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Berlin, Dezember 2003

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www.diw.de

ISSN 1619-4535

International Market Integration for Natural Gas ? A Cointegration Analysis of Prices in Europe, North America and Japan

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Abstract

We examine the degree of natural gas market integration in Europe, North America and Japan, between the mid 1990's and 2002. The relationship between the international gas marker prices, and their relation to the oil price, are investigated through principal component analysis and Johansen likelihood-based procedures. Both of them show a high level of integration within the European/Japanese and North American markets; but they also show that the European resp. Japanese and the North American markets were not integrated.

Keywords: Market Integration, gas markets, cointegration test, globalization

JEL class.no.: C32,D43,L95,Q41

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1 Introduction

This paper analyzes whether the international natural gas markets were integrated in the last half decade (1997-2002). The paper is motivated by the most recent literature on the supposed integration of world natural gas markets (Cornot-Gandolphe, 2003; Deutsche Bank, 2003). This literature suggests that Liquefied Natural Gas (LNG) trade has led to an increasing integration of world gas markets. However, traditionally gas trade was limited regionally, due to a lack of pipeline infrastructure, and little availability of LNG transport capacity. One would therefore expect the absence of integration in international natural gas prices for the period under observation.

The paper fills a gap in the existing literature on the relationship between international gas prices. We apply both a principal component analysis and cointegration tests to price developments, in order to analyze the integration of the European, Japanese and North American markets for natural gas. We find evidence of integration within the regional European/Japanese and North American markets, but confirm our hypothesis of the absence of integration between the European/Japanese and the North American markets.

The paper is structured as follows: the next section surveys international market structures and the existing literature. Section 3 describes the price data, whereas Section 4 presents the approach to, and the results of the principal component analysis and the cointegration tests. Section 5 concludes.

2 International Market Structures

2.1 Development of International Natural Gas Markets

In all industrialized countries, natural gas deregulation is changing the structure of the natural gas markets. Having been regionally segmented until the nineties, they are now developing towards integrated global markets with new structures. Financial risks of gas import were absorbed by regional monopolies of transmission and/or distribution companies. Security of supply thus was provided but was paid for at relatively high prices to industry and households. Only recently, this situation is changing. [1]

There are today three main regional gas markets: OECD Europe, with Western Europe importing mainly from Norway, Russia and Algeria; North America, importing from Canada and Mexico; Japan and South Korea importing mainly from Indonesia, Australia, Malaysia and the Middle East. Each regional gas market is characterized by specific supply costs and conditions, gas demand patterns and the prevailing nature of competition.

2.1.1 Pricing Structure in Europe and Japan

Until now prices in the European countries may have still been determined by their linkage to the prices of alternative oil-based fuels. Most of the gas sold in Europe is based on long-term take-or-pay contracts. In these contracts, the buyer agrees to receive a certain volume of gas per year or, alternatively, to pay for the portion of gas it does not want to receive. The current price on gas delivered according to the long-term contract is determined by a price formula that links the current gas price to the price of relevant energy substitutes. Gas prices are thus set at such a level that the relation between gas prices and oil product prices does not give gas users any incentive to switch to the alternative fuel. With the so-called netback market value concept, the price for the gas producers is derived from the end user prices for the cheapest alternative fuel. Consequently, fluctuations in oil prices are passed on to the producers of the gas. These long-term contracts include the possibility of price renegotiation to adjust to the oil price every three to six months.

In the Asian market, 97% of the gas comes from LNG, and Japan alone imports over 50% of

[1] Governments in many parts of the world are liberalizing their gas industries by introducing gas-to-gas competition based on third-party access to gas supply infrastructure and/or by privatizing public gas utilities. Moves to liberalize gas markets generally started earlier and have been taken further in Canada, United States and United Kingdom. Gas market opening is currently underway in continental Europe.

the world production (Cayrade, 2003). As in the European countries, the Asia-Pacific LNG prices are typically indexed to crude oil prices, either in Japan or Indonesia, in some cases shaped with an *S curve* to limit the impact of extreme oil price movements (International Energy Agency, 2002).

2.1.2 Pricing Structure in North America and the United Kingdom

In North America, gas-to-gas competition has been developed, supply and demand are matched by market mechanisms, and the market is liquid and until now self-sufficient. The UK is in a similar position, with a fully liberalized, competitive and currently self-sufficient gas market (International Energy Agency, 2003). But even in such a situation, gas prices and oil product prices are still linked in some way. In the *longer* term, the availability and prices of oil substitutes in addition to the user's technical possibilities to change fuels will still co-determine gas prices. Even though there is no general contractual linkage in the American pricing structure, there is frequently some market linkage between oil product prices and the Henry Hub gas prices. And in the UK, the opening of the Interconnector in 2000 has linked the UK gas market with the continental wholesale gas price, dominated by the contractual linkage with oil.

2.1.3 The LNG Markets

Liquefied Natural Gas (LNG) represents 22% of the world's total cross-border gas trade, and markets for LNG are undergoing a substantial change at the moment (Jensen, 2003). Trade in LNG doubled in the past decade and there is a broad industry consensus that the coming years will experience strong growth, as demand is expected to double to approximately to 220-270 BCM per year by 2010 (International Energy Agency, 2002; Deutsche Bank, 2003).

There are three current markets: the Asian market, dominated by the high demand of Japan; the North American market; and the European market. In 2001, 71% of the world demand for LNG was concentrated in the Asia-Pacific region and 29% in the Atlantic basin alone (Cornot-Gandolphe, 2003). The common contract form for the LNG business is the LNG Sales and Purchasing Agreement (SPA). There are different pricing systems used in the three major market regions of Asia-Pacific, Europe and the USA. In the Asia-Pacific, LNG prices are indexed to crude oil prices. In Europe, LNG competes with pipeline gas and adopts similar formulae which are typically indexed to crude oil or oil products (gas oil and fuel oil) although there may also be elements of coal, electricity or inflation indexation. In the USA, gas prices are set by gas-to-gas competition, driven by supply and demand. LNG-delivered prices are typically based on Henry Hub gas prices plus or minus a locational differential reflecting the basis between the LNG delivery point and the Henry Hub. Until now there has been little physical interregional LNG trade between the three regional markets (Europe, North America and Asia).

2.2 Literature Survey

There are only a few studies on the integration of regional natural gas markets, and the linkages between the international gas markets have so far not been analyzed at all. Here we review the major studies on regional gas price integration that have used similar approaches to those of this paper.

2.2.1 Studies on North America

De Vany and Walls (1995) analyze the degree of integration of the North American gas market and the way price dynamics evolved as these markets were progressively embedded in a larger web of open pipelines and interconnected markets. Daily spot prices in six networks of six or nine pipeline interconnection points, across North America, partitioned into three one-year sub-samples (1987-1990), are investigated. Results show an increasing level of network connectedness as well as an increasing speed of shock absorption by the networks and thus a growing efficiency of arbitrage mechanisms. With the two-step Engle-Granger test for co-integration, spot prices are thus found to be increasingly co-integrated as open access to the pipelines expands through the network.

King and Cuc (1996) investigate the strength of spot price integration between various natural gas producing basins of North America, from the the mid 1980's untill the mid 1990's and with time varying parameter (Kalman Filter) and co-integration analysis. Bivariate cointegration tests (Engle-Granger procedure) results are qualitatively similar to De Vany and Walls (1995). Time varying parameter analysis results indicate that price convergence has been emerging in regional markets, but that an east-west split in natural gas pricing has also been emerging.

Serletis (1997), in a slightly different manner, test for shared stochastic trends in the North American markets in order to investigate the robustness of the results of King and Cuc (1996). Evidence concerning the shared stochastic trends in eight North American natural gas spot markets, using monthly data ($1990:06-1996:01$), is obtained by the Engle-Granger approach and the Johansen maximum likelihood approach. Prices within eastern and western areas are found to be driven by different stochastic trends. It contradicts the conclusion of King and Cuc (1996): arbitrages within these markets fail to discipline prices and there is no east-west split in the North American markets.

Serletis and Herbert (1999) investigate the dynamics of North American natural gas, fuel oil and power prices in the area of eastern Pennsylvania, New Jersey, Maryland and Delaware, using daily data ($1996:10-1997:11$) on the Henry Hub and Transco Zone 6 natural gas prices, the PJM (Pennsylvania, New-Jersey and Maryland) power market for electricity price and the fuel oil price for New York Harbor. Correlation between prices in log levels is first investigated and the stationary properties of the prices are analysed using the ADF test. The Engle-Granger bivariate cointegration test for the pairs of integrated series shows that each pair cointegrate, leading to the conclusion that the same underlying stochastic component affects the three markets.

2.2.2 Studies on the European Market

Little empirical work has been carried out with respect to the market integration for natural gas in Europe. Asche et al. (2002) examine whether the German market is integrated by investigating time series of Norwegian, Dutch and Russian Gas monthly export prices to Germany from January 1990 to December 1997. The Johansen multivariate procedure results show that gas from the three suppliers compete closely in the same markets since the prices move proportionally over time, but at different price levels. Asche et al. (2000) investigate the degree of market integration for France, Germany and Belgium in a similar way. Cointegration tests show that the different border prices for gas to France move proportionally over time and without any significant differences in mean. Furthermore, national markets in Germany, France and Belgium are found to be highly integrated.

3 Description of the Data Set

For the empirical analysis, we use standard international import prices from the major gas consuming regions of the world (Europe, USA, Japan). Import prices represent a weighted average based on all imports for which prices are available, hence there are no pipeline import prices for Japan, as all natural gas is being imported via LNG. European prices are the average of all Member States importing the commodity and merely give an indication of the average import cost rather than a precise and exact import price[2]. American import prices are derived calculating the average of nine countries exporting LNG and only two countries (Canada and Mexico) delivering pipeline gas. Monthly data in US$/MBTU is available since 1993. Japanese LNG import prices are derived in the same way by calculating the average of eight countries exporting LNG. To verify the close interaction of oil and gas prices, we furthermore include monthly average Brent crude oil spot prices. Monthly average crude oil prices are calculated from daily quotations and are quoted in US$/bbl thus converted into US$/MBTU using the standard conversion factor (1 bbl crude = 5.46 MBTU). The data described above was taken from several IEA publications "Energy Prices & Taxes" quarterly statistics. Since the liberalization of American gas markets encouraged the emergence of spot markets, the prices of the Henry Hub will be included in the analysis. Henry

[2]See the notes on definitions in International Energy Agency (2002) for details.

Hub is the largest of 39 trading hubs in the US connecting 13 pipelines. Monthly average spot prices are taken from the Oil & Gas Journal Energy Database and are quoted in US $/MBTU. We use LNG USA, LNG Europe and LNG Japan to denote the LNG import price in each; Pipe Europe and Pipe USA refer to the pipeline gas import price in each. Henry Hub represents the natural gas price traded in the Henry Hub, and Brent, the price of the Brent as defined above.

Figure 1 shows the prices of interest in log level, and Table 1 presents some descriptive statistics of the prices in level and log-level. Prices reflect extraordinary events such as the Gulf War (January 1991), the Californian Energy Crisis (late 2000) and the terrorist attack of September 11th 2001 (see Figure 1). The rise in world oil prices during 1999 and the sustained high level of oil product prices during 2000 and into 2001 has resulted in significant increases in most gas prices throughout the world. Moreover, American gas prices shot up at the end of 2000 because of record demand, less natural gas than usual in storage, some bottleneck problems at points in the system and high oil prices, but return to prior levels after only two months (see Eurogas Economic Study Task Force, 2001). European and Japanese natural gas prices do not reflect this peak as clearly.

4 Empirical Results

4.1 Stationary Properties of the Time Series

It is well known that most financial times series are not (covariance) stationary. Since the late 1980s and the seminal work of Engle and Granger (Engle and Granger, 1987), co-integration has emerged as a powerful framework for investigating shared trends in multivariate and non stationary time series, providing a set of procedures for modelling both long-run and short-run dynamics.

The first step in testing for shared stochastic trends is to test for stochastic trends (unit roots) in the autoregressive representation of each individual time series and thus to determine the degree of integration of each series. A series with no deterministic component which has a stationary, invertible ARMA representation after differencing d times, is said to be integrated of order d, denoted $I(d)$. To address the topic of the degree of integration, two unit root tests are used: the Augmented Dickey-Fuller test (t-ratio), denoted ADF and the Phillips-Perron test (t-ratio), denoted PP. Prices are used in log levels. For the ADF test, the lag length value is set to the order selected by the Akaike information criterion plus two (see Pantula et al., 1994). Most of the series seem not to be trending, except Pipe USA and Henry Hub, for which the absence of a linear trend is not so clear (Figure 1). The presence of a linear trend is thus tested for these two with the ϕ_3 statistic of Dickey-Fuller. Pipe USA and Henry Hub are not found to be trending (see L'Hégaret, 2003). We apply the two tests to data in level and then in first differences to test for the degree at which prices are stationary.

Table 2 presents the results of the two tests. All prices, in log level, are found $I(1)$ at the 5% level, except LNG Europe and LNG Japan. The ADF test may indicate that for LNG Europe and LNG Japan, the integration degree is more than one, but the PP test, as well as graphical considerations, indicate that these prices are $I(1)$. Consequently, all prices in log levels are assumed to be $I(1)$. In this case, we can use cointegration analysis. x_t, a N-dimensional process, is co-integrated if each component the process is $I(1)$ but there exists α, a N-dimensional vector, such that $\alpha' x_t \sim\ I(0)$. Each vector corresponding to a stationary linear combination is called a cointegrating vector and acts like a long-term relation in the system. Furthermore, r linearly independent cointegrating vectors are equivalent to have $N - r$ stochastic trends in the process (Engle and Granger, 1987). r, the dimension of the space spanned by the cointegrating vectors, is called the cointegration rank.

4.2 Principal Component Analysis

Co-movements and co-integration can be analyzed with Principal Component Analysis: examination of the empirical covariance matrix can give indications about the cointegration rank and the cointegrating vectors [3].

[3] See L'Hégaret (2003) for details on the link between Principal Component Analysis and Co-integration.

A principal component analysis is thus performed with the seven prices in log level for the largest period without missing values for the seven prices, $1997:04-2002:06$. Table 3 presents the results of the analysis. Examination of the stationary properties of the principal components [4] tends to prove that there are least two stochastic trends in the multivariate system. The fact that at least the two first eigenvalues of the empirical covariance matrix are non-null (see Table 3) confirms that point.

As a consequence, collinearity between the projections in the first factorial plane (spanned by the two first principal components) of two prices should be seen as a rule of thumb as a necessary condition for co-integration between those prices. In our analysis, the first component represents the usual *size effect* with variables which are all positively correlated. The second component is more interesting because it puts the stress on more differences between prices. The first factorial plane (see Figure 2) clearly shows two groups. The first one is LNG Europe, Pipe Europe and LNG Japan; the second one is Henry Hub and Pipe US. LNG US and Brent are not close to any group, but Brent is collinear to Group 1 and LNG US to Group 2, so that Brent could be expected to belong to Group 1 and LNG US to Group 2. As the third column of Table 3 (components of the third eigenvectors) shows, the third principal component underlines the link between Pipe US, Henry Hub but separates LNG USA from this group. For the third component, LNG Europe and Pipe Europe are very close, but Brent and LNG Japan are far from the European gas prices. As the stationary properties of the third principal component are more contestable than the two first ones, the results involving the third component are debatable.

The Principal Component Analysis suggests co-movements within the European/Japanese and the North American prices, but that the European/Japanese and North American markets are

[4] Let denote T the sample size, x_t the 7-dimensional log prices process, M_T the empirical covariance matrix divided by T, $\{f_{i,T},\ 1 \leq i \leq 7\}$ the eigenvectors of the empirical covariance matrix M_T, $\lambda_{i,T}$ its eigenvalues, with $\lambda_{1,T} \geq \lambda_{2,T} \geq \ldots \geq \lambda_{7,T} \geq 0$. Unit root tests, performed in the same way as in Section 4.1, applied to $x_t' f_{i,T}$, the *i-th* principal component, show clearly that at least the two first principal components are $I(1)$.

connected to a much lesser extent. This would support our hypothesis of a split prevailing between the European and the North American gas markets in the 1990's. We formally test this hypothesis using co-integration tests in the following section.

4.3 Cointegration Methodology: the Empirical Model Specification

Two different tests for cointegration are commonly used in the literature. They are the Engle and Granger test (Engle and Granger, 1987) and the Johansen test (Johansen, 1995). We here use the latter, since hypothesis testing on the the cointegration vectors is possible only in this framework. The Johansen tests are based on the eigenvalues of a stochastic matrix and in fact reduce to a canonical correlation problem similar to that of principal components. They are based on the Error Correction form of the multivariate system (VEC):

$$\Delta X_t = \Sigma_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Pi X_{t-k} + \mu + \epsilon_t.$$

When there exist r linearly independent co-integrating vectors, Π_k may be written $-\alpha\beta'$, where both α and β are $N \times r$ matrices with rank r. β contains the co-integrating vectors and α adjustment parameters and the Johansen procedure allows testing on coefficients α and β, using several likelihood ratio tests. A bivariate co-integration analysis is performed for each couple of variables in log level. Some groups of three or four variables are also studied with the Johansen test to check the coherence of the bivariate results. For each Johansen test, the following methodology is used [5].

Likelihood ratio tests are used to test for the significance of the lags in the unrestricted VAR in log level. As previously seen, no price is trending, so among the five deterministic trend cases considered by Johansen (1995), only two cases are considered. Let us denote as Model 2 the VEC model without linear trend and as Model 1, the VEC model without linear trend and without intercept in the cointegrating equation. The Johansen test is performed with the previous selected

[5] See L'Hégaret (2003) for details.

lag length for both models. By imposing the cointegration rank, a likelihood ratio test is performed to test whether Model 2 can be restricted to Model 1. The absence of autocorrelation in the estimated VEC residuals are tested as well as the normality of their empirical distribution. If there is strong evidence that the normality assumption is violated and/or whether there are outlier values for the co-integrating equation residuals, intervention dummies are used[6]. If the rank of cointegration is found to be equal to the number of prices in the system minus one, there is only one stochastic trend in the system and each pair of prices is cointegrated. In this case, the Law of One Price (LOP) is tested by testing the linear restriction on the co-integrating space *co-integrating vectors sum to zero* against the unrestricted VEC, given the rank of cointegration and with the previously selected model (see Asche et al., 2002). If the LOP holds, every relative price in the system of interest is constant in the long term. In the case where the cointegration rank is strictly less than the number of prices minus one, the exclusion of one price out of the co-integrating space can be tested in the same way, and if this is accepted, the excluded price is not linked in the long term with the other prices.

4.4 Cointegration Tests Results

4.4.1 Cointegration in the American Markets

The North American markets show an intense level of integration: evidence for co-integration is rather strong for LNG USA and the Henry Hub, as well as for LNG USA and Pipe USA (see Table 4). Surprisingly, the pair Henry Hub, Pipe USA is found to be co-integrated only at the 10%

[6] As we assume that no event could have caused a permanent shift in the prices, transitory blip dummies for the VEC - which corresponds to an impulse effect on the prices - are used following Hendry and Juselius (1999). The transitory blip dummy $Dxxyy$ is unity for $t = 19xx : yy$, -1 for $t = 19xx : yy + 1$ and zero otherwise. As the components of this dummy sum to zero, they do not not affect the Johansen test critical values. Dummies are chosen according to economic considerations (for instance, months of the Californian Energy Crisis) and examining the residual values in the same way as in Hendry and Juselius (1999).

level[7]. Therefore, without dummies, co-integration is found at the 5% level, which is an evidence of co-integration.

At the 5% level, the LOP is rejected for each pair, except for Henry Hub, Pipe USA. It may indicate that the relative prices for LNG USA and Henry Hub, as well as for LNG USA and Pipe USA are not constant in the long term, whereas they are for Henry Hub and Pipe USA[8]. This point may reflect the differences in the pricing structures: LNG USA is supposed to be *indexed* to pipeline spot prices (Henry Hub) whereas pipeline gas may be linked by efficient arbitrage mechanisms to Henry Hub. Notice that the first factorial plane results (see Figure 2) confirm this point: relative to the two first principal components, Henry Hub and Pipe USA are very close to each other whereas LNG USA is only collinear to them.

4.4.2 Cointegration in the European and Japanese Markets

The European and Japanese markets (LNG Japan, LNG Europe, Pipe Europe and Brent) are found to be integrated. Each pair of prices, with the exception of LNG Japan and Pipe Europe, are found to be cointegrated at the 1% level (see Table 4). Studying the group LNG Europe, LNG Japan and Pipe Europe, two relations are found at the 1% level, which may indicate that the link between LNG Japan and Pipe Europe is the weakest in this group of markets.

Moreover, the LOP holds in the group LNG Europe, LNG Japan, Pipe Europe, so that relative prices should be assumed to be constant in the long term. Bivariate tests of the LOP between LNG Europe, LNG Japan and Pipe Europe confirm this point: the LOP is accepted for each pair, except LNG Europe and Pipe Europe, but for this pair the cointegration vector is very close to $(1, -1)$ (see Table 5).

In addition, the LOP is rejected for the group Brent, LNG Japan, LNG Europe and Pipe Europe. Bivariate tests for the LOP, with the pairs formed by Brent and prices among LNG

[7] The Null hypothesis of no co-integration is accepted at the 5% level but rejected at the 10% level.

[8] See Asche et al. (2002) for more details on this interpretation.

Europe, LNG Japan and Pipe Europe, confirm this point by showing that the LOP does not hold between Brent and natural gas prices in Europe/Japan (see Table 5). As for the American market, the first factorial plane confirms these results. On the one hand, LNG Europe, LNG Japan and Pipe Europe are very close to each other - they share the same stochastic trend - and within them, the LOP holds. On the other hand, Brent is only collinear to the group: Brent shares the same stochastic trend, thus each price is linked to it in the long term, but the relative prices of LNG Europe, LNG Japan and Pipe Europe to the Brent are not constant in the long term. (LNG Japan, Brent) is the pair for which the LOP is the most clearly rejected, which may be due to the fact that the indexation of the LNG in Japanese long-term contracts does not have a linear shape, but might have the shape of an *S curve*.

4.4.3 Cointegration between the European, Japanese and North-American Markets

The previous results have shown clearly two groups in which cointegration is found between prices. Among the twelve pairs of prices of these two groups, eight are clearly non-cointegrated. For the four other pairs (LNG Europe and Henry Hub, LNG Europe and Pipe USA, Brent and LNG USA, Henry Hub and LNG Japan), whether there is cointegration or not depends on the model. Consequently, the likelihood ratio test for the model selection is not well-fitted and the model selection is ambiguous (see Table 3).

Consequently, systems of three prices are investigated. These groups are made of two prices, which are found to be strongly cointegrated in the bivariate framework and are in the same market (European/Japanese or American), and by a *third* price, not in this market. Table 6 reports the Johansen test results. In each group, only one cointegrating relation is found at the 5% level with each model [9]. Furthermore, the exclusion of the *third* price is, in four groups, clearly accepted. As a consequence, it can be assumed that no combined pair of prices is cointegrated and that the

[9] For LNG Europe, LNG USA, Pipe USA, the model 1 indicates no cointegration. This result contradicts the clear cointegration between LNG USA and Pipe USA, so that it is not taken into account and the model 2 is used.

European and Japanese markets are disconnected in the long-term with the North American one.

But notice that our results are not so clear for each group, for instance LNG Europe, LNG USA and LNG Japan. Johansen test results for this group are reported in Table 6. As expected, one cointegrating relation is found, but the exclusion of LNG USA of the cointegrating space is rejected at the 5% level. However, it is accepted at the 1% level. Examination of the estimated cointegration relation is instructive: the proximity to zero of the LNG USA component [10] may only suggest that LNG USA does not appear in the long-term relation between LNG Japan and LNG Europe.

5 Conclusion

This paper has explored the behavior of European, Japanese and North American gas prices and their interrelations, from the mid-1990s until the beginning of this decade. The principal component analysis has shown co-movements within the European/Japanese and the North American prices. The Johansen test procedure has confirmed this result through evidence of cointegration within the European/Japanese and the North American markets as well as the absence of integration between the two groups of markets. This result converges with the conventional wisdom that gas markets were not integrated across continents, and in particular the divide between the European and the North American gas markets during the 1990s.

In concluding, let us mention that this situation might be changing now. Not only traders but also researchers and industry are increasingly citing facts that point towards intensified repercussions between the three formerly segmented regional markets in Europe, North America, and Asia (Cornot-Gandolphe, 2003; Deutsche Bank, 2003; Jensen, 2003). An interesting hypothesis to study further would be an increasing integration of natural gas prices, in particular between Europe and

[10] The estimated cointegrating vector for LNG Japan, LNG Europe, LNG USA, with normalization of its first component is (1,-1.11,0.21), with 0.09 and 0.08 as standard errors for the second, respectively third component.

North America.

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Table 1: Descriptive Statistics

Variable	N. of obs.	Period	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
Brent Level	156	90:01-02:12	3.68	0.96	1.80	6.63	0.72	3.31
Log			1.27	0.26	0.59	1.89	0.02	2.95
Pipe Europe Level	127	92:01-02:07	2.65	0.44	1.68	3.9	0.47	3.83
Log			0.96	0.17	0.52	1.36	-0.18	3.71
LNG Japan Level	127	92:09-02:09	3.74	0.59	2.74	5.12	0.48	2.51
Log			1.31	0.15	1.01	1.63	0.17	2.42
Pipe USA Level	114	93:01-02:06	2.43	1.22	1.34	9.45	3.00	14.25
Log			0.81	0.36	0.29	2.25	1.49	5.54
Henry Hub Level	109	93:11-02:11	2.73	1.24	1.42	8.50	2.31	9.93
Log			0.93	0.37	0.35	2.14	0.97	3.94
LNG USA Level	104	96:07-02:06	2.80	0.78	1.77	6.41	2.05	8.76
Log			1.00	0.24	0.57	1.86	1.01	4.65
LNG Europe Level	64	97:04-02:07	2.84	0.63	1.8	4.1	0.15	2.27
Log			1.02	0.23	0.59	1.41	-0.25	2.24

Table 2: Unit Root tests

Market	Log Levels		First differenced of log levels	
	ADF	PP	ADF	PP
Brent	-1.88	-1.91	-3.85***	-9.55***
LNG US	-1.75	-2.65*	-5.47***	-13.44***
LNG Europe	-1.45	-1.10	-2.31	-6.21 ***
Pipe Europe	-2.06	-1.74	-4.08***	-10.00***
LNG Japan	-2.17	-1.63	-2.86*	-9.57***
Henry Hub	-2.07	-2.22	-4.10***	-8.50***
Pipe US	-1.94	-1.91	-5.74***	-9.55***

Note: Tests for prices in level use a constant but not a time trend. Tests for first differences are performed with neither intercept nor linear trend. An asterisk indicates significance at the 10% level, two asterisks show significance at the 5% level and three asterisks, significance at the 1% level.

Table 3: Principal Component Analysis of Brent, Pipe Europe, LNG Europe, Henry Hub, LNG Japan, LNG US and Pipe US, from 1997:04 to 2002:06

Covariance Matrix of the log levels							
	Comp.1	Comp.2	Comp.3	Comp.4	Comp.5	Comp.6	Comp.7
Eigenvalue	0.48	0.05	0.04	0.01	0.00	0.00	0.00
Var. Prop.	0.81	0.09	0.07	0.02	0.01	0.00	0.00
Cumul. Prop.	0.81	0.90	0.97	0.99	1.00	1.00	1.00
Eigenvectors							
Variable	Vector 1	Vector 2	Vector 3	Vector 4	Vector 5	Vector 6	Vector 7
LNG US	0.31	0.26	0.30	0.65	-0.55	-0.13	0.00
Pipe US	0.54	0.44	-0.10	0.20	0.68	0.08	-0.05
HHub	0.50	0.32	-0.18	-0.65	-0.42	-0.06	0.10
Brent	0.40	-0.57	-0.58	0.25	-0.15	0.30	-0.12
LNG Europe	0.28	-0.30	0.46	-0.20	0.06	-0.14	-0.74
LNG Japan	0.25	-0.38	0.03	0.02	0.17	-0.76	0.42
Pipe Europe	0.26	-0.28	0.56	-0.11	0.06	0.53	0.49

Table 4: Bivariate Johansen Test Results

	Henry Hub	Pipe USA	LNG USA	LNG Europe	Brent	LNG Japan
Pipe USA	11.25* **18.07*** 4.44**					
LNG USA	16.44*** **27.75***** 7.75***	14.60** **38.42***** 19.58***				
LNG Europe	15.05** 17.69 0.30	12.75** 15.86 0.12	7.54 9.97			
Brent	6.23 12.99	5.36 9.13	13.93** 16.57 0.64	**30.23***** 33.89*** 0.30		
LNG Japan	7.64 18.37* 5.83**	3.84 13.25	8.21 14.12	26.02*** **42.60***** 12.28***	14.50** **59.37***** 41.1***	
Pipe Europe	8.46 13.37	7.37 10.88	7.04 10.19	**16.88***** 21.00** 1.74	**26.73***** 34.45*** 0.02	10.26 19.60* 2.93*

Note: For each pair of prices, the first/second number is the trace statistic for the Null hypothesis of no cointegration in Model 1/Model 2. If one or two of these values are found to be significant, the likelihood ratio to test if Model 2 could be restricted to Model 1, given a cointegration rank of one, is reported as a third number. With this statistic, Model 1 or Model 2 is selected (trace statistics are in bold for the selected model row). For each pair, the period used is the longest with available data for both prices. If found necessary, dummies are used. An asterisk indicates significance at the 10% level, two asterisks significance at the 5% level and three asterisks significance at the 1% level. Johansen test critical values are those from Osterwald-Lenum (1992). The likelihood ratio statistic is distributed as a χ^2 with one degree of freedom.

Table 5: Estimated Cointegrated Vector and Law of One Price

Pair	LOP L.R.	Coint. Vector
Brent, LNG Japan	39.2***	1, -1.51 (0.04)
Brent, Pipe Europe	20.32***	1, -1.28 (0.03)
LNG Europe, Brent	23.25***	1,-0.80 (0.02)
LNG Europe, Pipe Europe	10.38***	1,-1.04 (0.01)
LNG Europe, LNG Japan	1.65	1,-1.08 (0.07)
LNG Japan, Pipe Europe	0.39	1,-0.87 (0.14)
Henry Hub, Pipe USA	2.97*	1,-0.85 (0.07)
Henry Hub, LNG USA	6.66***	1,-0.67 (0.07)
LNG USA, Pipe USA	16.21***	1,-0.59 (0.05)

Note: For each pair of prices, the first number is the likelihood ratio statistic to test if the cointegrating vector is summing to zero, given one cointegration relation. It is distributed as a χ^2 with one degree of freedom. The second column reports the estimated cointegrating vector with the Likelihood-based approach of Johansen. The vector is normalized by the non-restrictive condition that its first component is one. Standard error is reported below the second component. An asterisk indicates significance at the 10% level, two asterisks significance at the 5% level and three asterisks significance at the 1% level.

Table 6: Multivariate Johansen Test Results

Group	Trace Statistic		Likelihood Ratio Statistic	
	$r = 0$	$r \leq 1$	Model 1/ model 2	Price out of the coint. space
LNG Japan, Brent, Henry Hub	24.19**	5.83	33.12***	Henry Hub
	65.68****	**14.21**		0.08
LNG Europe, LNG USA, Henry Hub	36.00***	12.00*	14.52***	LNG Europe
	52.13****	**13.60**		0.50
LNG Europe, LNG USA, Pipe USA	21.00	7.96	15.7***	LNG Europe
	42.04****	**13.32**		0.48
Brent, LNG Europe, LNG USA	**37.46******	**8.37**	0.12	LNG USA
	41.32***	12.01		0.00
LNG Europe, LNG Japan, LNG USA	39.80***	9.29	14.96***	LNG USA
	58.03****	**13.57**		4.67**

Note: For each group, the trace statistics in Model 1/Model 2 are reported at the beginning of the first/second row. r is the cointegration rank. For each group, two likelihood ratio statistics are reported. The first one is the likelihood ratio to test if Model 2 could be restricted to Model 1, given a cointegration rank of one. With this statistic, Model 1 or Model 2 is selected (trace statistics are in bold for the selected model row). The second one is the likelihood ratio statistic to test if one price can be eliminated for the cointegration space in the model previously selected. An asterisk indicates significance at the 10% level, two asterisks significance at the 5% level and three asterisks significance at the 1% level. Johansen test critical values are from Osterwald-Lenum (1992). The likelihood ratio statistic is distributed as a χ^2 with one degree of freedom.

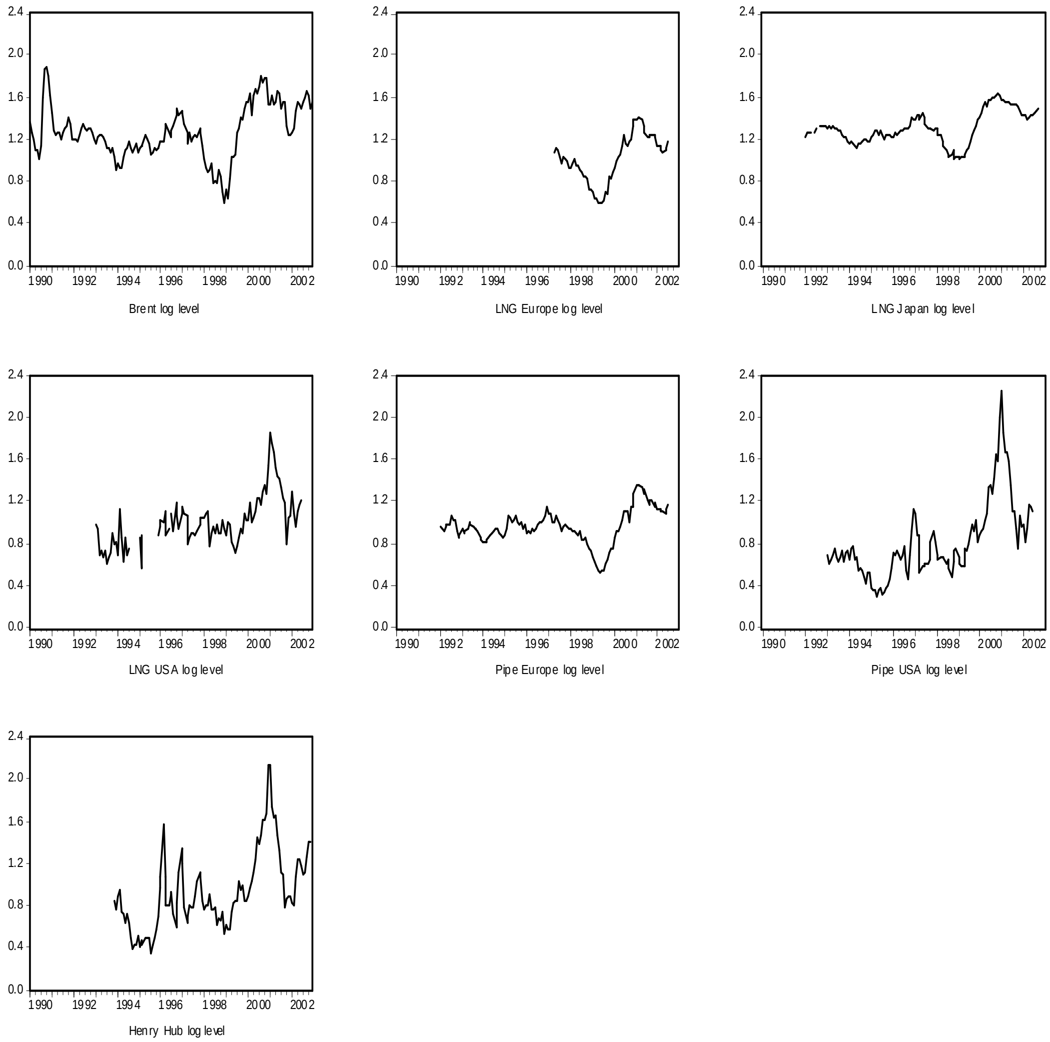

Figure 1: Prices in log level

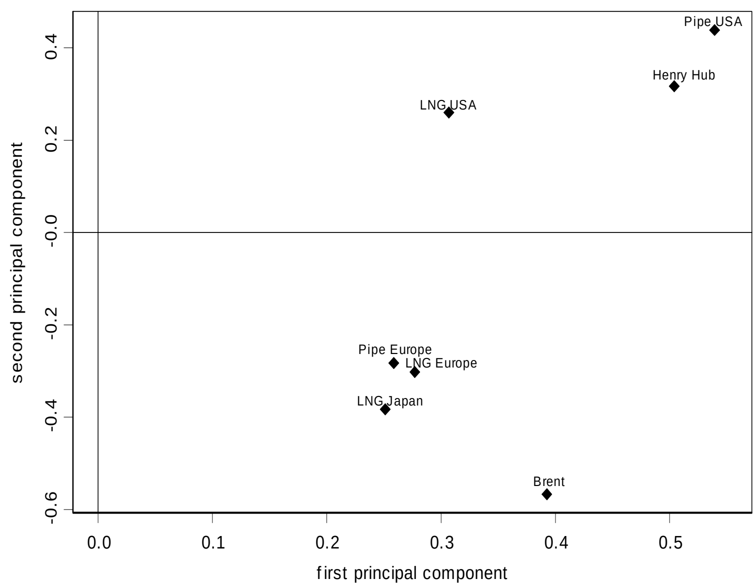

Figure 2: First Factorial Plane (Principal Component Analysis), 1997:04-2002:07