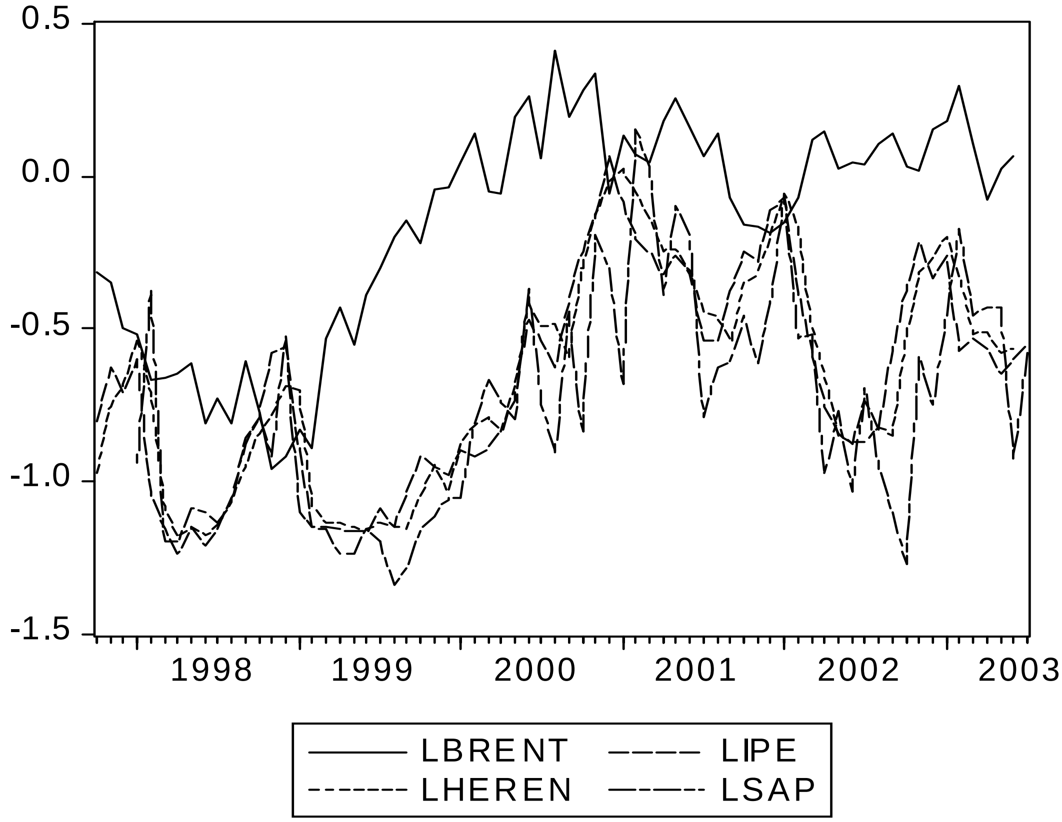


Figure 2



Note: see the discussion in Section 3 for the unit of measurement.

Figure 3: Recursive Trace tests (Heren-Brent)
Critical Values from MacKinnon-Haug-Michelis (1999)

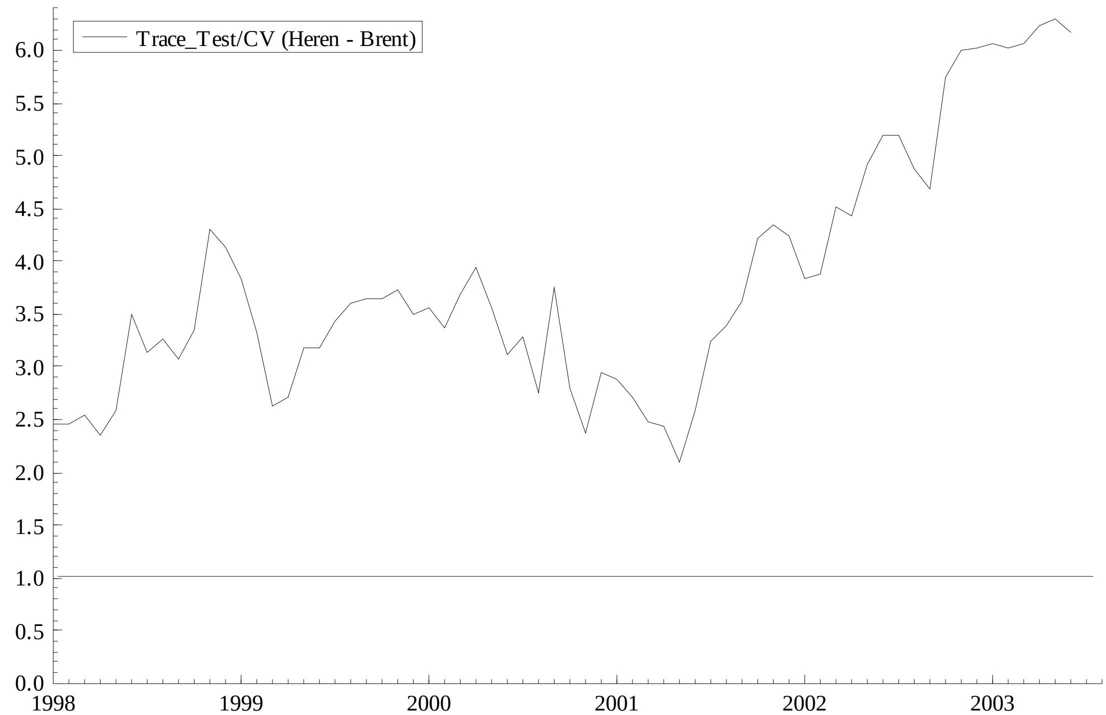


Figure 4: Recursive Beta Coefficients (Heren-Brent)

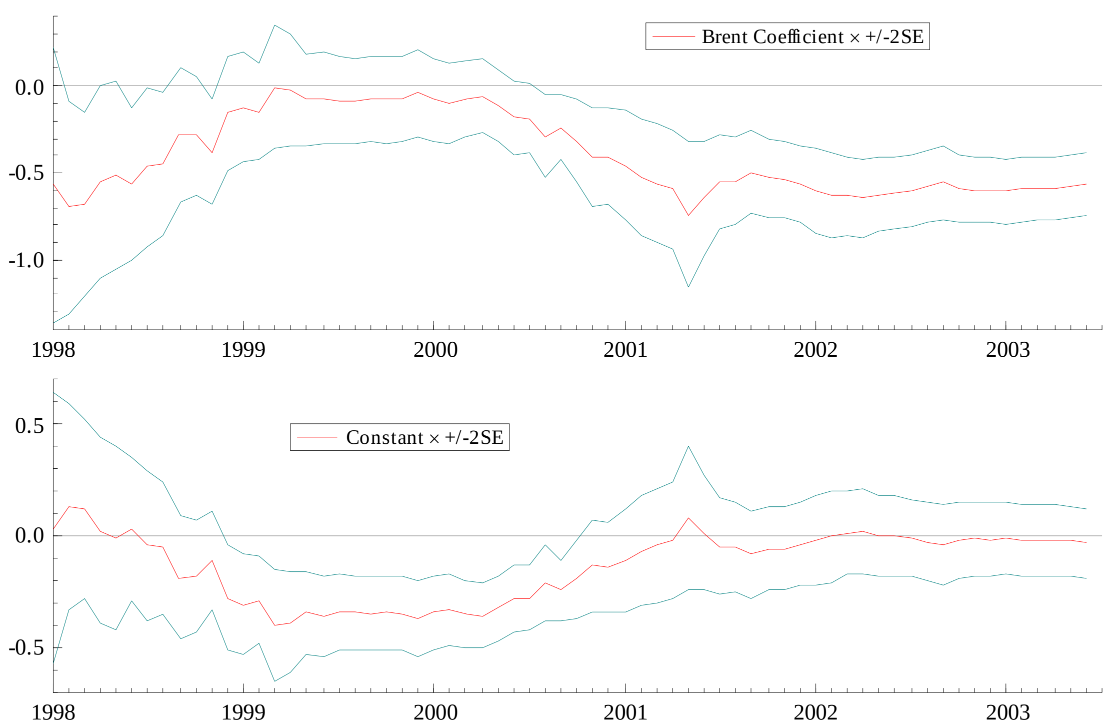


Figure 5: Recursive Trace test (LHeren – LBrent)

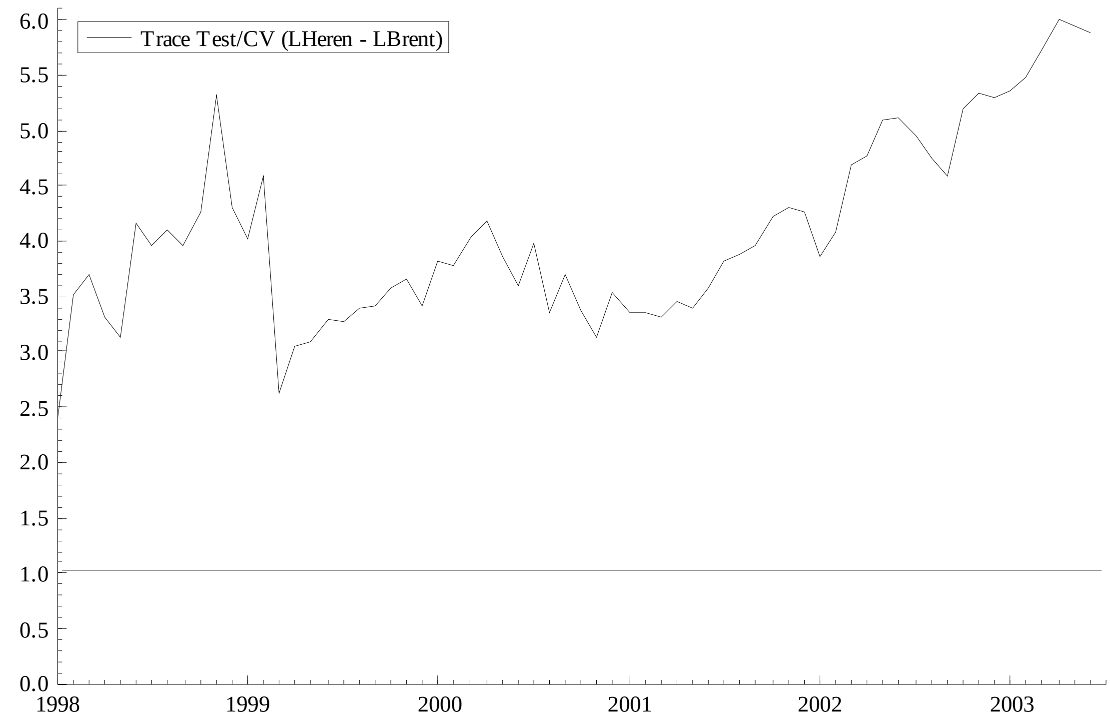


Figure 6: Recursive Beta Coefficients (LHeren - LBrent)

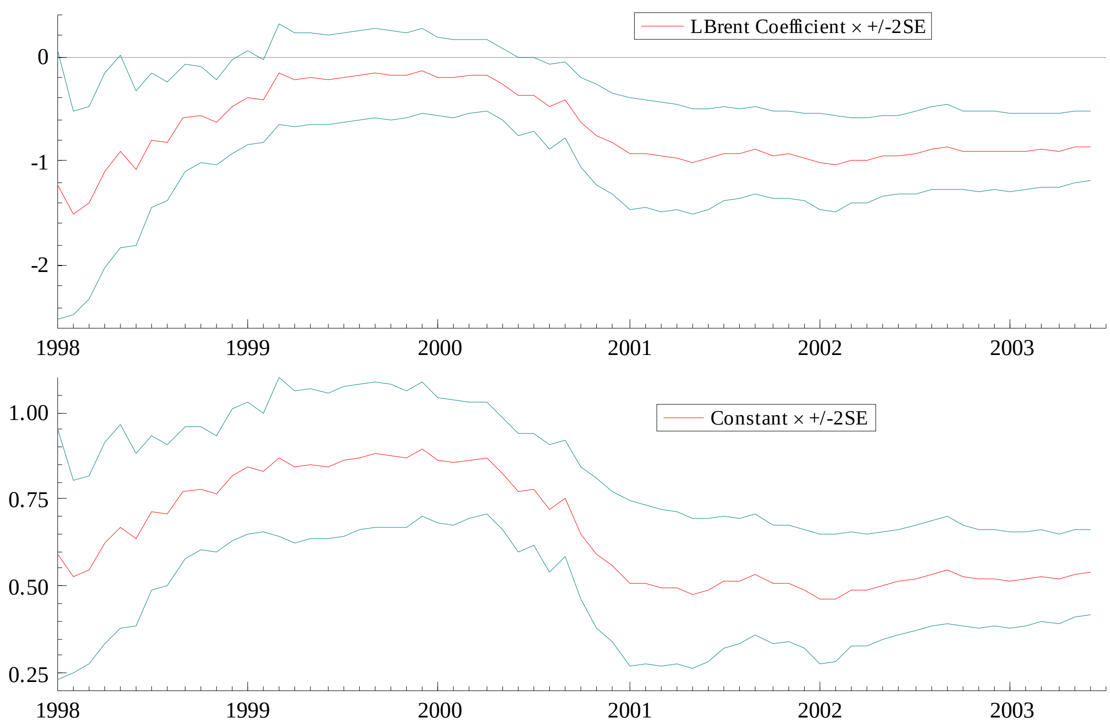


Figure 7: Impulse response Function (from Model 1). Response standard errors were calculated using 1000 Monte Carlo repetitions.

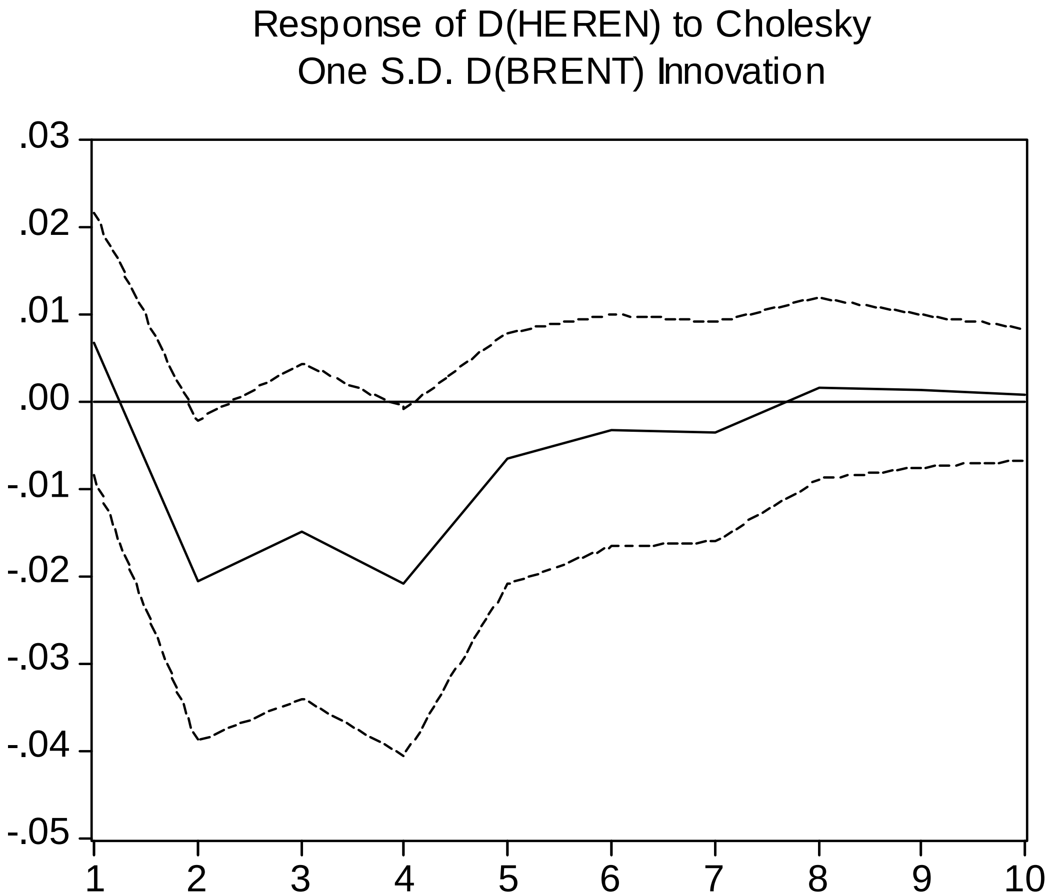


Figure 8 Impulse Response Function (from Model 2). Response standard errors were calculated using 1000 Monte Carlo repetitions.

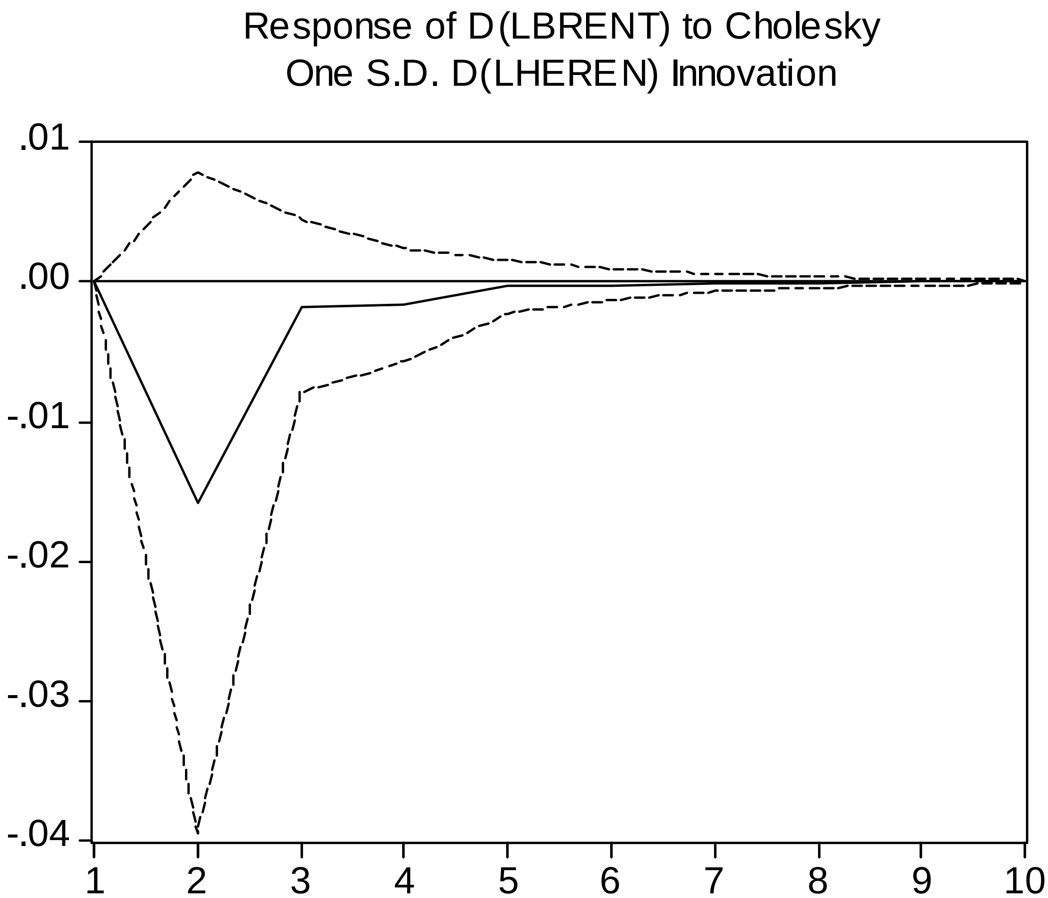


Table 1: Unit Root tests

	Sample		Levels		First Differences		Levels-Logs		First Differences-Logs	
			t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	Prob.*
Brent	1996:01-2003:6	ADF	-1.6102	0.4733	-12.9788	0.0001	-1.7962	0.3802	-11.8837	0.0001
		Breitung	0.0481	0.4000	0.0004	0.0000	0.0433	0.4000	0.0006	0.0000
		UR with Structural Break	-0.7447	Used Break Date		2000:12	-1.592	Used Break Date		1999:3
Heren	1996:01-2003:6	ADF	-0.7310	0.3972	-7.0174	0.0000	-2.7727	0.0660	-7.5093	0.0000
		Breitung	0.0419	0.2000	0.0005	0.0000	0.0446	0.3000	0.0006	0.0000
		UR with Structural Break	-2.1991	Used Break Date		2002:3	-2.4257	Used Break Date		1999:2
IPE	1997:01-2003:7	ADF	-1.9892	0.2910	-7.2432	0.0000	-2.4529	0.1311	-7.0196	0.0000
		Breitung	0.0430	0.9000	0.0007	0.0000	0.0482	0.4000	0.0008	0.0000
		UR with Structural Break	-2.0514	Used Break Date		2003:2	-2.0695	Used Break Date		2003:2
SAP	1997:12-2003:7	ADF	-2.3988	0.1462	-9.7133	0.0000	-0.8105	0.3610	-8.8628	0.0000
		Breitung	0.0234	0.5000	0.0002	0.0000	0.0285	0.3000	0.0003	0.0000
		UR with Structural Break	-1.4107	Used Break Date		2001:4	-1.5381	Used Break Date		2002:11
		CV (ADF & PP):		*1% level*	*-3.499167*	*5% level*	*-2.89155*	*10% level*	*-2.582846*	
		CV (Lanne et al. 2001):		*1% level*	*-3.48*	*5% level*	*-2.88*	*10% level*	*-2.58*	

Note: *MacKinnon (1996) one-sided p-values. ADF is the Augmented Dickey-Fuller test statistic, CV Critical Values, ADF Lag Length: (Decision based on Schwartz Info Criterion, MINLAG=0 MAXLAG=11), Breitung test is the nonparametric unit root test suggested by Breitung (2002), The *p*-value of the test is simulated on the basis of a Gaussian AR(*p*) model for $z(t)$-$z(t$-1), in batches of k replications. The errors are drawn from the normal distribution with zero mean and variances the squared OLS residuals (wild bootstrapping). Unit Root test (UR) with structural break is the unit root tests suggested by Saikonen and Lutkepohl (2002) and Lanne et al (2002).

Table 2: Testing for Cointegration

	H0: rank<=	Trace Test	[Prob]	Breitung Test	10%CV	5% CV	Simulated *p*-values	Data
1Heren-Brent	0	23.67	0.015**	454.66**	261	329.9	0.0154**	1996:1-2003:6
	1	2.2	0.737	18.06	67.89	95.6	0.5361	
2SAP-Brent	0	28.41	0.002***	330.06**	261	329.9	0.0487**	1997:12-2003:6
	1	4.06	0.415	16.63	67.89	95.6	0.5808	
3IPE-Brent	0	23.94	0.013**	396.15**	261	329.9	0.0251**	1997:1-2003:6
	1	2.08	0.759	15.11	67.89	95.6	0.654	
4LHeren-LBrent	0	22.55	0.022**	369.93**	261	329.9	0.0368**	1996:1-2003:6
	1	2.45	0.69	18.48	67.89	95.6	0.5265	
5LSAP-LBrent	0	26.07	0.006***	288.34*	261	329.9	0.0771*	1997:12-2003:6
	1	3.94	0.433	15.28	67.89	95.6	0.6411	
6LIPE-LBrent	0	19.98	0.053*	366.04**	261	329.9	0.0358**	1997:1-2003:6
	1	2.22	0.734	14.78	67.89	95.6	0.6568	

**, * denotes rejection at the 1%, and 5% significance level respectively (critical values from Doornik, 1998). Trace Test is the cointegration test proposed by Johansen (1995). Breitung test is the nonparametric cointegration test suggested by Breitung (2002). The simulated *p*-values are based on 10000 replications of Gaussian random walks with length n = 90.

Table 3: Long-run Cointegrating Equations (Johansen)

		Constant s.e.	Coefficient s.e.
(1)	*Heren= 0.033 + 0.567 Brent*	(0.078)	(0.089)
(2)	*SAP = 0.179 + 0.38 Brent*	(0.067)	(0.071)
(3)	*IPE = 0.07 + 0.54 Brent*	(0.064)	(0.07)
(4)	*LHeren = -0.542 + 0.855 LBrent*	(0.061)	(0.1698)
(5)	*LSAP = -0.61 + 0.592 LBrent*	(0.042772)	(0.11204)
(6)	*LIPE = -0.51 + 0.808 LBrent*	(0.047)	(0.12)

Table 4: VECM for Brent – Heren (Model 1)

	D(BRENT)	D(HEREN)
D(BRENT(-1))	-0.366263	-0.202569
	[-3.145]	[-2.849]
D(BRENT(-2))	-0.159369	-0.137813
	[-1.323]	[-1.874]
D(BRENT(-3))	0.136781	-0.175990
	[1.198]	[-2.524]
D(HEREN(-1))	-0.151838	0.386844
	[-0.941]	[3.926]
D(HEREN(-2))	0.029989	0.033838
	[0.173]	[0.320]
D(HEREN(-3))	0.271467	0.007904
	[1.600]	[0.076]
C	0.004508	0.003308
	[0.371]	[0.446]
CV1(-1)	-0.054633	-0.278945
	(0.09937)	(0.06067)
	[-0.550]	[-4.598]
R-squared	0.195086	0.317301
Adj. R-squared	0.125526	0.258302
S.E. equation	0.113984	0.069594
F-statistic	2.804560	5.378101
Log likelihood	71.18688	115.0975
Akaike AIC	-1.419930	-2.406685
Schwarz SC	-1.196232	-2.182987
Log likelihood		186.6995
Akaike information criterion		-3.835943
Schwarz criterion		-3.388548

Table 5 VECM for LBrent – LHeren (Model 2)

	D(LBRENT)	D(LHEREN)
D(LBRENT(-1))	-0.227250	-0.144515
	[-2.112]	[-1.249]
D(LHEREN(-1))	-0.120214	0.335327
	[-1.324]	[3.435]
C	0.006452	0.004084
	[0.494]	[0.291]
CV2(-1)	-0.014647	-0.211189
	(0.04810)	(0.05171)
	[-0.304]	[-4.084]
R-squared	0.074198	0.220152
Adj. R-squared	0.041523	0.192628
Sum sq. resids	1.287229	1.487766
S.E. equation	0.123060	0.132299
F-statistic	2.270777	7.998548
Log likelihood	62.22290	55.78002
Akaike AIC	-1.308380	-1.163596
Schwarz SC	-1.196531	-1.051747
Mean dependent	0.004942	0.005692
S.D. dependent	0.125698	0.147238
Determinant resid covariance (dof adj.)		0.000263
Determinant resid covariance		0.000240
Log likelihood		118.3787
Akaike information criterion		-2.480420
Schwarz criterion		-2.256722

Standard Errors in ( ) and t-statistics in [ ]
CV1 and CV2 are the error correction terms.

Table 6: Linearity Tests for the Residuals of Models 1 and 2
(only from the Heren and LHeren equations)

	ε_H (from Model 1)		ε_{LH} (from Model 2)	
	BOOTSTRAP	ASYMPTOTIC	BOOTSTRAP	ASYMPTOTIC
MCLEOD-LI TEST				
USING UP TO LAG 20	0.895	1.00	0.829	1.00
USING UP TO LAG 24	0.882	1.00	0.753	1.00
ENGLE TEST				
USING UP TO LAG 1	0.703	0.777	0.772	0.827
USING UP TO LAG 2	0.782	0.891	0.774	0.891
USING UP TO LAG 3	0.920	0.972	0.894	0.968
USING UP TO LAG 4	0.967	0.993	0.961	0.992
TSAY TEST	0.631	0.721	0.658	0.726
BDS				
Dimension				
2	0.1108	0.0649	0.3412	0.3031
3	0.1348	0.0942	0.4062	0.4004
4	0.1810	0.1477	0.6064	0.6783
5	0.1804	0.1523	0.7102	0.8391
6	0.2938	0.3109	0.6266	0.7477

Note: only *p*-values are reported