RECONSIDERING THE OIL-LINKED PRICING RULE BASED ON EVIDENCE OF UNSTABLE COINTEGRATING RELATIONS IN ASIAN LNG MARKETS

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Abstract

It is crucial to evaluate price integration for Asian LNG markets because the market is searching a new pricing fundamental. However, major changes in the LNG market during the global economic crisis and the characteristics of the LNG trading mechanisms may lead smooth structural changes. Thus, in contrast to the conventional linear assumptions applied in previous research, this study uses the smooth transition regression (STR) model and the nonlinear co-integration test to explore the long-run price relationship among the main LNG-importers in Asia (Japan, Korea, and Taiwan). Our study indicates the limitation of linear model in testing the LNG market integration. Further, the empirical result of this study suggests a nonlinear co-integration in the Asian LNG market and shows evidence of smooth transition in the long-run relationships in the LNG market, but do not support the law of one price (LOP). This article provides quantitative evidence that LNG prices in Asia market adjust slowly to a new equilibrium relationship under a buyer’s market but not converge. A direct policy implication of our findings is that a new trading mechanism with a more rational pricing rule is needed for facilitating information transmission in Asian LNG market. A reliable pricing can benefit countries which have less negotiation power, and lead to more efficient allocation of energy resources.

Keywords: Liquefied natural gas; Smooth Transition; Nonlinear Cointegration;

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1. Introduction

As a result of shale gas production by the United States and the low demand for natural gas in Europe since the global economic crisis, Asia has become the main target market for exports of liquefied natural gas (LNG). Moreover, the strong growth of LNG demand in Asia is expected to attract existing and new suppliers to join the Asian LNG market. Does LNG price converge automatically in a buyer’s market? To answer this question, market integration under the current trading mechanism must be evaluated quantitatively.

Currently, Asia does not have a common LNG market. Thus, LNG is traded based on long-term bilateral contracts containing price renegotiation clauses that allow prices to be adapted to changes in the market, and LNG import prices are oil-indexed in most Asian countries.

The original rationale for oil indexation in LNG contracts was to look for its replacement value. There is confidence in the oil market because of the low probability of oil price manipulations and uncertainty. On the supply side, LNG exports have aimed at calorific parity with the oil price and the Gas Exporters Country Forum (GECF) endorsed oil indexation as the preferred pricing scheme (IEA 2013). For importers, the primary advantage of using an oil-indexed LNG price is that the price is easy to understand and the importers can focus only on oil risk.

However, the logic behind using oil as a replacement comparator for gas has changed, and setting an oil-indexed price for LNG has become not easily to be rationalized. For example, oil is now used as a fuel for transportation rather than for generating power. The oil-indexed gas price poorly reflects supply and demand in the natural gas market. The weak rationality of oil-indexed pricing has resulted in higher transaction costs because of price renegotiations, which is harmful for market integration.

Market integration allows price signals to be transmitted from one market to another. When markets are integrated, Asian economies have a greater opportunity to receive a fair price for LNG imports and they can increase their overall economic efficiency to satisfy the growing demand for energy. To create a rational pricing rule and to improve competition in natural gas markets, the IEA proposed the concept of an Asian LNG trading hub. In a competitive market, low prices are not guaranteed, but reliable pricing can create greater transparency and efficiency for the mature Asian LNG market.

The current LNG market, however, is dominated by a few integrated organizations that have maintained a long corporate relationship based on oil-indexed contracts. Keeping the domestic supply of LNG secure is usually the highest priority to Asian importers, who are not motivated to promote competition. Thus, the evidence of LNG market integration and prices converge is crucial to evaluating the requirement of an Asian LNG trading hub.

Therefore, the purpose of this study was to investigate price integration for the Asian LNG market. When markets are fully integrated, prices of homogeneous commodities in two markets should converge based on the law of one price (LOP). Therefore, in addition to examining the cointegration of LNG prices, we also tested the strict convergence criteria of the LOP.

The standard Engle-Granger two-stage method (Engle and Granger, 1987) was widely used to test the cointegrating properties of a pair of non-stationary series. However, the LNG market has changed, particularly during the global economic crisis. The LNG market appears to have become a buyer’s market, and a linear model may not accurately describe the relationship among LNG prices.

Here we used the rolling-window approach as a preliminary method for examining the stability in the linear cointegration relationship. The advantage of observing test statistics using the rolling-window approach is that this approach provides simple evidence that can reveal whether the convergency is time dependent.
Considering the structural changes and slow adjustments in the LNG market, the smooth transition regression (STR) model was applied to describe the nonlinearity of relationships between LNG prices. Furthermore, the nonlinear cointegration test introduced by Choi and Saikkonen (2010) was used to investigate the nonlinear long-run relationship among LNG prices in the Asian market.

This paper provides the following contributions to the LNG market-integration literature. First, we show the evidence that the linear model is limited when examining the market cointegration for Asian LNG market. Second, we capture the smooth transition in the LNG price relationship by using the STR model and nonlinear cointegration test. Applying the nonlinear model is critical, but the model has not been used in previous studies, especially in relation to energy commodities being traded based on long-term contracts.

The remaining of this paper is organized as follow: Section 2 gives a brief review of empirical literatures of LNG/NG market integration and show the importance of allowing smooth transitions in the integration relation. Section 3 introduces the STR model and the nonlinear cointegration test used in this study. Section 4 provides empirical results from linear system, shows the instability of cointegration relationship under linear system, and displays estimation results from nonlinear system. Policy implications and conclusions are given in Section 5.

2. Consideration of structural change and smooth transition

Most of LNG import price in Asia market are oil-indexed. The LNG import contract is linked to a common target- the Japanese Crude Cocktail (JCC)\(^1\) price- for Japan (JPN), Korea (KOR) and Taiwan (TWN). In general, the LNG pricing formula can be expressed as \( P = a + b \times \text{JCC} \). Coefficient \( a \) and \( b \) depends on transportation cost and the market situation. For instance, when there is an excess supply in market, \( b \) should be lower than the theoretical value that based on calorific parity.

Because it is hard to compare the contract price due to the data availability and the complexity of contract structure. The average import price is usually used in empirical studies. Fig. 1. shows the LNG import prices (dotted line) and JCC price (solid line) with common unit. It is quite obvious some consistency between LNG and JCC prices, and LNG price linked to JCC prices with a 3-9 month lag. Thus, it is plausible to assume the comovement or intergration of LNG import prices among JPN, KOR and TWN. Suppose that LNG exports aimed at calorific parity with oil price, prices may tend to convergence if there exits arbitrage opportunity.

![Fig. 1. JCC vs. LNG import prices](image)

Before the 20th century, most of literatures on integration of natural gas (NG) markets has been limited to the regional level only. As technology advances and cost decreases, LNG has acquired almost a global reach connection between regional markets, the integration of NG markets at the interregional level becomes a serious issue.

The first investigation of interregional NG/LNG market integration can be found in Silverstovs et al., (2005). At the interregional level, they shows cointegration relationship between Japan and Europe market even though the import price indexation in these two markets are different (Japan refers to the JCC price for oil that mainly from the Middle East, but European gas prices are indexed to the North Sea Brent crude oil.

\(^1\) The JCC is also referred as to the Japanese Custom Cleared.
price). But the LOP only hold at the regional level, for North American market (Henry Hub and US Pipeline) and Europe (Europe LNG and Europe Pipeline).

While a growing amount of literature that focuses on the NG/LNG market integration at the interregional level, however, there is still very limited research discusses the integration in Asia. Such as Li et al., (2012), they indicate the cointegration among Japan, Korea and Taiwan but the relationship is not stable over the period. Thus, only few evidences about LNG market integration inside Asia and provide weak support for trading-hub developing.

In previous literatures, the cointegration test is commonly used to test the long run relationship between prices time series, such as Silverstovs et al. (2005), Kao and Wan (2009) and Li et al. (2012). It is intuitively reasonable discussing the long run convergence over long spans of data in LNG market. But we have noting that structural change becomes more likely with long spans of data, especially the sample period includes the global economic crisis.

Several important changes in the LNG market are described as following: First, there is increased infrastructure investment such as liquefaction and regasification capacity across a larger number of countries. LNG market becomes a buyer's market as the result of capacity expansions and the global recession. Second, LNG suppliers are looking to abandon the S-curve LNG price formula from 2007. The contract shifts from bilateral long-term contracts toward spot and more flexible short-term contracts. Third, the competition of Asian LNG market seems increasing due to the growth of shale gas in North America, including the potential LNG exporting from the US and more parties willing to provide LNG transport services. LNG supply is likely to become more flexible and transport costs become lower.

More than 80% LNG are traded through long-term contract with different duration. Negotiation and regulatory factors causes high transaction costs. It is highly unlikely that agents react simultaneously to a change in the market that could lead to slow price adjustments, the structural change is a potentially smooth process over time rather than an instantaneous break. Thus, the research presented in our paper is unique in the literature on LNG markets in that it allows the smooth transition in LNG price relationship.

3. Methodology
3.1 linear model and cointegration test

In this study, we examine whether Asia LNG market are integrated by testing the cointegration of LNG price. The relationship between LNG prices can be represented as Eq. (1), Where \( P_{t}^{A} \) and \( P_{t}^{B} \) denotes the LNG import price of country A and B respectively; \( t \) denotes the time index; \( \alpha \) and \( \beta \) are parameters, while \( \epsilon \) denotes the residual. An strict test for price convergency carried out by testing the null hypothesis of LOP that \( H_0: \beta=1 \).

\[
P_{t}^{A} = \alpha + \beta P_{t}^{B} + \epsilon_{t}
\]  

(1)

Since the LNG market responds slowly due to the long-term contract and the time series process of LNG price has unit root, Engle-Granger’s (1987) residual-based cointegration approach is widely employed to investigate the long run relationship. The Engle-Granger (EG) test for cointegration is a two-step residual-based test: Suppose there are two I(1) variable. First, estimate the linear regression on level variable. Second, test to see whether the least squares residual appears to be I(0). The least squares residual is regarded as the deviation from the long run equilibrium, if the residual is found to be stationary, two series are cointegrated of order(1,1).

Thus, the null hypothesis for testing the cointegration in LNG market is corresponding to test the stationarity of \( \epsilon_{t} \) from eq. (1). In this study, ADF test, PP test and KPSSS test are applied to testing the stationarity of residual derived from linear model. The estimated parameter obtained from the first step is the
However, as described in section 2, relationships between LNG import prices in Asia are tend to change around the global economic crisis. We are interest in the stability of cointegration relationship of LNG price over time. Here we use a rolling window approach with a fixed window size to check whether the results of unit root tests are stable.

3.2 The STR model and nonlinear cointegration test

Considering that each LNG import contract with different duration, high negotiation cost and regulatory factors, it is highly unlikely that agents react simultaneously to a change in the market, we have a strong reason for allowing a smooth transition process in LNG price relationship. In this study, smooth transition regression (STR) model is employed to describe such relationship. The STR model has two main advantages over competing nonlinear models. First, the STR model allowed smooth transitions in coefficients, in addition, abrupt change is a special case of the STR model. Second, the location of breaks can be treated as an unknown. The general form of the STR model can be illustrated as follows.

$y_t = x_t\pi_t + x_t\pi_tF(z_t) + u_t \quad \text{where} \quad t = 1, \ldots, T \quad (2)$

$F(t; \gamma) = \frac{1}{1 + e^{-\gamma t^{c_1} + \ldots + c_k}}} \quad \text{where} \quad k = 1, 2 \text{ or } 3 \quad (3)$

$x$ is a vector of explanatory variables; $t$ denotes the time index; $\pi$ are parameter vectors; $u$ is the residual. In the transition function $F(z_t)$, $z$ is the transition variable which can be an exogenous variable or a lagged endogenous variable, $\gamma$ is the speed parameter and $c_i$ are location parameters. The choice for $k$ can be determined by LM test proposed by Lin and Terasvirta (1994).

The STR model applied in this study is represented as Eq. (4). The Wald statistics can be used to examine the LOP by testing the null $\beta_1=1$ in regime I that $F(t)$ equals to 0 and testing the null $\beta_1+\beta_2=1$ in regime II that $F(t)$ equals to 1.

$P_t^\Lambda = \alpha_i + \beta_iP_{t-1}^\Lambda + \gamma t [\alpha_i + \beta_iP_{t-1}^\Lambda] + u_t \quad (4)$

when $F(t) = 0 \quad P_t^\Lambda = \alpha_i + \beta_iP_{t-1}^\Lambda + u_t \quad (5)$

when $F(t) = 1 \quad P_t^\Lambda = (\alpha_i + \alpha_s) + (\beta_i + \beta_s)P_{t-1}^\Lambda + u_t \quad (6)$

In order to investigate the cointegration under the nonlinear system, the nonlinear cointegration test introduced by Choi and Saikkonen (2010) was adopted in this study. Choi and Saikkonen (2010) proposed the KPSS type test, which is the first residual-based cointegration test for the STR model. Different with another line of residual-based approach that focus on modeling the nonlinear adjustment mechanisms of deviations from long-run equilibrium (eg. Saikkonen, 2008), Choi and Saikkonen’s (2010) method is direct to make the cointegration relationship nonlinear.

The nonlinear cointegration test statistics is described briefly as follows. The test has the same function as KPSS test which shown in Eq. (7). Where $T$ is full sample size, and $u$ is residual, $\hat{\omega}_n^2$ denotes a consistent estimator of the long-run variance $\omega_n^2$. The null is assumed that the series is stationary, the estimated short-run and long-run variance convergence toward a specific distribution under the stationary assumption.
\[ C_{\text{NLLS}} = T^{-2} \hat{\sigma}^2 \sum_{i=1}^{T} \left( \sum_{j=1}^{b} \tilde{u}_j \right)^2 \] (7)

Choi and Saikkonen (2010) suggest an application of Bonferrone procedure to solve the limiting distribution of test statistics of \( C_{\text{NLLS}} \) when the regression model is nonlinear. The statistics using subresiduals from STR model is given by

\[ C_{\text{NLLS}}^{b_i} = b^{-2} \hat{\sigma}^2 \sum_{i=1}^{b} \left( \sum_{j=1}^{b} \tilde{u}_j \right)^2 \] (8)

where \( b \) denotes the size of subresiduals which called block size, \( i \) denotes the starting point or the subresiduals. The smallest \( b = T^{0.7} \) and the largest \( b = T^{0.9} \) and the optimal block size is chosen by the minimum volatility rule. Then, \( C_{\text{NLLS}}^{b_{i, \text{max}}} = \max(C_{\text{NLLS}}^{b_{1}}, \ldots, C_{\text{NLLS}}^{b_{M}}) \) These M tests use different starting points but have the same block size. The critical value of the test can be found in Hong and Wagner (2008).

4. Empirical Results

4.1 Description of the data set

Monthly LNG import prices of the major LNG-importing countries in Asian are used in our empirical investigation, they are Japan (JPN), South Korea (KOR) and Taiwan (TWN). The data source of LNG price of JPN and KOR is OECD i-Library as reported in IEA Natural Gas Information Statistics. The LNG import price for Taiwan is obtained from Energy Statistics Monthly. The integration relationship is analyzed for the period from 2002 to 2011. Time series plot of LNG import prices is shown in Fig. 2. As noted in section 2, LNG price are share a common trend because they are all indexed to the JCC price.

![Fig. 2. LNG import prices in Asia](image)

Table 1 presents the descriptive statistics of LNG price. The import price are around 8 to 9 USD/MBtu. The highest and lowest LNG prices are 19.23USD/MBtu and 3.67 USD/MBtu in South Korea. In general, Taiwan’s import price is the most expensive when compare to the other two countries according to mean and median statistics. The standard deviations of LNG import price are quite close but slightly higher in Korea.
<table>
<thead>
<tr>
<th>Table 1 Descriptive statistics</th>
<th>JPN</th>
<th>KOR</th>
<th>TWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>8.01</td>
<td>8.76</td>
<td>9.51</td>
</tr>
<tr>
<td>Maximum</td>
<td>16.79</td>
<td>19.23</td>
<td>18.56</td>
</tr>
<tr>
<td>Minimum</td>
<td>4.04</td>
<td>3.67</td>
<td>4.20</td>
</tr>
<tr>
<td>Median</td>
<td>7.15</td>
<td>8.92</td>
<td>9.43</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>3.23</td>
<td>3.36</td>
<td>3.32</td>
</tr>
<tr>
<td>Obs.</td>
<td>116</td>
<td>116</td>
<td>116</td>
</tr>
</tbody>
</table>

Table 2 shows the results of the unit root tests in levels variable and its first differences. The null hypothesis that the corresponding time series are non-stationary is accepted by both the ADF and PP tests. The null hypothesis that the corresponding time series are stationary is rejected in all cases by the KPSS test. Furthermore, the results of the unit root tests on first differences of LNG import prices, shows that all are stationary. Thus, the test result indicates that LNG import prices in Asian market are I(1) variables.

<table>
<thead>
<tr>
<th>Table 2 Unit root test on LNG import price</th>
<th>ADF</th>
<th>PP</th>
<th>KPSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPN</td>
<td>-4.006**</td>
<td>-2.358</td>
<td>1.129***</td>
</tr>
<tr>
<td>KOR</td>
<td>0.808</td>
<td>0.455</td>
<td>0.944***</td>
</tr>
<tr>
<td>TWN</td>
<td>-2.355</td>
<td>-2.355</td>
<td>0.911***</td>
</tr>
<tr>
<td>First difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPN</td>
<td>-5.297***</td>
<td>-6.540**</td>
<td>0.119</td>
</tr>
<tr>
<td>KOR</td>
<td>-17.300***</td>
<td>-15.999***</td>
<td>0.054</td>
</tr>
<tr>
<td>TWN</td>
<td>-10.037***</td>
<td>-10.048***</td>
<td>0.046</td>
</tr>
</tbody>
</table>

Note: (1)The ADF and the PP tests with the null hypothesis of non-stationarity. The null hypothesis of the KPSS test is stationarity, complementing the ADF or the PP tests. (2)*, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4.2 Price relationship in linear system

In this subsection, The Engle-Granger (EG) test is applied to test the cointegration relationship between LNG prices pair. Table 3 presents estimation results for linear regression of JPN on KOR (and JPN on TWN). The unit root test result here support the literature on gas market integration, residual form linear regression are stationary both for KOR and TWN. Thus, the linear cointegration relationship seems exist in Asian market. Moreover, the Wald test does not reject the null hypothesis $H_0: \beta=1$ in the case of Korea.
Table 3 Estimation results of OLS model.

\[ P_i^t = \alpha + \beta P_i^{t-1} + \epsilon_i \]

<table>
<thead>
<tr>
<th>Coef.</th>
<th>KOR</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>1.236</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.793)</td>
</tr>
<tr>
<td>(\beta)</td>
<td>0.939</td>
<td>0.829</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
</tbody>
</table>

Adjusted R-squared | 0.809 | 0.725 |
Log likelihood     | -208.269 | -224.497 |

Unit root test on OLS residual

<table>
<thead>
<tr>
<th>Test</th>
<th>KOR</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>-1.943*</td>
<td>-3.121***</td>
</tr>
<tr>
<td>PP</td>
<td>-4.191***</td>
<td>-3.036***</td>
</tr>
<tr>
<td>KPSS</td>
<td>0.306</td>
<td>0.257</td>
</tr>
</tbody>
</table>

Wald test

\[ H_0: \beta = 1 \]

<table>
<thead>
<tr>
<th>Test</th>
<th>KOR</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>H0</td>
<td>-1.433</td>
<td>-2.425**</td>
</tr>
</tbody>
</table>

Note: (1) The ADF and the PP tests with the null hypothesis of non-stationarity. The null hypothesis of the KPSS test is stationarity, complementing the ADF or the PP tests. (2) *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. (3) Numerals in (.) are p-value.

In order to detect the stability of linear cointegration in Asian LNG prices, we apply a rolling window approach in this subsection. The unit root test statistics from subsample with fixed window size 60 (5-years) are shown in Fig. 3. The dotted horizontal line presents the critical value corresponding to 5% significant level for each type of unit root test. As shown in Fig. 3, the residual are not stationary over time, moreover, the test result of three types unit root test are not consistence. Such rolling window plots show a preliminary evidence of potentially unstable linear relationship. The unstable linear relationship indicates the LOP between Japan and Korea that concluded for the Wald test may not correct.

![Fig. 3. Rolling window analysis of unit root test on OLS residuals.](image)

4.3 Empirical results of the STR model and nonlinear cointegration

According to the preliminary evidence of unstable linear relationships shown in Fig. 3 and the consideration of slow adjustment in LNG market, here we introduce an application of smooth transition regression (STR) model on describing the nonlinear relationship between LNG prices. Furthermore, we use...
the nonlinear cointegration test developed by Choi and Saikkonen (2010) to examine the stationarity of residual derived from the STR model.

Before estimating the STR model, we start the modeling cycle for smooth transition models with a formal test for nonlinearity. Details about nonlinearity and model specifications can be found in Lin and Teräsvirta (1994). The result of the LM tests presented in Table 4, it show that the P value of LM1, LM2 and LM3 are significantly lower than 1%, thus hypothesis of linearity is strongly rejected. Further, follow the decision rule to select the most adequate transition function introduced by Lin and Teräsvirta (1994), LSTR (k=1) is chosen for both KOR and TWN because H01 has lowest p-value.

Table 4 Linearity Tests and specifications Tests for the STR model.

<table>
<thead>
<tr>
<th></th>
<th>LM1(H01)</th>
<th>LM2</th>
<th>LM3</th>
<th>H03</th>
<th>H02</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWN</td>
<td>41.166</td>
<td>50.299</td>
<td>68.172</td>
<td>31.555</td>
<td>41.861</td>
</tr>
<tr>
<td></td>
<td>(1.2×10^{-9})</td>
<td>(3.1×10^{-10})</td>
<td>(9.7×10^{-13})</td>
<td>(1.4×10^{-7})</td>
<td>(1.8×10^{-8})</td>
</tr>
<tr>
<td>KOR</td>
<td>70.64</td>
<td>71.21</td>
<td>78.16</td>
<td>18.00</td>
<td>19.24</td>
</tr>
<tr>
<td></td>
<td>(4×10^{-16})</td>
<td>(1×10^{-14})</td>
<td>(9×10^{-15})</td>
<td>(1×10^{-4})</td>
<td>(7×10^{-3})</td>
</tr>
</tbody>
</table>

Note: Numerals in (.) are p-value.

The results of STR estimations carried out by nonlinear least squares (NLS) are presented in Table 5. It may be worthwhile mentioning firstly that the null hypothesis of linearity can be expressed as H0: γ=0. Thus, slope parameters γ are significantly different from zero, which provides the evidence of structural change or regime switch.
Table 5 Estimation results of STR model

\[ P_t^\lambda = \alpha_t + \beta_t \lambda_t^\delta + F(t)[\alpha_2 + \beta_2 \lambda_t^\delta] + \epsilon_t \]

\[ F(t; \gamma) = \frac{1}{1 + e^{-\gamma(t-\gamma)}} \]

<table>
<thead>
<tr>
<th>Coef.</th>
<th>KOR</th>
<th>TWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_1)</td>
<td>-3.565</td>
<td>-1.148</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>(\beta_1)</td>
<td>1.810</td>
<td>1.524</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>(\alpha_2)</td>
<td>5.757</td>
<td>4.597</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>(\beta_2)</td>
<td>-1.099</td>
<td>-0.854</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>(\gamma) (slope parameter)</td>
<td>0.124</td>
<td>1.853</td>
</tr>
<tr>
<td>(0.001)</td>
<td>(0.008)</td>
<td></td>
</tr>
<tr>
<td>(c) (location parameter)</td>
<td>77.779</td>
<td>81.347</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-142.960</td>
<td>-152.295</td>
</tr>
</tbody>
</table>

Regime I: \(F(t)=0\)

- \(C_1\) | -3.565 | -1.148 |
- \(\beta_1\) | 1.810 | 1.524 |

Regime II: \(F(t)=1\)

- \(C_1+C_2\) | 2.192 | 3.449 |
- \(\beta_1+\beta_2\) | 0.711 | 0.670 |

Wald test

- \(H_0: \beta_1=1\) | 6.092*** | -4.705*** |
- \(H_0: \beta_1+\beta_2=1\) | -4.217*** | 10.187*** |

\(C_{NLLS}\) | 0.858 | 0.188 |

Critical value 10\%(m=2) | 1.656 | 1.656 |

Note: (1) *** denote a test statistic is statistically significant at the 1% level of significance. (2) Numerals in (.) are p-value.

Before discussing the estimation result, here, we would like to test the stationarity of residual derived from the STR model firstly. The KPSS type tests with sub-residuals introduced in Choi and Saikkonen (2010) is applied. Both in KOR and TWN cases, b equals 72 has minimum volatility. The critical value with m equals 2 (m=T/b) reported in Hong and Wagner (2008) is 2.135 (5% confidence level) As shown in Fig. 4., the dotted horizontal line presents the critical value coresponding to 10% significant, the stationarity of residual under the nonlinear system is much more stable than under the liner system.

The max \(C_{NLLS}\) for KOR is 0.188 and for TWN is 0.858. The \(C_{NLLS}\) is much smaller than the critical value and do not reject the null of \(\sigma-\lambda(0)\) for both KOR and TWN. In other words, the LNG import prices are nonlinear cointegration. Further, we discuss the estimation of STR parameters and employ the Wald test to investigate whether the LNG price convergence toward LOP.
Fig. 4. Rolling window analysis of unit root test on STR residuals

Fig. 5. and Fig. 6. represent the constant term and coefficient $\beta$ for KOR and TWN respectively according to STR parameters in Table 5. We can discuss an interest finding in Fig. 5. and Fig. 6. First, The estimated coefficient $\gamma$ is corresponding to the speed parameter. For KOR, $\gamma$ is relatively small, implying that the transition from one regime to another is smooth, in other word, the current trading mechanism cause the market to adjust slowly. But $\gamma$ for TWN is relatively large, a possible explanation is that number of market participants and contract in Taiwan are lesser than Korea and Taiwan renew its major contract with Qatar in 2008.

Second, the estimations of location parameters for KOR and TWN are corresponding to May 2008 (obs.77) and Sep 2008 (obs.81), which around the global economic crisis. LNG market changes from a seller’s market to a buyer’s market around that period. The estimated $\beta$ is smaller in regime II (buyer’s market) than in regime I (seller’s market) both for KOR and TWN. On the other hand, we observe that the constant term are negative in regime I (buyer’s market) but positive in regime II (buyer’s market). Table 5 lists Wald test results for testing the LOP under the STR model. However, in the cases of either KOR or TWN, the null hypothesis is rejected. Thus we conclude that the Asia LNG markets are cointegrated in a nonlinear relationship, but does not support the LOP.

Fig. 5. Estimated Coefficient for KOR

Fig. 6. Estimated Coefficient for TWN
5. Concluding remarks and implications

The Asian market is looking for a new fundamental principle for LNG pricing. To evaluate market integration under the oil-indexed pricing rule is crucial, thus, this study investigated the long-run price relationship of the Asian LNG market. The residual-based cointegration approach was used in empirical testing. Unlike previous NG/LNG empirical studies, we examined the cointegration relationship based on both linear and nonlinear systems. Moreover, we focus on a little-discussed but important issue: the smooth transition in the long-run price relationship. The STR model and the nonlinear cointegration test are used to investigate the long-run relationship between LNG prices.

Our empirical results show that the cointegration relationship obtained using a linear assumption is unstable. The linear model is limited when examining cointegration in LNG prices when potential structural changes are occurring in the LNG market. By contrast, we can use a nonlinear model with the smooth transition function to show that a cointegration relationship exists in the Asian LNG market. We found strong evidence of price relationships with regime changes during the period of global economic crisis. Furthermore, the price relationship tended to adjust smoothly rather than change abruptly.

The empirical finding of this study imply that the process of market integration is slow in the Asian LNG market; moreover, it continues to deviate from the LOP in the buyer’s market. These findings have the following policy implications. First, the LOP may not hold in the Asian LNG market because a mutually agreeable method to assess LNG value is unavailable. LNG trading contracts have been developed based on formulas that have divergent slopes, constants, or kink points. Thus, buyers and sellers adhere to subjective arguments, causing negotiations to become deadlocked (Akbar, 2011). Therefore, establishing a more rational way for setting LNG value could improve price integration and market efficiency.

Second, the smooth transition feature indicates slow responses in the LNG market under current trading mechanisms. To improve the ability of the market to respond quickly, an optimal contract portfolio must be developed for long- and short-term trading, spot trading, and swap trading. To support cross-border gas networks, storage foundations and the transparency of laws must be improved. Moreover, the governments and institutional systems of the Asian countries involved should be harmonized to support the expansion of energy trading in the region, especially when involving countries that with unconventional gas endowment, such as China. East Asia should develop a formal program for increasing gas trading within the area to improve market integration and energy security.

Finally, the nonlinear cointegration relationship found in this study indicates that LNG import prices in Asia show a long-run relationship, but this relationship changes over time. As the rationality of oil as the replacement comparator for gas becomes weaker, LNG import prices should be determined by factors other than the price of oil, such as a country’s competitive force or the market situation, these factors are not easy to quantify or predict. If predicting the LNG price increases in complexity, market participants’ cost of avoiding risk in energy prices increases.

The LOP did not hold over our sampling period (form 2002 to 2011) even though the increase in North American LNG production appeared to increase competition in the Asian market. Is it possible that the LNG price converge in the Asian market during the next few years? We discuss this issue briefly based on the LNG strategies implemented by the three countries in our study.

First, swaps between Asian buyers are increasing because Japan’s nuclear power plants were shut down. The Japan/Korea Marker (JKM) LNG swap was lunched by ICE Clear Europe in 2012. Contracts are based
on the Platts JKM price indicator, which reflects the open-market value of spot LNG delivered to Japan and South Korea daily. Second, both Japan and Korea implement upstream verticalized strategies; for example, Korea seeks to co-own LNG vessels to reduce shipping costs, and Japan invests in upstream natural gas resources. Third, Korea has negotiated successfully with the United States for importing shale gas, and Japan has permission from the U.S. government to import natural gas from 2016. When the LNG supply source is diversified, the power controlled by a single supplier is diminished. Thus, Japan and Korea have a greater chance of receiving a consistently fair price than Taiwan does. However, Taiwan, which has less LNG storage capacity and faces limits on import strategies, may require an Asian LNG trading hub to receive a fair market price.

A new trading mechanism with a more rational pricing rule is necessary for facilitating information transmission in Asian LNG market, especially for countries which have less negotiation power, and it can create greater efficiency for resource allocation for whole energy market. If LNG prices change from being oil-indexed to being set on multiple indices or on spot gas-indexing, a new hedge strategy must be considered. Vertical risk-sharing could be used for lowering the risk in the LNG market before a direct hedge market, such as an LNG futures market, is available. Upstream integrating are usually used as the method to improve the security of a country’s domestic LNG supply, however, it is costly. A rational and reliable pricing rule is needed in Asian LNG market.
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