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Abstract

This paper investigated whether the effect of the shale gas revolution on the U.S. gas market is still a domestic phenomenon or this revolution is influencing the global natural gas market. We used the Bai-Perron test to identify the break date related to the shale gas revolution and tested the price linkages among the U.S., European and Japanese gas markets for the periods before and after this break date. The result indicated that the U.S. gas market had a price linkage with the international market for the period before the revolution affected the U.S. gas production, but this price linkage disappeared for the period after the revolution. This result implied that the U.S. gas market became independent after the shale gas revolution occurred and that the price linkage between the U.S. and international gas market became weaker after the shale gas revolution occurred.

Keywords

shale gas revolution, natural gas market, structural break

1. Introduction

The development in new technology for shale gas drilling increased shale gas production in the U.S. from 1% to 20% between 2000 and 2010. It is believed that this increased gas production has caused a downward pressure on gas prices worldwide (Stevens, 2012). This dramatic movement in the U.S. gas market, which is said to have begun in late 2005, is now known as the 'shale gas revolution' (McGregor, 2012). The U.S. Department of Energy estimates that the total unproved technically recoverable shale gas has more than quadrupled since 2006 to 482 trillion cubic feet at the end of 2011 (EIA, 2012). As the amount of extractable natural gas is increasing in the U.S., the U.S. will likely start to expand fracking to export shale gas to other countries. However, infrastructure such as the new liquefaction facilities and other technologies to liquefy natural gas is currently almost non-existent, and it may take several years before the U.S. is able to export this gas to other countries. Thus, although the shale gas revolution has dropped the price of natural gas in the U.S. market, we believe that the effect of the U.S. gas market on the international gas market is still limited at this stage. If this hypothesis is correct, it might be that the impact of the U.S. shale gas revolution is still a domestic phenomenon.

The objectives of this paper are to elucidate this issue and to determine whether the effect of the shale gas revolution on the U.S. gas market is still a domestic phenomenon or whether this revolution is influencing the global natural gas market. Accordingly, we will test how the relationships among the U.S., European, and Japanese natural gas markets have changed before and after the shale gas revolution took place around the mid-2000s.

Although many studies have investigated the integration of natural gas markets among different gas markets (Seletis and Herbert, 1997; Asche et al., 2002), most of these studies are limited to the regional level, such as within North America or Europe. To analyze market integration among international gas markets, Siliverstovs et al. (2005) tested the long-run market relationships among the North American, European, and Japanese natural gas markets. Their study indicated that the U.S. market is not integrated with the European and Japanese gas markets and that the European and Japanese markets are somewhat integrated. However, the period used for that study was 1993:11-2004:3, which is the period before the shale gas revolution is said to have taken place in the U.S. Thus, we hope that our study will update and configure the market relationship for the international gas market when the effects from the shale gas revolution are considered using the latest dataset.

The paper consists of two parts. In the first part, we statistically identify the break date using the U.S. natural gas marketed production time series data. Although it is claimed that the shale gas revolution occurred the in mid-2000s, no agreement exists in the U.S. regarding when exactly it happened. Hence, we assume that the statistically identified break point around the mid-2000s in the U.S. marketed production time series is the point at which the revolution began. In the second part of the paper, we split the U.S., European, and Japanese natural gas price series using the break point discovered in the first part and test how the price relationships among these three natural gas markets change.

We expect that the price relationships among the three countries will not change if the U.S. gas market continues to move together with the international market even after the shale gas revolution occurred. If this is the case, the price drop in the U.S. gas market will have a direct impact on the international gas market so that the prices of the international gas market will drop with the U.S. gas price. This phenomenon will occur if the international gas market responds quickly after the U.S. increases its gas production through the new technology for shale gas drilling. There are several possible reasons for the international gas market to be affected by the U.S. shale gas revolution. First, if the U.S. export of natural gas increases after the shale gas revolution, the structure of the international gas supply will be affected, and hence, the international gas price will drop because of the increased supply in the market. Second, even if the U.S. export of natural gas does not grow immediately, and if market participants expect the price of the international gas market to drop in the long run, the international gas market will likely be influenced by the revolution. Third, as the U.S. starts to use its own natural gas after the revolution the amount of natural gas imported to the U.S. will decrease, and if this amount is large, the demand structure of the international gas market can be affected. However, if the price linkage between the U.S. and the international gas markets changes after the break point, it is probable that the shale gas revolution only changed the structure of the U.S. gas market and did not affect the international gas market. This finding would mean that the causes that could influence the international gas market after the shale gas revolution were not very dramatic and that the supply shock after the revolution only affected the U.S. market. Thus such a finding would imply that the shale gas revolution is currently a domestic phenomenon.

We believe that the results of our study will help elucidate how newly discovered unconventional gas resources will influence the domestic market of the country where such new production becomes possible and how such production will affect the international gas market. Japan is currently the world leader for scientific research on methane hydrate gas recovery (Koh et al., 2012), and if the technology to obtain natural gas from methane hydrate becomes possible in Japan, a revolution similar to the U.S. shale gas revolution will likely occur in the Japanese gas market.

In the following section, we discuss the methods used to identify the break date for the shale gas revolution and the effects of this revolution on the international market linkages for natural gas. In the third section, the results of the econometric analysis are discussed. Finally, in the last section, we present the conclusion drawn from this study.

2. Methods

We use the Bai-Perron (BP) method (Bai and Perron, 1998) to statistically determine the break points in the production data. This method is useful when the break point is unknown and when the time series data contain more than one break point (Aruga and Managi, 2011). The statistical model used in the BP test is based on the following multiple regression models with *m* breaks:

$$\mathrm{y_t} = \mathrm{x_t'}\beta_\mathrm{j} + \mathrm{u_t} \quad (t = \mathrm{T_{j-1}} + 1, \dots, \mathrm{T_j},\ j = 1, \dots, m + 1) \tag{1}$$

where y_t is the dependent variable at time t $(t = 1, \dots, T)$, x_t is the vector of regressors, β_j is the corresponding vector of regression coefficients, and by convention, $T_0 = 0$ and $T_{m+1} = T$. The BP test uses the maximum F-statistic that is calculated from the global minimum of the sum of squared residuals obtained from equation (1) to statistically identify the number of appropriate breaks in the time series data by applying F tests for 0 vs. l breaks and l vs. $l + 1$ breaks (see Bai and Perron, 1998). The maximum number of breaks m is set to 2 in our model because the recursive estimates test (Ploberger et al., 1989) and F statistics test (Andrews, 1993) suggested that $m = 2$ is the favored model compared with other models. After setting m to 2, the statistically optimal number of breaks was identified when the residual sum of squares (RSS) and the Bayesian information criterion (BIC) became the smallest (see Zeileis et al., 2003). For the BP procedure, we mostly followed the explanation given in Zeileis et al. (2003).

Because we think that the effect of the U.S. shale gas revolution would be the most apparent in the natural gas withdrawal data, we use the natural log of the U.S. natural gas marketed production (million cubic feet) data to identify the break point. The data are obtained from the U.S. Energy Information Administration (EIA), and the length of the series we used is the 1992:1-2012:10 period. Figure 1 shows that the U.S. natural gas marketed production has an increasing trend after the drop in production related to Hurricane Katrina in September 2005. It is evident that this increasing trend after late 2005 is strongly related to the shale gas revolution.

We expect that the BP test will identify break points other than the one found around the mid-2000s. If we find other such breaks, we create exogenous dummy variables based on these break points. We then incorporate the effects of these breaks by including them in the cointegration model as an exogenous dummy variable. The dummy variable takes the value of 1 for periods after the break date and takes the value of 0 for periods before the break date. Because the maximum number of breaks m is set to 2 in our econometric model only one exogenous dummy variable is included in the cointegration model.

After identifying the break point that is relevant to the shale gas revolution, we separate the U.S., European, and Japanese natural gas price series into periods before and after this break point. All of the natural gas price series are obtained from the International Monetary Fund (IMF) Primary Commodity Prices. The U.S. gas price represents the spot price at the Henry Hub terminal in Louisiana. The European price is the Russian border price in Germany, and the Japanese price is the imported Indonesian liquefied natural gas price.

Figure 2 illustrates the natural log of the natural gas prices of the three countries. The figure shows that the natural gas prices of all three countries have a spiked in late 2008, which is related to the economic boom and collapse after the world financial crisis of 2008, but the U.S. gas price reflects a different trend compared to the European and Japanese gas prices. The minor difference is that the U.S. natural gas price has had several spikes around 2000-2001, 2005-2006, and 2008-2009. These spikes around 2000-2001 and 2005-2006 are related to U.S. domestic crises such as the California natural gas crisis of 2000-2001 and Hurricane Katrina in 2005. However, the major difference is that, as shown in the figure, although the world financial crisis of 2008 affected the natural gas markets of all three countries, the U.S. gas market exhibited a different trend after this crisis occurred compared to that of Europe and Japan. While the European and Japanese gas prices recovered from the drop after the financial crisis of 2008, the U.S. gas price continued to fall. This difference in the U.S. price trend is likely to be strongly connected to the shale gas revolution. The U.S. natural gas reserve has grown from 10% in 2007 to 32% in 2010, which is attributed to the development of shale gas. Furthermore, in 2009, the U.S. became the world’s leading producer of natural gas, surpassing Russia (Pirog and Ratner, 2012). To identify this different trend in the U.S. gas market after the effects of the shale gas revolution became apparent, we test the price linkages among the three countries.

To test the international price linkages, we apply the Johansen cointegration method (Johansen and Juselius, 1990) to the natural log of the U.S., European, and Japanese gas prices. We conduct stationarity tests on all prices series before performing the cointegration test. We use the augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests for this purpose. We perform these unit root and cointegration tests among the U.S., European, and Japanese prices series for the period before and after the break point around the mid-2000s.

The econometric model for the Johansen test has the following form:

$$\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Phi D_t + \varepsilon_t \quad (2)$$

where P_t is the $n \times 1$ vector of the natural gas prices, k is the order of the vector autoregressive process, $\Pi = -I + \sum_{i=1}^{k} A_i$ and $\Gamma_i = -\sum_{j=i+1}^{k} A_i$ when A_i is a $n \times n$ matrix of parameters, and D_t is the deterministic term that includes the exogenous dummy variable created from the results of the BP break test. The appropriate lag length for the cointegration model is determined by the Akaike information criteria (AIC). Because the prices in P_t are integrated of the same order by assumption, whether the variables of interest become cointegrated depends on the rank of the Π matrix. The rank of a matrix is equal to its number of significantly positive characteristic roots, which is called the eigenvalue. The test statistics for the cointegration tests are identified by this eigenvalue.

3. Results

From the results of the BP test, both the RSS and the BIC were smallest when tested for the model with two breaks compared to models with zero breaks and one break (see Table 1). This result indicates that two breaks is the statistically appropriate number of breaks in the U.S. natural gas marketed production series. The BP test found breaks in 2006:8 and 2009:9. As the shale gas revolution reportedly took place in the U.S. around the mid-2000s (McGregor, 2012), we assume that the break point relevant to the revolution is the break found in 2006:8. We believe that the break identified in 2009:9 is related to the world financial crisis, and this phenomenon was used to create an exogenous dummy variable to be included in the cointegration model. As 2009:9 occurs after 2006:8, this dummy variable was included when testing the cointegration relationships for the period after 2006:8.

Table 2 shows the result of the unit root tests conducted for the natural gas prices of the three countries. The stationarity tests performed for the entire period and the periods before and after 2006:8 all indicated that they are integrated of order one. The price series were non-stationary for the levels series, but they became stationary for their first differenced series. We then performed the cointegration tests for the entire period and the periods before and after 2006:8 among the pairs of natural gas prices for the three countries.

Table 3 shows the results of the cointegration tests. First, the test conducted for the entire period suggests that the U.S. gas price is not cointegrated with the European and Japanese gas prices. However, the prices of the European and Japanese gas markets have a cointegration relationship. This result is consistent with the study of Siliverstovs et al. (2005). Those authors find that while the U.S. gas market did not have a long-run relationship with the European and Japanese gas markets, a long-run relationship did persist between the European and Japanese gas markets. The change in the gas supply in the U.S. due to the shale gas revolution is the probable reason why the U.S. gas market is independent from that of European and Japanese markets. The U.S. may have started to manage more of its natural gas consumption by its domestic production after the shale gas revolution. However, because of technological issues such as the lack of liquefaction technology, exporting natural gas from the U.S. to other countries has been very limited during the 2000s. Hence, Europe and Japan had to continue to import natural gas from Russia, the Middle East, and Southeast Asian countries. The cointegration relationship among Europe and Japan may be implying that Europe and Japan remained importers of natural gas.

Second, as shown in Table 3, the cointegration test on the period before 2006:8 suggested that all pairs of the three countries have cointegration relationships. This finding implies that before the shale gas revolution occurred in the U.S., the gas markets of the three countries had market linkages and that the international gas market shared price information. Although shale gas drilling began in the 1990s, the dramatic increase in production in the U.S. did not occur until the mid-2000s. Thus, before the shale gas revolution, the U.S. had to rely on imported gas as did the European countries and Japan. This condition of the U.S. gas demand from the international gas market perhaps explains why the three countries had market linkages before 2006:8.

Finally, the test conducted for the period after 2006:8 indicated that none of the pairs of the three countries have cointegration relationships. These results indicate that the market linkage among the U.S. and the international gas market has weakened after the break in 2006:8. This weakening of the price linkage is likely related to the increase in the natural gas production in the U.S. Since the U.S. began to use its domestic gas production, the U.S. became less dependent on imported natural gas after the shale gas revolution. Thus, the U.S. gas market became less influenced by the international gas market after 2006:8. If the U.S. shale gas revolution had made the U.S. an exporter of natural gas, the gas prices of Europe and Japan could have dropped dramatically, as occurred in the U.S. market. However, as shown in Figure 2, this phenomenon did not happen. This finding suggests that the drop in the gas market in the U.S. due to the shale gas revolution is a domestic phenomenon.

4. Conclusions

Because the world still lacks the technology and infrastructure for gas export, we anticipated that the significant drop in the natural gas market related to the shale gas revolution in the U.S. is currently only a domestic phenomenon. We tried to show this phenomenon by testing whether the market linkage between the U.S. and international gas markets changed after the period when the shale gas revolution is said to have occurred. As we expected, our results indicated that the U.S. gas market had a price linkage with the international market for the period before the revolution affected the U.S. gas production, but this price linkage disappeared for the period after the revolution.

Our results indicated that the U.S. gas market became more independent from the international gas market after the shale gas revolution occurred, but this revolution has not yet increased the amount of U.S. gas export and does not currently influence the international gas market. Hence, it can be concluded that, currently, the effect of the U.S. shale gas revolution is a domestic phenomenon However, the results of this study will likely change when the facilities and technologies for exporting gas become available and when the production of shale gas or other unconventional gas begins to increase dramatically in other parts of the world. We believe that our study will become a useful comparison when such changes occur in the future.

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Table 1 Bai-Perron test

Number of breaks	0	1	2
RSS	1.62	0.64	0.58
BIC	-539.20	-759.07	-775.60

Table 2 Unit root tests

All (1992:1-2012:10)

	Level			First differences		
	ADF	PP	KPSS	ADF	PP	KPSS
US	-1.822	-2.315	1.343***	-5.382***	-13.948***	0.084
Japan	-0.728	-0.366	1.748***	-8.696***	-12.691***	0.121
Europe	-0.486	-0.777	1.722***	-5.924***	-15.093***	0.068

Before (1992:1-2006:7)

	Level			First differences		
	ADF	PP	KPSS	ADF	PP	KPSS
US	-1.052	-1.857	1.385***	-4.421***	-11.496***	0.026
Japan	-0.186	-0.313	1.113***	-11.784***	-11.784***	0.200
Europe	-1.037	0.073	0.968***	-3.901***	-13.922***	0.230

After (2006:8-2012:10)

	Level			First differences		
	ADF	PP	KPSS	ADF	PP	KPSS
US	-0.884	-1.365	0.850***	-4.285***	-7.934***	0.065
Japan	-1.711	-1.163	0.693**	-3.879***	-5.917***	0.083
Europe	-1.805	-1.979	0.154	-3.940***	-7.0342***	0.061

The unit root includes a constant but not a trend. *** and ** denote significance at 1% and 5%, respectively.

Table 3 Cointegration tests

All (1992:1-2012:10)

Variables	H_0: rank=r	Trace test	Max test
US vs. Japan	r=0	7.474	7.190
	r<=1	0.284	0.284
US vs. Europe	r=0	10.908	8.737
	r<=1	2.170	2.170
Europe vs. Japan	r=0	14.661*	14.520**
	r<=1	0.140	0.140

Before the shale gas revolution (1992:1-2006:7)

Variables	H_0: rank=r	Trace test	Max test
US vs. Japan	r=0	15.672**	15.265**
	r<=1	0.407	0.407
US vs. Europe	r=0	16.290**	14.265*
	r<=1	2.430	3.841
Europe vs. Japan	r=0	24.347**	23.665**
	r<=1	0.682	0.682

After the shale gas revolution (2006:8-2012:10)

Variables	H_0: rank=r	Trace test	Max test
US vs. Japan	r=0	9.868	8.592
	r<=1	1.276	1.276
US vs. Europe	r=0	25.491**	17.680**
	r<=1	7.811**	7.811**
Europe vs. Japan	r=0	11.806	11.455
	r<=1	0.351	0.351

** and * denote significance at 5% and 10%, repectively.

Figure 1 U.S. natural gas marketed production

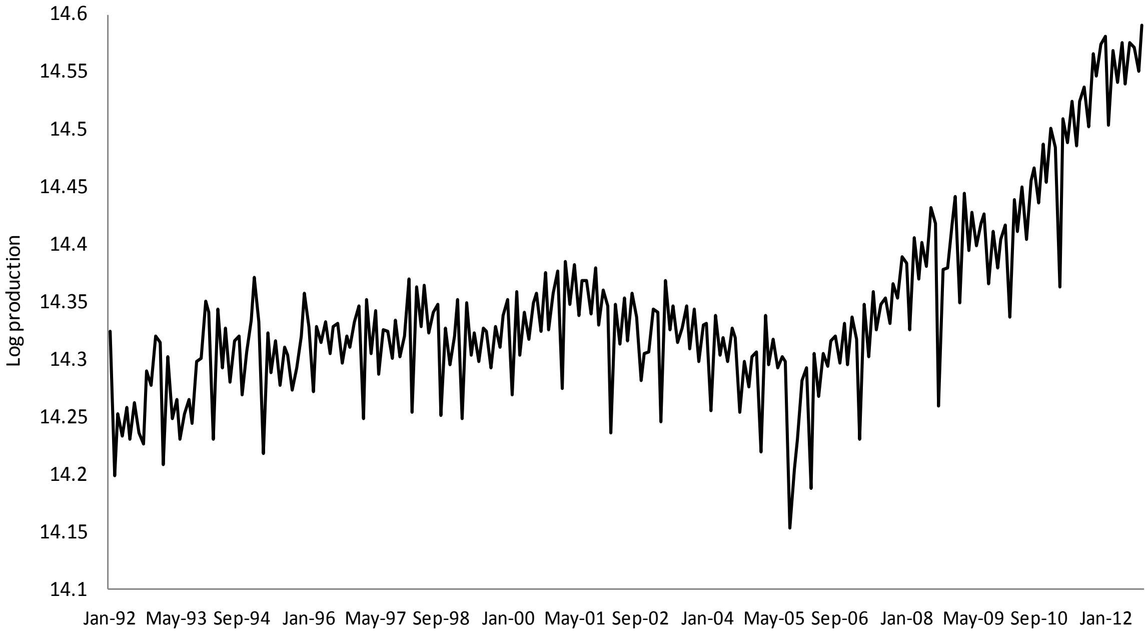

Figure 2 Plots of natural gas prices