Further evidence on the debate of oil-gas price decoupling: A long memory approach

Dayong Zhang\textsuperscript{a}, Qiang Ji\textsuperscript{b,c,*}

\textsuperscript{a} Research Institute of Economics and Management, Southwestern University of Finance and Economics, China
\textsuperscript{b} Center for Energy and Environmental Policy Research, Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China
\textsuperscript{c} School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China

\textbf{A B S T R A C T}

The long-run oil–gas price relationship has been challenged more often in recent years, as these two prices have shown evidence of decoupling from each other. This paper proposes the use of a long-memory approach and a rolling-windows method to model the time-varying oil–gas price relationship in three markets, namely, the United States, Europe and Japan. The results extend existing research conclusions on the oil–gas price relationship and answer the question of whether it is a temporary phenomenon or a permanent market change. Our findings indicate that the US oil–gas relationship remains nonstationary at almost all windows and illustrate strong evidence of decoupling. Conversely, the European and Asian oil–gas prices exhibit temporary decoupling over time, although the overall relationship still favours the oil-indexation hypothesis. The US experience suggests that oil and gas do not share the same fundamentals and a pricing hub can better reflect the true value of natural gas. Policy makers in Europe and Asia should reinforce their efforts towards a market based pricing mechanism for gas.

\textbf{1. Introduction}

Since the North American shale gas revolution, the role of natural gas has become more important in the global economy, with ever-increasing impacts on international energy markets. Major consumers of natural gas have increased their demand for natural gas, for example, Japan after the Fukushima accident, and China with the burgeoning natural gas have increased their demand for natural gas, for example, Japan after the Fukushima accident, and China with the burgeoning natural gas have increased their demand for natural gas. Policy makers in Europe and Asia should reinforce their efforts towards a market based pricing mechanism for gas.

For many years, natural gas prices have generally been indexed to crude oil prices, often referred to as oil indexation. Even today, most natural gas trades in Europe and the Asia-Pacific region are priced through oil indexation (Ji et al., 2014; Asche et al., 2017). According to the International Gas Union (International Gas Union (IGU), 2016), 83.7% of Asia's total natural gas imports in 2015 were oil indexed. However, oil indexation has started to lose its foundation in the face of dramatic changes in the global energy market (Stern, 2014; Shi and Variam, 2016). Shi and Variam (2017) investigate the influence of oil indexation on economic behaviour in the East Asian gas sector and they suggest that the transition of pricing mechanisms from oil indexation to hub pricing should be advanced and claim that "the market failures due to exogenously pricing demonstrates the need for hub pricing". In recent years, there have been extensive investigations into whether these two prices are decoupled (e.g. Hartley et al., 2008; Erdős, 2012). There is also a heated debate in the literature on whether oil indexation is the best solution for the natural gas market (Komlev, 2016) or whether to establish pricing hubs to better reflect the fundamentals in natural gas itself (Stern, 2014).

In order to contribute to the debate and provide evidence of the oil–gas price link, it is important to further investigate the dynamic relationship between oil and natural gas prices. This paper adopts a long-memory approach, which extends existing empirical strategies by introducing a more flexible technique to model the time-series behaviour of oil and natural gas prices. A rolling-windows method is also used to enable us to show the time-varying possibility of the oil–gas relationship. Another major contribution of this paper is the use of a cross-market comparison to acknowledge the fundamental differences between natural gas markets around the world.

Unlike crude oil, which has a global market, natural gas markets are...
geographically segmented into three distinct regional markets: North America, Europe and Asia (Geng et al., 2014, 2016a). Pricing mechanisms differ significantly across these three markets and they all face substantially different demand side factors. The North American market has switched over to gas-to-gas competition pricing for a long time. The European market has been in the process of shifting to market-based pricing, while the Asian market is mostly priced according to oil indexation.

In addition, energy mix in these three regions has distinctive differentiaation (BP, 2017). In 2016, the share of oil and gas in the total primary energy in the North America is 37.5% and 31.8%, respectively. Gas production in the US has increased quickly since 2008 due to the shale gas revolution and caused a downward pressure on gas prices. However, decreased gas prices has raised its comparative advantage over oil in the US and also eliminated the need of import gas, which further changed the relationship between oil and gas (Geng et al., 2016a; Caporin and Fontini, 2017). In the Europe & Eurasia region, gas has become the largest energy source with a 32.3% share, whereas the share of oil is only 30.9%. In the Asia Pacific region, coal and oil still dominate the energy mix with market share of 49.4% and 27.9%, respectively. The share of gas is much lower than the other two markets with a merely 11.7%. These characteristics have led to a series of studies investigating whether there is a separation between oil and gas prices across regions (Erdös, 2012; Geng et al., 2016b; Ogland et al., 2015).

Technically, oil indexation can be interpreted as a long-term equilibrium relationship. In other words, oil and natural gas prices should be cointegrated or should follow an error-correction model. Either price can move away from the equilibrium (if it exists) due to external shocks, but the deviation should not persist. In other words, an error-correction mechanism will retrain the equilibrium in the long run. Some earlier studies, such as those of Asche et al. (2006) and Brown and Yücel (2008), have found supporting evidence of the long-term relationship; however, more recent research has concluded that the cointegration relationship is weak and has even disappeared (Ramberg and Parsons, 2012; Batten et al., 2017).

The inconclusiveness of existing studies is not overly surprising since markets have become more complicated in the twenty-first century. The 2008 global financial crisis brought significant changes in international energy markets. Moreover, financial markets have been shown to be more influential in energy prices, and the energy market has become more financialised (Creti and Nguyen, 2015; Zhang, 2017). Oil and gas prices have been found to include more information from financial markets than from their own fundamentals. This means that supply and demand fundamentals can no longer fully explain the market price volatilities and that there are more new driving factors affecting the market trading behaviour (Ji and Guo, 2015).

Another explanation for the inconsistent findings regarding the oil–gas relationship revolves around methodological issues. The majority of existing empirical studies have established an error-correction model, either with a constant cointegrating relationship (e.g. Panagiotidis and Rutledge, 2007) or allowing multiple regimes (Brígida, 2014) in the relationship. One of the common features of these models is their assumption of either confirming or refuting the long-term relationship. Zhang et al. (2015) criticise such models as being overly restrictive, suggesting that a more flexible model is needed to gain a better understanding of the underlying mechanism behind the data. A fractional integrated approach should be used to capture the possible long-range dependence. One more methodological issue is that the relationship may be time varying. It would be interesting to know whether a particular pattern of the oil–gas relationship is only a temporary phenomenon or has permanent effects. This imposes a major concern for the major gas importers of the European and Asia Pacific regions and especially relevant to the existing debates on oil-indexation versus hub pricing mechanism. Therefore, it is necessary to allow the underlying relationship to change over time.

To address the aforementioned methodological issues and complement the findings of existing studies, this paper makes at least two major contributions. First, it uses a long-memory approach (technically equivalent to the fractional integrated model) and a rolling-windows estimation method. The first approach allows flexibility, whereas the second makes it possible to show the time-varying relationship between oil and gas prices. Noteworthy, the dynamics between oil and gas prices are modelled to provide further evidence of the issue of whether the oil–gas relationship is temporary or permanent. Second, a cross-market comparison is undertaken to address the regional characteristics of the natural gas market. The data from the three main gas markets are used to cover a market with pure hub pricing system (the US), a mixture of hub pricing and oil indexation (Europe) and also a major oil indexation regime (Japan). The empirical results provide further insights to the understanding of a dynamic relationship between oil and natural gas and have important implications for policymakers in natural gas-importing countries as well as for the portfolio strategies of market investors.

The remainder of this paper is organised as follows: Section 2 summarises the previous literature on the topic. Section 3 briefly describes the long-memory model and the estimation techniques used in the paper. Section 4 discusses the price data. Section 5 reports and explains the empirical results. Finally, Section 6 concludes and discusses with policy implications.

2. Literature review

Earlier studies have supported the long-term cointegration relationship between oil and gas prices. For example, Villar and Joutz (2006) study the relationship between the Henry Hub natural gas prices and the WTI crude oil prices. Their empirical results support the long-term equilibrium between these two prices. Brown and Yücel (2008) also find a stable and long-term oil–gas price relationship in the US, especially when market fundamentals are included. Hartley et al. (2008) also confirm the long-term relationship between oil and gas prices in the US and find that the short-term disequilibrium are mainly influenced by weather, inventories and other seasonal factors.

Compared to the highly regulated European continental energy market, the UK natural gas market has been liberalised, with the National Balancing Point natural gas-trading hub being founded in 1994. Asche et al. (2006) use a vector error-correction model to the UK data and support a single energy market in the UK and they find that the Brent crude oil price is exogenous and represents the leading price. Panagiotidis and Rutledge (2007) confirm a similar cointegration relationship. Asche et al. (2017) find that the UK natural gas prices and the Brent prices are cointegrated for the majority of the sample from 1997 to 2014 with a regime switching framework. Gas prices tend to decouple during the fall and early winter when gas-specific pricing becomes dominant due to the increased demand for heating.

Several studies have investigated the impact of the shale gas revolution on the oil–gas relationship (Wakamatsu and Aruga, 2013; Caporin and Fontini, 2017; Geng et al., 2016a). Atil et al. (2014) show that oil prices lead natural gas prices using a nonlinear autoregressive distributed lags model. Ji et al. (2014) find that the global economic condition is the primary contributing factor to natural gas prices in North America, while the prices in Asia and Europe are still driven mainly by oil prices.

The equilibrium relationship between oil and gas prices has recently been challenged. Erdös (2012) finds that both the UK and the US had a long-term oil–gas price equilibrium before 2009 but that the relationship broke in the US around January 2009. Erdös (2012) also raises the question of whether this decoupling from oil indexation is permanent. Ramberg and Parsons (2012) confirm that the cointegration relationship between oil and gas prices is not constant and can shift dramatically over time. Brígida (2014) explicitly models the possible time-varying cointegration between natural gas and oil prices via a regime-
switching model. While these two prices are still cointegrated, a temporary shift in the relationship was found in the early 2000s.

In a cross market study, Lin and Li (2015) confirm the decoupling relationship in the US but support the cointegration hypothesis in Europe and Japan. Batten et al. (2017) investigate the time-varying price spillovers between natural gas and crude oil and conclude that since 2006, there have been few price dependencies between them.

It is clear that the recent literature shows an increasing interest in modelling the oil-gas price relationship or testing for the decoupling hypothesis between oil and gas prices. The research results are quite different from one another, depending on the market studied or the empirical methodology used. More evidence has been found to be against the oil-indexation hypothesis, although it is unclear whether this decoupling is permanent or temporary. New methods, such as nonlinear and regime-switching models, have been introduced to reflect the complexity of the pricing mechanism. Unfortunately, these models are still subject to the standard cointegration/noncointegration dichotomy. This paper thus aims to extend the existing literature with a long-memory approach (which allows for greater flexibility) and intends to add information to the existing debate on the oil-gas price nexus.

3. Methodology

The long-memory model was first introduced by Hurst (1951) in hydrology to determine the optimal dam size for the Nile River. It was observed that the river's flood and drought conditions tended to last for long periods of time and that heavy flood years tended to be followed by heavier flood years. The Hurst exponent, or Hurst coefficient, is often used to measure the long-term memory of time series. Since the 1980s, the long-memory model has been extended to study economic and finance issues. It has become a useful econometric tool for modelling time-series data (Lo, 1991).

Analogic to the standard time-series econometric terminology, long-memory or long-range dependence is defined by the persistence of autocorrelations. In a typical stationary ARMA model, autocorrelations decay geometrically over time, whereas the decaying process for a long-memory model is much slower (see, e.g., Lo, 1991). Hosking (1981) presents a more intuitive yet technically equivalent interpretation of the long-memory model for time-series $y_t$, with $t = \{1, \ldots, T\}$:

$$
(1 - L)y_t = u_t; \quad u_t \sim \text{iid}(0, \sigma^2),
$$

(1)

where $L$ represents the lag operator, and $u_t$ is a standard white noise process with a zero mean and constant variance $\sigma^2$. The difference polynomial can be written as:

$$
(1 - L)^d = \sum_{j = 0}^{\infty} \Gamma(j - d) \Gamma(j + 1) L^j = \sum_{j = 0}^{\infty} (-1)^j \binom{d}{j} L^j,
$$

(2)

with

$$
\binom{d}{j} = \frac{d(d-1)(d-2)-\cdots-(d-j+1)}{j!}.
$$

Typically, in a time-series model, a nonstationary process (with one unit root) is integrated at order one (I(1)), whereas I(0) relates to the stationary process. This dichotomy may be overly restrictive. In the long-memory model, however, a flexible setup is possible. For example, in Eq. (1), when $d = 1$, $y_t$ has a unit root; when $d = 0$, $y_t$ is the stationary white noise process. The order of integration ($d$) in this model is allowed to be a non-integer value, thus providing much greater flexibility. Specifically, for $0 < d < 0.5$, $y_t$ is stationary but has a long memory. However, if $0.5 < d < 1$, the process is covariance nonstationary, but unlike the I(1) process, it is mean-reverting, which means that a shock will have no permanent effect.

The techniques used to identify long-memory processes are well developed in the literature, for example, the ‘rescaled range’ or the ‘R/S’ statistic by Hurst (1951) and Mandelbrot and Wallis (1969) was the first technique used to test for the long-memory process. Geweke and Porter-Hudak (1983) propose an estimator of $d$ based on the ordinary least squares (OLS) method (hereafter the GPH approach) in the frequency domain. They assume that the first $m$ normalised periodogram ordinates in $\{f(\lambda_j)\}_{j=1}^m$ are identically independently distributed (i.i.d.), where $f(\lambda_j)$ is defined as the spectral density function, and $\lambda_j = 2\pi j/T$ denotes the frequencies.

A simple linear regression is proposed to estimate the order $d$:

$$
\ln[I(\lambda_j)] = \alpha - d \ln[4 \sin^2(\lambda_j/2)] + \varepsilon_j,
$$

(4)

where $\varepsilon_j = c + \ln[I(\lambda_j)]/f(\lambda_j)_{j=1}^m \sim \text{iid}(-c, \pi^2/6)$, and $c = 0.577216$.

The GPH approach is simple and has been widely employed. However, Banerjee and Urga (2005) show that it has noticeable limits. This has been further discussed by Robinson (1995), who proposes a semiparametric Gaussian estimator for the order of $d$ as an alternative. The new method is known as the local Whittle (LW) estimator. It is not defined in a closed form but has better properties than the GPH. For example, it is asymptotically more efficient and contains much weaker assumptions on Gaussianity. The frequency domain Gaussian likelihood in the vicinity of the origin is:

$$
Q_m(G, d) = m^{-1} \sum_{j=1}^m \ln[G(\lambda_j^2)] + \frac{\lambda_j^{2d}}{G} F(\lambda_j),
$$

(5)

where $m < T$ is an integer that controls the number of frequencies included in the local likelihood. Estimates of $G$ and $d$ are then obtained through the minimisation of $Q_m(G, d)$. Shimotsu and Phillips (2006) show that $\sqrt{m}(d - d_0) \rightarrow N(0, 1/4)$ for $d_0 \in (-1/2, 1/2)$ and then further extend the Robinson (1995) estimator and develop the exact local Whittle (ELW) estimator, whose asymptotics are based on the exact frequency domain of the data-generating process. This is obtained from the minimisation of the objective function:

$$
Q_m^*(G, d) = m^{-1} \sum_{j=1}^m \ln[G(\lambda_j^{2d})] + \frac{1}{G} l_{(1-L)\lambda_j}(\lambda_j).
$$

(6)

The ELW is shown to be consistent and asymptotically normally distributed for any value of $d$ and is therefore valid in a wider range of cases. The choice of $m$ is also discussed in a set of simulations conducted by Shimotsu and Phillips (2006). They suggest that $m$ has to grow fast to $d$ to be consistent, but an overly large value of $m$ may induce a bias in the estimator from the short-run dynamics. A parameter $\delta$ between 0.45 and 0.7 is often considered, however, $m = T^\delta$ is used in their simulation. In our empirical analysis, three values of $\delta$ (0.5, 0.55 and 0.6, respectively) are used to check for robustness, with consistent results.

The long-memory approach or fractional integration techniques have also been implemented to test for fractional cointegration. For example, Zhang et al. (2015) demonstrate that the GPH and LW, as well as their variants, can be used to detect fractional cointegration in a residual-based approach. When there are only two time series in the cointegration test, a simplified version, follows Campbell and Shiller (1987), is to construct a univariate series by taking the ratios. The fractional integration test on the ratio is equivalent to testing for co-integration between two time series. In other words, a unit root of the ratio indicates no cointegration of the two underlying series, whereas a stationary result (I(0)) is equivalent to saying that the underlying two time series are cointegrated. A similar logic can be used for the fractional case.

In the following empirical study, we use the fractional integration test on the oil-gas price ratios, which is equivalent to testing the long-run equilibrium between these two prices. In the interest of consistency and simplicity, a stationary ratio represents the existence of long-run equilibrium, and a nonstationary ratio means no long-run equilibrium. However, the non-integer $d$ represents long-memory/fractional
integration, which is equivalent to fractional cointegration. A $d$ that is smaller than 0.5 means that the long-run equilibrium exists and will be re-established quickly when external shocks are applied. When the order of $d$ is between 0.5 and 1, the long-run equilibrium still exists, but it requires much more time to be restored when shocks break the equilibrium. In the last case, in which $d$ is equal to 1 or higher, there is no long-run equilibrium.

4. Data description

The data used in this paper were collected from the World Bank Global Economic Monitor (GEM) commodity prices. For the oil price, Brent crude oil prices (2000 constant price in US dollars) were used.\(^1\) The sample period starts in January 1982 and ends in February 2015. The monthly frequency provides a total of 398 observations for each series. Natural gas prices are defined differently for each market. The European price is the average import border price (excluding the UK between June 2000 and March 2010). The Henry Hub spot price is used for the US. For Japan, the GEM reports the imported LNG prices with the most recent two-month averages. The left panel of Fig. 1 plots the three international crude oil prices, and the right panel plots the natural gas prices in the three markets.

Fig. 1 clearly shows that the trends in the international crude oil prices are almost identical, with the exception of some slight deviation in the WTI prices at the end of the sample period. The WTI changes, which are decoupled from the international crude oil price system, are attributed to the WTI's unique driving factors. These are determined by the WTI's independent geographic position and the local imbalances in oil supply and demand, which are induced by the increase in unconventional oil resources (Ji and Fan, 2015). The price trends of natural gas in the three regional markets were basically consistent before 2009 and then they began to diverge from one another. Generally, after 2009, the US Henry Hub prices have gradually decreased and have been kept at a low level, while the natural gas import prices in Europe and Japan have increased significantly. The main reason is that excess supply of shale gas and the deficiency of its domestic natural gas-exporting infrastructures has driven down the US gas price to much lower levels than those in Europe and Japan (Geng et al., 2016c; Jadidzadeh and Serletis, 2017). The rebound in crude oil prices after 2009 (shown on the left panel of Fig. 1) also pushed up the natural gas prices.

Fig. 1. Oil prices and natural gas prices.
(Source: The World Bank Global Economic Monitor commodities price)

As discussed, if a long-term equilibrium relationship exists between oil and natural gas prices, then the cointegration of these two series would be expected, or their linear combination should be a stationary I (0) process. In other words, shocks may affect the relationship, but an error-correction mechanism will revert to the equilibrium in the long run. The impact on or the deviation in the long-term relationship should be temporary, and equilibrium will be restored quickly. Given that only two series (oil and gas) are considered in each market, tests for cointegration are essentially equivalent to those for the stationary feature of their ratios (a univariate approach). A stationary ratio means that a long-term relationship exists and that shocks that move away from the

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\(^1\) The main empirical results presented in this paper use Brent oil price. WTI is used for robustness check and the results are almost identical and are available upon request.
relationship will dissipate quickly without permanent effects. To obtain some basic information that is consistent with the previous literature, standard unit root tests were applied to each ratio. Table 1 reports the standard unit root test results using the two most popular tests—the ADF and KPSS.

The ADF results suggest that among the three ratios, the US employs an I(1) nonstationary process, whereas the other two use an I(0) process. This is consistent with intuitive judgment from the evidence in Fig. 2. However, the results are less clear with the addition of the KPSS test. Although the nonstationary characteristic of the US oil/gas ratio can still be confirmed, the conclusion for the other two series changes. The KPSS unit root tests reject the null hypothesis at the 1% significance level that the Europe and Japan oil–gas price ratio series are stationary. There are two possibilities regarding this inconsistency between the ADF and KPSS results. First, the KPSS test has the power to test for fractional integration. Rejecting the stationary null hypothesis of the KPSS test means that the underlying series may have a long memory. Second, the inconsistency may reflect the time-varying relationship or a possible structural break, which is essentially a special case of the time-varying relationship. The following two subsections address these issues separately.

Note: *For the ADF test, only the intercept has been included, and the lags are selected using the Bayesian information criteria (BIC). The null hypothesis of the ADF test is that the series is stationary, whereas the null hypothesis of the KPSS test is that the series is nonstationary.

b*** denotes significance at the 1% level.

Perron (1989)’s test is applied to the level of the series and assumes one unknown break in the intercept.

5.2. Estimation of the order of integration

Table 2 reports the estimation of the order of integration with the three methods discussed in Section 3. Despite occasional differences that are subject to the model specification, they are generally consistent with one another. In Table 2, three distinctive processes can be observed. First, the value of \( d \) for Europe is always less than 0.5, either of the three tests or the different constraint variable of \( m \). This means that the European oil–gas relationship is stationary with a long memory. Second, for the Japanese market, the value of \( d \) is around 0.5, and its value is less than 0.5 for one of the GPH tests and more than 0.5 for other tests. Thus, there is no consistent conclusion from the stationary test for Japan’s oil–gas relationship. In this context, there is a long-run equilibrium between oil and gas in Asia, but when shocks break the equilibrium, the time to restore is uncertain. Finally, the US oil–gas relationship is definitely nonstationary, with a \( d \) value close to 1.

A clearer and more straightforward interpretation of these relationships can be obtained by using the level of persistence of the shocks. In the cases of Europe and Japan, the order of \( d \) are all smaller than 1, suggesting that the equilibrium exists but not in the same manner as the standard stationary process would indicate. In other words, there is evidence of long memory. External shocks may shake the oil–gas relationship, but their effects will disappear over time (returning to their long-run equilibrium), though in a slower process than the typical stationary ARMA case. A relatively higher order of \( d \) in Japan, relative to the European case, means that the shock will last longer in Japan than in Europe. The US oil–gas nonstationary relationship means the absence of a long-term equilibrium relationship between oil and gas prices. Shocks to the US oil–gas relationship will persist and augment, with permanent effects. Under the current situation in the US energy market, shale gas represents the shock to the US natural gas market, separating the oil and gas markets. In contrast, a long-term relationship exists in the European case. The impacts of the shocks will dissipate, but the evidence of the long memory means that the decaying process will be slower than the standard I(0) process would indicate.
5.3. Rolling-windows estimation

The use of the long-memory model helps solve the inconsistency of the ADF and KPSS tests and shows that the series can be fractionally integrated instead of a strict I(1) versus I(0) process. The data also clearly indicate that the relationships across all three series vary over time. Given that the sample period covers over 30 years, there are both regulatory and market condition changes, which may result in adjustments in the pricing mechanisms. To accommodate this possibility, the rolling-windows approach was used to investigate the potential time-varying patterns.

By setting the window size at 1/2 of the total observation, the order of integration for both the GPH and the ELW estimators on each rolling window can be plotted in Figs. 3–5 for the three natural gas markets. Despite some slight differences between the ELW and the GPH estimations, the general patterns are similar. The level of persistence (measured by the order of integration) is shown to increase across the three markets when the windows move towards more recent years. This means that the oil–gas relationship is now generally more unstable than before. Again, there are clear differences across these markets. To provide a more intuitive picture of the dynamic, a rather subjective shaded area is included in each international Gas Union IGU figure, showing major changes in the order of integration.

In the US case (shown in Fig. 3), the average order of integration is 0.73 (measured by the ELW estimator), which is roughly consistent with the full sample estimation. However, the level of integration in the last part of the sample has become markedly higher, which indicates a higher level of decoupling in the oil–gas price relationship. The dynamic changes in the level of integration appropriately capture the influence of the US shale gas revolution in 2009 on the price of natural gas, which is when the real decoupling of the oil–gas relationship began.

The Japanese market obviously differs from the US market (Fig. 4). First, the order of integration is generally lower, with an average value of 0.45, as measured by the ELW estimator (stationary with long-range dependence), which favours the oil-indexation measure. Second, the evidence regarding oil indexation was stronger before 2005 than after. Third, there is a temporary decoupling period in the shaded area (between June 2005 and August 2009), with the order of integration higher than 0.5 (occasionally towards 1). This is attributed to the sharp rise in international oil prices beyond the natural gas import prices in Japan during this period.

As Fig. 5 shows, the pattern in the European market is also different. The average ELW estimation is about 0.35, which is similar to that of Japan. This observation is consistent with the full sample estimation that the oil–gas relationship in Europe is stationary with a long memory. A temporary decoupling of the indexation hypothesis can also be found between 2007 and 2009. The orders of integration are generally above the 0.5 threshold and then fall back before increasing again at the end of the sample period. Given that the European market is moving towards the hub pricing regime (Council of European Energy Regulators CEER, 2011), gas prices are more likely to decouple from oil prices in the future.

6. Discussion and policy implications

The empirical results in Section 5 have presented interesting findings regarding the long-run oil–gas relationship, including their dynamic, in three different regions. These results answer the question of whether the decoupling of oil–gas relationship is a temporary phenomenon or a permanent change. Our results provide new evidence regarding the regional oil–gas relationship among the US, European and Asia-Pacific regions.

Generally, the significant difference in the oil–gas relationship in the three regions can be verified in our findings, which is attributed to the regional natural gas pricing mechanism and the domestic energy situations. The degree of oil–gas linkage partly depends on the extent of the oil indexation pricing of natural gas. According to International Gas Union (IGU) (2016) statistics, 48.7% of the world natural gas imports in 2015 were oil-index priced, in which Asia’s proportion was as high as 83.7% but only 36.1% for Europe. However, based on the results in Table 2, it was interesting to find that the oil–gas relationship in Europe was more stable than that in the Asia-Pacific region. This seems contradictory to the degree of oil indexation in these two regions. One possible reason is that the import source of European natural gas is stable and that more than 60% of natural gas trade in Europe is imported from Russia and Norway, which are also the main oil exporters in Europe. Although the proportion of European gas in oil-indexation pricing has been decreasing over time, the market-based pricing of both gas and oil reflects the real situation of supply and demand in Europe as...
well as the local energy policies. Therefore, the co-movement between oil and gas prices is relatively stable.

European natural gas markets have been undergoing a series of restructuring towards a more gas-on-gas pricing system, however, opinions on this process are diversified and the continental markets are mixed. The European Commission is working on the EU energy market integration proposal, which is committed to the construction of a unified European energy market. The proposal will be given the greater influence in the natural gas supply contract negotiations, and help to reduce the dependence on Russian gas. By this way, gas consumers can have more choices to reduce the price and trading barriers.

The UK NBP (National Balancing Point) hub is considered as the most powerful trading centre in the European natural gas market due to its flexible mechanism on gas transportation contracts to balance the gas supply and demand in the UK. The history experience in the US shows that the open access of gas pipeline is the key of market pricing which can help wholesale market shift from long-term contracts to market based pricing in the next few years. Moreover, the experience of the UK suggests that standardization contract has played a key role in market based pricing in the next few years. Moreover, the experience of the US shows that the open access of gas pipeline is the key of market pricing which can help wholesale market shift from long-term contracts to market based pricing in the next few years. Moreover, the experience of the UK suggests that standardization contract has played a key role in the success of the UK NBP trading hub. However, different from the US gas market, there are still many challenges to the integration of the European natural gas market. For example, it’s more difficult to build a unified natural gas market by coordinating the different progress in EU member countries. The development of natural gas industry in the EU is not consistent in which the liberalization degree in the UK natural gas market is high while the natural gas industries in France and Italy are high monopoly. In addition, as a major supplier for European natural gas, Russia has always insisted on oil indexation pricing trading on the EU long-term contracts which has limited the price flexibility in the EU market. So, the establishment of a unified gas market in EU still needs a long transition period.

For the Asian market, Japan’s oil and gas are completely dependent on exports as well as on different exporting countries. Correspondingly, oil and gas prices cannot reflect local energy conditions, and they depend heavily on the different external environments in oil and gas markets. In addition, Japan’s gas import prices are based on Japanese crude cocktail prices (JCC), which is the average price of customs-cleared crude oil imports into Japan. However, in order to avoid the risk of a natural gas market caused by oil price volatility, cap and floor prices are set in reference to JCC prices. Therefore, oil-gas relationship in Asia is not stable over time. By tracking the changes in the order of integration in Fig. 4, we see that the oil-gas relationship is stationary, with a long memory before June 2005, nonstationary during the period from July 2005 to July 2009 and uncertain after July 2009. This is also the reason why there is an urgent need for a gas trading hub in Asia, which would effectively reflect the real supply and demand situation in Asia and reduce volatility in natural gas prices.

Similar to EU gas market, there also exists some constraints on different political system, market mechanism and development degree of industry in Asian countries. However, different from the European gas market, LNG is the main channel of importing natural gas in Asian countries due to its particular geography, especially for Japan and Korea. LNG has its advantage on flexible transportation and can provide arbitrage opportunities for natural gas producers and help to promote market integration among countries. Thus, it’s a common interest for Asian countries to build its own gas trading hubs which can gradually eliminate the impact of oil indexation. According to the conclusions found by Shi and Variam (2016), multiple hubs initiatives are not mutually exclusive. So for Asian countries, they should establish an effective dialogue mechanism and refer to the international pricing experience in the US and EU to discuss the standards of natural gas pricing. In the meantime, they should speed up the domestic natural gas marketization reform and fully connect the supply and demand at home and abroad to realize its balance and price linkages.

7. Conclusions

This paper has investigated the oil-gas price relationships in the US, Europe and Japan. It extends the existing literature with a long-memory approach. By allowing the order of integration to be a non-integer value, the long-memory model provides a much more flexible alternative to the standard unit root/cointegration framework for modelling the oil-gas price relationship.

Through the OLS-based GPH estimation and the maximum likelihood-based LW/ELW estimation, the full sample results demonstrate clear differences among the three markets. The results for the US market conspicuously vary from those for the European and Japanese markets, although the latter two share some similarities. Specifically, gas prices in the US market are significantly decoupled from oil prices; however, the oil-indexation hypothesis is supported in the other two markets. The existence of the long memory further indicates that the process of adjusting to a long-term equilibrium in Europe and Japan is longer than a typically stationary I(0) process.

A rolling-windows estimation was used to address the potential time-varying features found in the existing literature. The results are informative. The order of integration differed across time, with clear distinctions across all three markets. The US market remained nonstationary at almost all windows, but a higher order of integration (stronger decoupling) was found in the latter part of the sample. Even in Europe and Japan, both of which favour oil indexation, there are noticeably nonstationary periods, showing that temporary decoupling may well exist.

Unlike most of the previous studies supporting the stable cointegration relationship between oil and gas prices in the European and Asian markets, this paper provides additional information on the dynamic integration of their oil–gas relationships. One of the most important implications is that oil prices no longer constitute the unique determinant of natural gas prices, even if oil indexation still exists in the European and Asian markets. The pricing mechanism of natural gas prices is becoming more complex, with multiple factors from fundamental and external dimensions. For the European market, the market-based pricing pattern is progressing, and the percentage of oil-indexed trade is decreasing. Nevertheless, compared with the North American market, the natural gas price competition in the European market is still not sufficient to deviate completely from oil-indexation. For the Asian market, the oil indexation pricing format of gas imports remains dominant and will be difficult to change in the short term. Some countries such as China and Japan are competing over market power and will try to develop a natural gas-trading hub (Shi and Variam, 2016). Furthermore, spot LNG imports have been increasing and will contribute to the rise in gas-to-gas proportions. Moreover, the expected natural gas exports from the US will further push the integration of regional natural gas markets and the process towards a market-based pricing system.

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