

Article

Impact of US Shale Gas on the Vertical and Horizontal Dynamics of Ethylene Price

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Abstract: The rise of shale resources in the United States is changing the petrochemical industries. Ethylene, the first building block of petrochemical products, is becoming the first target to be hit by the shale boom, and its shifting price dynamics needs to be explored. This study analyzes the transition of ethylene prices from crude oil to natural gas (vertical price dynamics) and investigates widening gaps among regional ethylene prices (horizontal price dynamics). To do this, we detect structural changes in cointegrating relationships and derive time-varying cointegration equations. In addition, for the long- and short-run dynamics, this study established and estimated an error correction model (ECM), with controlling, time-varying cointegrations. This study develops econometric studies by applying time-varying cointegration to nonenergy uses of fossil fuels. Thereby, our results discover that the feedstock structure of US ethylene is moving from crude oil to natural gas and that the comovement of US and Japanese prices is getting intensified.

Keywords: time-varying cointegration; ethylene market; shale gas; error correction model

1. Introduction

The United States shale boom is widening the ethylene price gap between the US and other regions. From 2010 to 2014, the price range between the US, Northwest Europe, and Japan was narrow, from 1202 to 1272 USD/mt. However, from 2015 to 2018, the average price in the US was 612 USD/mt; while it was over 1000 USD/mt in Northwest Europe and Japan. This widening price difference is mainly due to the decline in natural gas and ethane prices, which are the feedstock of ethylene, with the advent of the shale era in the US. This study aims to explore the effect of shale boom on 1) the changing vertical relationship between US ethylene price and crude oil/natural gas, and 2) the horizontal gap between regional prices in the US, Japan, and Northwest Europe.

Ethylene (C₂H₄) is the most basic material in the petrochemical industry, and is used as a raw material for manufacturing various synthetic resins (e.g., high-density polyethylene, low-density polyethylene, and linear low-density polyethylene), synthetic fibers (polyester fibers), and synthetic rubber. Ethylene is produced by thermally decomposing hydrocarbons, such as petroleum or natural gas. Its production method is divided into naphtha cracking center (NCC), using naphtha refined from crude oil; and ethane cracking center (ECC), using ethane extracted from natural gas. In Asia and Europe, where the oil refining industry is developed, ethylene is mainly produced by the NCC method; while the ECC is adopted in North America and the Middle East, which have an abundance of natural gas. The NCC method has the advantage of coproducing not only ethylene, but also other petrochemicals such as propylene (C₃H₆), butylene (C₄H₈), and aromatics. With the ECC, ethylene yield is about 80%, and ethane is used almost exclusively as a feedstock for ethylene [1].

As of 2018, NCC's share of ethylene production facilities is 68% (ECC 15%) in Asia (excluding China), and it is 56% (ECC 12%) in Europe. On the other hand, the proportion of ECC facilities is 79% (NCC 3%) in North America and 69% in the Middle East (NCC 8%) [2]. In China, the share of NCC is large, but the proportion of coal-to-olefins (CTO) and methanol-to-olefins (MTO) is significant. Since ethylene is a gas at room temperature and pressure, the market tends to be divided into continents due to transportation restrictions. The main markets are North America, Asia, Europe, and the Middle East; the US makes up 21.4% of the market, China 15.4%, Saudi 10.1%, Korea 5.6%, Iran 4.2%, India 4.3%, and Japan 3.7% [3]. This study focuses on ethylene prices in the US, a representative ethane-based producer; and in Japan and Northwest Europe, which are both naphtha-based producers. Data are available for analysis in these areas.

The US has been the largest game-changer in the global ethylene market since its shale gas development has soared. Engineering studies of Armor [4], Kneißel [5], and Al-Douri et al. [6] predicted that the role of US shale gas is growing in the petrochemical industry, and shale gas technologies will significantly lower ethylene prices. Shale wells are wet gas wells containing large amounts of natural gas liquids (NGL), and they have rich ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and C_5 s. Alongside the US shale gas production, the extraction of ethane—the feedstock for ethylene—has also increased, and ethane prices plummeted. The emergence of cheap ethane in the US in the 2010s has encouraged companies to invest in ethylene production facilities. According to a report by the American Chemical Council, nearly 100 investments worth \$71.7 billion, which include ethylene and ethylene derivative projects, were announced in the chemical industry as of March 2013 [7]. By 2020, this number rose further, with facilities increasing production of ethylene to 11 million Metric Tons per Annum (MTA) in the last five years, and an additional 14 MTAs are expected over the next five [8,9]. With the abundant supply of natural gas and low ethane prices, the US is expected to increase its market share in the global ethylene market from 20% in 2017 to 22% in 2025, accounting for a significant share of ethane-based chemical exports in the mid- and long-run [10]. The expansion of the US, based on ECC and natural gas, would pose a threat to Asian and European countries using NCC and crude oil, further intensifying supply competition in the global market. Accordingly, the ethylene price difference between the US and other regions is expected to widen further. Moreover, the US is likely to expand the market based on ethylene price competitiveness.

Despite the shifting dynamics, economic research on ethylene and petrochemical markets, prices, and supply and demand has been limited. One of the biggest reasons for the lack of economic analysis on the ethylene market is the restricted access to data [11,12]. Researchers must pay an unaffordable subscription fee to obtain comprehensive data on the ethylene market, including prices, production, consumption, and inventory—and even then, the authority to publish research or reports is often limited. Nevertheless, limited data have been used in attempts to analyze the petrochemical market and price.

The relationship between prices of raw materials and petrochemical products (vertical relationship) has been covered in several previous studies [11,13]. The study by Titov and Ziane [11] was the first to examine the relationship between the prices of US ethylene and propylene, crude oil, and natural gas after the shale boom. However, it only provided a simple chart analysis due to data limitations. Oglend et al. [13] used an econometric approach of structural break tests and cointegration tests to find that the shale boom affected the weakening of the relationship between the prices of liquefied petroleum gas (LPG) and crude oil. However, there has not been a study that applies this type of econometric analysis to ethylene prices. This study, therefore, aims to develop literature and analyze structural breaks and cointegration relationship changes in the prices of ethylene and raw materials.

Our analysis on regional price gap (horizontal relationship) is rooted in studies by Kim et al. [12] and Masih et al. [14]. In the study by Kim et al., ethylene and propylene prices in the US and Asia were compared for regional difference and production methods. The research though, overlooked the changing dynamics after the shale boom because it estimated fixed parameters over the sample period. The study of Masih et al. is significant in that it explored regional differences by analyzing the

relationship between Far Eastern, Northwest European, and Mediterranean prices. However, because the focus was only on naphtha-intensive ethylene markets, US shale gas development, natural gas prices, and ethane-based production were not covered in the research. Our study differs in that it is not limited to naphtha-based regions but compares ethylene prices by expanding to the ethane-based regions like the US.

Other references on the ethylene market include a study on forecasted US ethylene supply in 2035 and 2050 in a conflicting environment of shale gas development and climate change risk [15]. The study predicted that despite various climate change scenarios, shale gas development and low feedstock prices would increase mid- to long-term US ethylene supply. In the research by Zhang et al., the economic performance and risks of China's coal-based ethylene and oil-based ethylene were compared [16].

In terms of methodology, this study develops models and ideas of Park and Zhao [17], and Brigida [18]. Both are representative econometric studies that reflect time-varying dynamics in the error correction model (ECM). Park and Zhao estimated time-varying cointegration equations and built an ECM that includes the residual as an error correction term. In Brigida's ECM, regime-switching cointegration equations were included. Both models commonly embodied the time-variance of the cointegration relation. However, the previous studies have mostly applied such techniques to crude oil, natural gas, and fuel products, and research applying them to nonenergy uses of fossil fuels does not exist to date. Therefore, this study develops literature by incorporating ECM with time-varying cointegration for nonenergy products of fossil fuels, by borrowing Brigida and Park and Zhao's methodology.

The objective of this research is to provide statistical and econometric analyses on the changing dynamics of ethylene prices using available data on the subject. It is to prove the hypothesis that the price relationships of ethylene and crude oil/natural gas and the comovement of regional prices are shifting after the shale boom in the US. On the price of ethylene since 2010, (1) we analyze the changes in the vertical relationship between the prices of crude oil and natural gas as raw materials, and ethylene as they were found to have structure-changed after the shale development [19]; and (2) the widening horizontal gap of US ethylene prices with other regional prices (Japan and Northwest Europe). First, the existence of structural breaks between variables are examined. Second, the change in the cointegration relationship is detected before and after multiple structural breaks. Third, cointegration equations allowing time variance are induced to estimate the ECM, determining the short- and long-term relationships among variables. This study has the originality of investigating the change in price dynamics of ethylene prices both vertically and horizontally, by applying time-varying econometric methods to nonenergy uses of fossil fuels.

This paper is organized as follows: Section 2 introduces the analytic methodologies of this study; Section 3 provides the results and significant findings of the analysis; Section 4 discusses these results; Section 5 presents the summary and implications of the research.

2. Materials and Methods

The detection method of multiple structural changes by Bai and Perron [20] was incorporated as the first step in showing whether (1) the vertical relationship among crude oil, natural gas, and ethylene prices has changed; and (2) if the horizontal relationship between US ethylene price to Japanese and Northwest European prices has shifted. Second, the cointegration tests of Johansen [21] were conducted within intervals between structural changes to check the time variance of the cointegrating relationships. Based on the results from the structural change and cointegration test, time-varying cointegration equations were estimated, applying the dynamic linear regression of Petris et al. [22]. Finally, ECM was estimated, borrowing the concept of Park and Zhao [17], who computed the ECM controlling for the time-variance of cointegration equations.

2.1. Detection of Multiple Structural Changes

According to Bai and Perron [20], if the total period is divided into m structural changes, and the regression coefficients β_j are estimated at each interval, the residual sum of squares (RSS) is given as

$$RSS(i, \dots, i_m) = \sum_{j=1}^{m+1} r_{ss}(i_{j-1} + 1, i_j). \quad (1)$$

The times (i, \dots, i_m) that minimizes the above RSS in Equation (1) are determined as the points of structural changes. To solve the minimization problem, Bai and Perron [20] adopted a dynamic programming technique of the Bellman equation, as shown in Equation (2):

$$RSS(I_m, n) = \min_{m n_h \leq i \leq n - n_h} [RSS(I_{m-1}, i) + r_{ss}(i + 1, n)]. \quad (2)$$

The process is computed with the R code offered by Zeileis et al. [23].

2.2. Cointegration Tests between Structural Changes

The cointegration test is used to determine whether the error of the linear combination between integrated variables is stationary. The Johansen [21] cointegration test is suitable for analyzing the cointegration of two or more variables given the lags of p , in the vector error correction model (VECM) of Equation (3):

$$\Delta Y_t = \Pi Y_{t-1} - \Gamma_1 \Delta Y_{t-1} + \dots + \Gamma_{p-1} \Delta Y_{t-p+1} + u_t. \quad (3)$$

If the rank of the matrix Π of Equation (4) is r , then y_t is determined to be cointegrated of rank r . In analyzing US ethylene price with crude oil and natural gas prices, $\Delta Y_t = [\Delta p_{US \text{ ethylene},t} \ \Delta p_{wti,t} \ \Delta p_{henryhumb,t}]$, and in analyzing the relationship between regional prices, $\Delta Y_t = [\Delta p_{JP \text{ ethylene},t} \ \Delta p_{US \text{ ethylene},t}]$ and $\Delta Y_t = [\Delta p_{NWE \text{ ethylene},t} \ \Delta p_{US \text{ ethylene},t}]$. The optimal lag p was selected by the Akaike information criterion (AIC).

$$\Pi = -(A_{i+1} + \dots + A_p), \quad i = 1, \dots, p - 1. \quad (4)$$

2.3. Error Correction Model with Time-Varying Cointegrating Equations

For the time-varying coefficients β_t in the cointegration equations of Equation (5), the Kalman filter and Kalman smoother of the state-space model are needed. The coefficient β_t s were set to unobservable state vectors, which follow independent random walks as in Equation (5).

$$y_t = \beta_{1t} + \beta_{2t}x_t + \varepsilon_t, \quad \varepsilon_t \sim N(0, \Sigma) \quad (5)$$

$$\beta_{it} = \beta_{i,t-1} + \epsilon_{it}, \quad \epsilon_{it} \sim N(0, V_i),$$

where in analyzing US ethylene price and raw material prices, $y_t = [p_{US \text{ ethylene},t}]$, $x_t = [p_{wti,t} \ p_{henryhumb,t}]$, and in analyzing the relationship between regional prices, $y_t = [p_{JP \text{ ethylene},t}]$, $x_t = [p_{US \text{ ethylene},t}]$, and $y_t = [p_{NWE \text{ ethylene},t}]$, $x_t = [p_{US \text{ ethylene},t}]$. In the above state-space model, β_t and Σ , V_i were estimated with maximum likelihood estimation (MLE) [22,24]. The estimates of time-varying coefficients were reported as Kalman-smoothed values that use information from the entire period, following the customs of time-varying estimations. After the residual in the cointegrating vector was determined stationary (variables are cointegrated), the ECM in Equation (6) was estimated with the error correction term (ect_{t-1}) computed from time-varying cointegration equations:

$$\Delta y_t = \theta_1 \Delta x_{t-1} + \dots + \theta_p \Delta x_{t-p} + \gamma_1 \Delta y_{t-1} + \dots + \gamma_p \Delta y_{t-p} + \phi ect_{t-1} + \omega_t, \quad (6)$$

$$ect_{t-1} = y_{t-1} - (\beta_{1,t-1} + \beta_{2,t-1}x_{t-1}).$$

2.4. Data and Sources

The analysis covers the period from January 2010 to December 2018. For the ethylene price data representing regional markets, the US Gulf price ($p_{US\ ethylene}$), Japanese price ($p_{JP\ ethylene}$), and Northwest European price ($p_{NWE\ ethylene}$) were used. For the raw material price of US ethylene, the crude oil price of Western Texas Intermediate (WTI) in Cushing Oklahoma and the natural gas price of Henry Hub were used. All data sets were obtained from Thomson Reuters’ Datastream [25]. Data were standardized to compare the size of coefficients and additional data, and processing was done depending on each methodology applied. It is computed by detrending time series and dividing it with its standard deviation. When testing cointegration and detecting its structural breaks, standardized level data were used; when estimating ECM, standardized first-differenced data were used following each model setting. Table 1 shows the descriptive statistics of the original data, and Figures 1 and 2 plot the trends of the raw and standardized data.

Table 1. Descriptive statistics. WTI—Western Texas Intermediate.

Data	Unit	Obs.	Mean	Std. Dev.	Min.	Max.
US ethylene price	USD/mt	471	918.8	367.0	270	1662
Japanese ethylene price	USD/mt	471	1168.4	167.7	739	1490
Northwest European ethylene price	USD/mt	471	1175.4	191.4	742	1670
WTI crude oil price	USD/bbl	471	74.09	22.41	28.1	112.3
Henry Hub natural gas price	USD/mmbtu	471	3.386	0.868	1.57	6.50

Source: Thomson Reuters Datastream [25].



Source: Thomson Reuters Datastream.

Figure 1. Trends of ethylene prices in the US, Japan, and Northwest Europe.

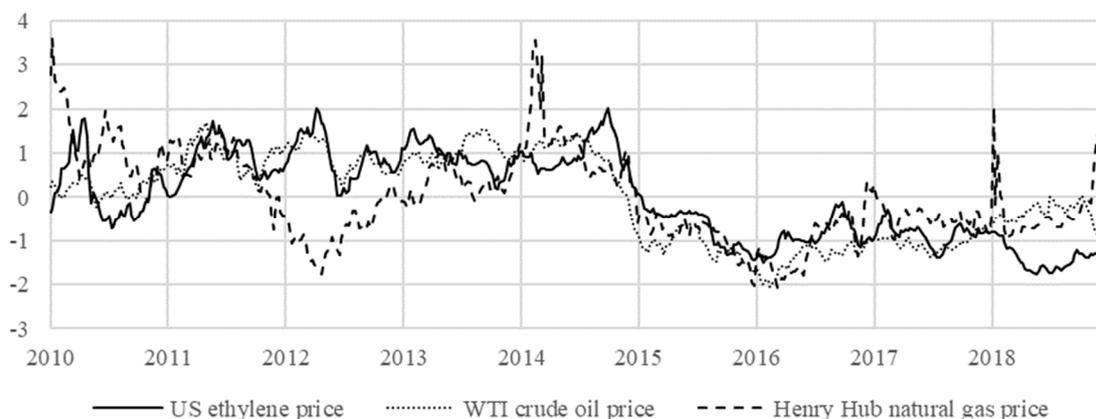
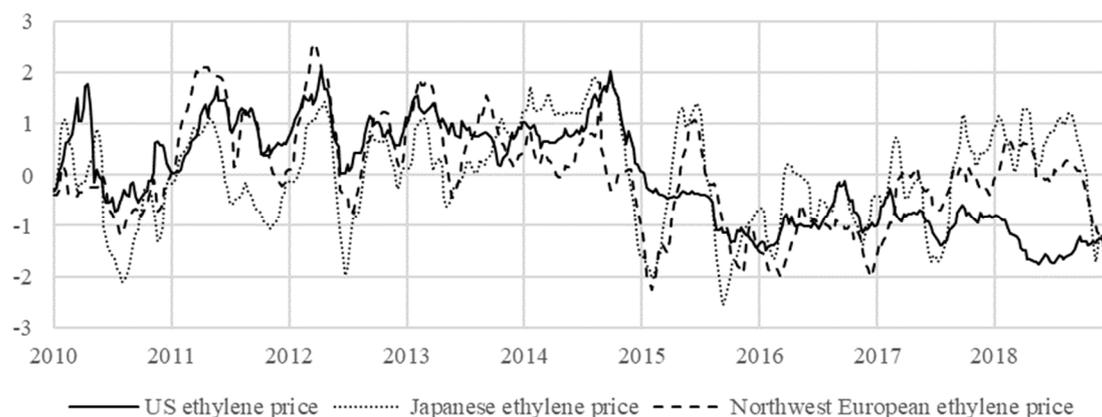


Figure 2. Cont.



Source: Thomson Reuters Datastream.

Figure 2. Standardized trends of ethylene vs. raw material prices (**top**) and regional prices (**bottom**).

3. Results

3.1. Relationship between the Prices of Ethylene and Its Raw Materials (Crude Oil and Natural Gas)

As a result of the structural change analysis on the relationship between raw materials and ethylene prices in the US, the optimal number of structural changes identified was four, and the timing was 29 April 2011, 22 March 2013, 25 August 2014, and 26 February 2016 (* in Table 2). It turns out that their relationship changed through the structural breaks. The result of the cointegration tests in five intervals between the endpoints and four structural break points shows that the existence and the number of cointegrating vectors have also varied over time (Table 3). Therefore, it can be determined that the relationship among variables and the presence/absence of equilibrium changed with the passage of time.

Table 2. Result of structural break analysis of US ethylene crude oil and natural gas prices.

No.	Date of Structural Breaks					BIC
0						825.87
1	26 May 2017					527.22
2			25 July 2014	26 February 2016		460.59
3	21 December 2012		18 July 2014	26 February 2016		423.21
4	29 April 2011	22 March 2013	25 July 2014	26 February 2016		418.01 *
5	29 April 2011	22 March 2013	25 July 2014	12 February 2016	16 June 2017	419.24

* marks the smallest Bayesian Information Criterion (BIC) statistics of Bai and Perron's test, which determines the points and the number of structural breaks.

Table 3. Result of cointegration test of US ethylene, crude oil and natural gas prices.

Dates	1 January 2010	29 April 2011	22 March 2013	25 July 2014	26 February 2016	31 December 2018
No. of cointegration	1	1	0	1	2	
Trace statistics	14.49	11.55	17.19	14.76	3.04	

The 5% critical value to reject the null hypothesis of zero maximal rank is 29.67, 15.41 for one maximal rank and 3.76 for two maximal rank; reported trace statistics are the ones at determined maximal rank (number of cointegration).

The time-varying coefficients of US ethylene prices on WTI crude oil price and Henry Hub natural gas prices are plotted in Figure 3. Overall, the effect on ethylene prices is more significant for crude oil than for natural gas, but the size of the coefficient of the former gradually decreases from 0.2 to 0.15 while that of the latter increases. Therefore, it can be summarized that the comovement of ethylene and

crude oil prices has weakened despite the larger contribution of crude oil to ethylene price, with the rising contribution of natural gas to ethylene price.

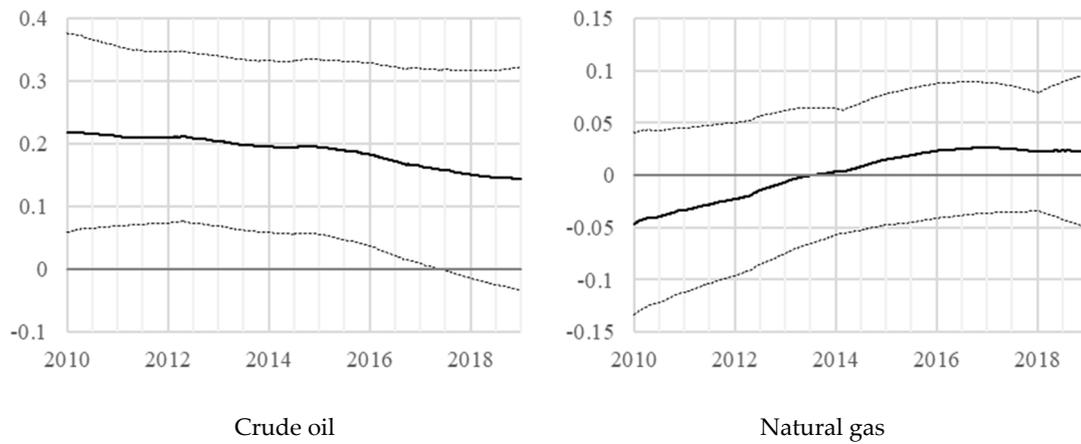


Figure 3. Time-varying coefficients of ethylene price on crude oil price (left) and natural gas price (right) in a cointegration equation.

When the residual from the time-varying cointegration equation was unit-root tested with Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) methodologies, the test results confirmed that it is stationary (Table 4). Thus, allowing time-variance in the cointegrating vector assures the cointegration among variables.

Table 4. Unit-root test results on residuals of the time-varying cointegration equation. ADF—Augmented Dickey–Fuller, PP—Phillips–Perron.

Unit-root Test Statistics	ADF	PP
Z-statistic	−30.33 ***	−41.02 ***

*** means Z-statistic rejects the null hypothesis of a unit root at a 1% significance level.

The estimated results of the ECM with time-varying cointegration equations are included in Table 5. It is noteworthy that the error correction term (ect_{t-1}) has a negative value at 1% significance level, which means when the three variables deviate from the equilibrium, they rapidly return to a new equilibrium that is set every time. In the case of explanatory variables, the ECM estimates the coefficients with one lag as negative at a 1% significance level (−0.126 and −0.013). Thus, when error correction terms and lagged coefficients are all considered, ethylene price recovers to equilibrium with a short-term adjustment, which it comoves with and goes opposite to raw material prices. In addition, the autoregressive coefficients with one lag are 0.995, with 1% significance in the ECM, and show that the autoregressive nature of ethylene prices is large.

Table 5. Estimated results of error correction model (ECM) including time-varying cointegration equations.

$y: \Delta p_{US\ ethylene,t}$	ECM
ect_{t-1}	-6.555×10^4 *** (491.01)
$\Delta p_{wti,t-1}$	−0.126 *** (0.010)
$\Delta p_{wti,t-2}$	−0.016 (0.010)
$\Delta p_{henryhub,t-1}$	−0.013 *** (0.003)
$\Delta p_{henryhub,t-2}$	0.002 (0.003)
$\Delta p_{US\ ethylene,t-1}$	0.995 *** (0.009)
$\Delta p_{US\ ethylene,t-2}$	0.012 (0.007)
R-squared	0.9778
Adj. R-squared	0.9775

*** indicates significance at the 1% significance level.

3.2. US Ethylene Price vs. Northwest European and Asian Prices

Structural breaks of US and Japanese prices and of US and Northwest European prices occurred four times in 2011, the second half of 2013, the first half of 2015, and the year 2017 (Table 6). The result of the cointegration tests in the five intervals before and after these four breaks are shown to change over time in Table 7.

Table 6. Structural changes in regional ethylene prices.

US—Japan						
No.	Date of Structural Breaks					BIC
0						1267.6
1						11 August 2017
2	20 September 2013					11 August 2017
3			13 September 2013	13 March 2015	11 August 2017	1039.0
4	16 September 2011			6 September 2013	13 March 2015	11 August 2017
5	29 April 2011	31 August 2012	3 January 2014	8 May 2015	11 August 2017	1086.6
US—Northwest Europe						
No.	Date of Structural Breaks					BIC
0						1101.9
1						24 February 2017
2	22 August 2014					24 February 2017
3			15 November 2013	3 April 2015	24 February 2017	910.3
4	29 April 2011			15 November 2013	3 April 2015	24 February 2017
5	29 April 2011	31 August 2012	24 January 2014	18 September 2015	17 February 2017	925.6

* marks the smallest BIC statistics of Bai and Perron's test, which determines the points and the number of structural breaks.

Table 7. Results of cointegration tests of the US–Japan and US–Northwest Europe.

US—Japan						
Dates	1 January 2010	16 June 2011	6 September 2013	13 March 2015	11 August 2017	31 December 2018
No. of cointegration		1	-	0	-	0
Trace statistics		2.11	-	13.35	-	3.55
US—Northwest Europe						
Dates	1 January 2010	29 April 2011	15 November 2013	3 April 2015	24 February 2017	31 December 2018
No. of cointegration		1	-	0	0	0
Trace statistics		5.14	-	11.17	13.44	8.54

'-' means that a trace statistics does not reject the null hypothesis that the number of cointegration vectors is at most 1; The 5% critical value to reject the null hypothesis zero maximal rank is 15.41 and 3.76 for one maximal rank; reported trace statistics are the ones at determined maximal rank (number of cointegration).

The cointegration equations allowing time variance were estimated and each coefficient was obtained, as shown in Figure 4. The upper panel of Figure 4 shows the regression coefficient and intercept of Japanese ethylene price on US ethylene price; and the lower panel of Figure 4 plots those of the Northwest European ethylene price on US ethylene price. First, the regression coefficient of Japanese ethylene prices shows a gradual increase from about zero in 2010 and has remained a significant positive value since 2012. It indicates that US and Japanese prices have even comoved since 2014, when the gap between the two prices has widened, and the gap is attributed to the fluctuations of the intercept. On the contrary, the regression coefficient Northwest European price continued to fall from the peak of 2012 and 2013 to almost zero in 2017, showing that US price has lost its explanatory power on Northwest European prices.

When residuals of time-varying cointegration equations are examined by the unit-root tests, the results in Table 8 show that the residual is stationary and the time-variance in cointegration vectors lets the variables cointegrate.

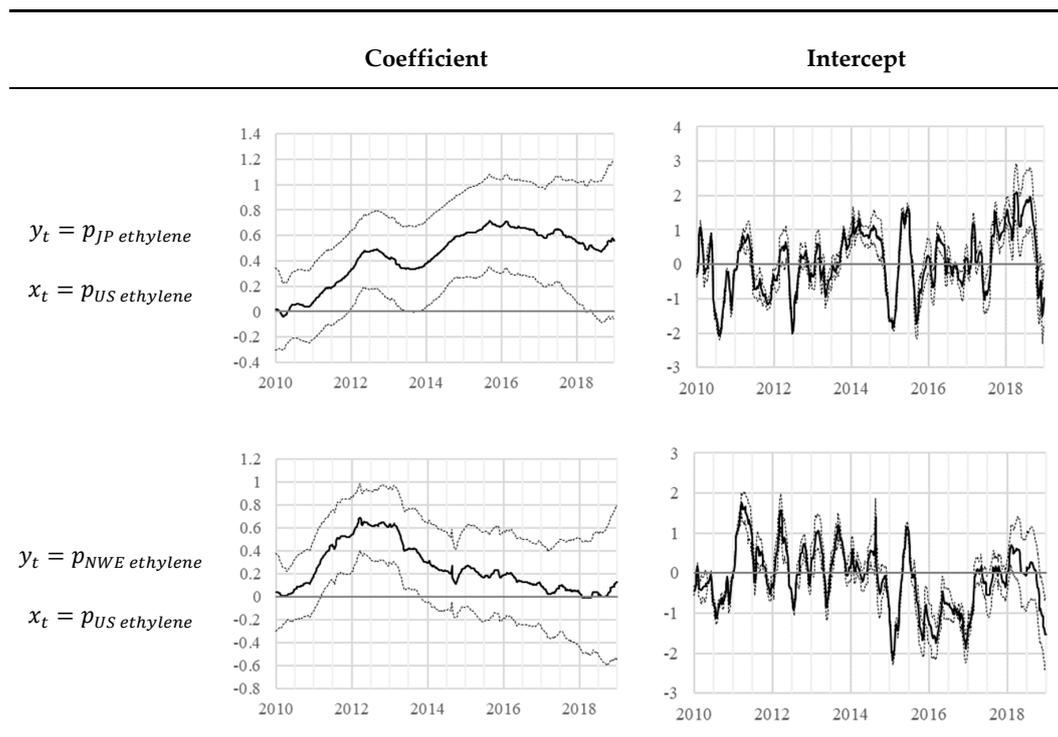


Figure 4. Time-varying coefficients and intercepts in cointegration equations.

Table 8. Unit-root test results (Z-statistic) on residuals of the time-varying cointegration equations.

Region	ADF	PP
US—Japan	−25.18 ***	−28.40 ***
US—Northwest Europe	−31.37 ***	−38.92 ***

*** indicates the test results reject null hypothesis of a unit root at 1% significance level.

The results of estimating the ECM using time-varying cointegration equations are shown in Table 9. The result of the analysis show that the error correction term has a negative value regardless of the estimating models and explained variables. In the case of Japanese ethylene price, the ECM result yields a negative one-lagged coefficient (−0.198) at the 1% significance level and a positive two-lagged coefficient (0.042) at the 5% significance level. This shows that Japanese prices decrease and increase with lags in response to the increase of US ethylene price. In the case of the Northwest European price, the resulting signs produced are similar to those of the Japanese price. The regression coefficient for the lagged US price is a significant negative value (−0.160) at the 1% level in the ECM. In both estimating models, the autoregressive coefficients are 0.971 and 0.965, respectively, indicating strong autoregressive traits.

Table 9. Estimated results of error correction model including time-varying cointegration equations.

	$y_t = \Delta p_{JP} \text{ ethylene}, t$	$y_t = \Delta p_{NWE} \text{ ethylene}, t$
ect_{t-1}	-1.420×10^7 *** (2.330×10^5)	-1.700×10^7 *** (2.909×10^5)
$\Delta p_{US} \text{ ethylene}, t-1$	−0.198 *** (0.021)	−0.160 *** (0.020)
$\Delta p_{US} \text{ ethylene}, t-2$	0.042 ** (0.021)	0.024 (0.021)
$\Delta p_{JP} \text{ ethylene}, t-1$	0.971 *** (0.016)	0.965 *** (0.019)
$\Delta p_{JP} \text{ ethylene}, t-2$	0.000 (0.015)	−0.024 (0.015)
R-squared	0.9318	0.9063
Adj. R-squared	0.9311	0.9053

, and * indicate significance at the 5%, and 1% significance levels, respectively.

4. Discussion

4.1. Relationship between the Prices of Ethylene and Its Raw Materials (Crude Oil and Natural Gas)

The relationship between the prices of ethylene and its raw materials has undergone structural changes since 2010. The timing of structural changes includes the year 2011, when oil price started to decline; 2012, when it rebounded; and 2014, when it significantly fluctuated. It can be assumed that fluctuations in oil prices have led to changes in these relationships.

Time-varying coefficients in cointegration equations show that the relationship between the prices of US ethylene and oil gradually weakened from 2010 to 2018. This finding is in line with the discovery of Oglend et al. that oil and LPG prices have weakened after the shale boom [13]. Contrary to the case of crude oil, the positive relationship between ethylene and natural gas prices strengthened. This reflects the close relationship between them as ethylene production from natural gas has increased since the shale boom. However, the crude oil price coefficient, which is larger than that of natural gas, shows that the former has a more significant relationship with ethylene price than that of the latter. This supports the findings of Foster, who indicated that crude oil prices exerted a stronger influence on US ethylene supply than natural gas prices [15]. In the ECM that includes time-varying cointegrating equations, the coefficient of crude oil price is higher than that of the natural gas price, supporting the higher explanatory power of crude oil.

4.2. US Ethylene Price vs. Northwest European and Asian Prices

The US, Japanese, and Northwest European prices also showed structural changes as the price gap among these regions widened. When analyzing the prices of US–Japan and US–Northwest Europe, the timing of structural changes between these two relationships commonly included the first half of 2015 and 2017. The year 2015 was the time when prices in Japan and Northwest Europe rebounded, but those in the US continued to remain low after the three prices fell simultaneously at the end of 2014. Likewise, in 2017, prices in Japan and Northwest Europe rose; as opposed to US prices, which hovered around the base. The 2017 result is interpreted as reflecting the expected completion of US ethylene production facilities and an increase in ethylene supply from the country.

When estimating the time-varying cointegration equations for US–Japan and US–Northwest European prices, the coefficient of Japan increases while that of Northwest Europe decreases. Such conflicting results can be interpreted in terms of ethylene trade. The US has replaced the reduction in ethylene exports to South America with the expansion in exports to Asia (from 10.2% in 2010 to 69% in 2017), which can lead to closer price relationships between the two regions. The US is also exporting to European nations, including Belgium–Luxembourg in Northwest Europe, but the exports to this area sharply decreased from 44% in 2015 to 12% in 2017 [26]. This seems to result in a weaker price relationship between the US and Northwest Europe. At present, US ethylene export growth has not been large due to transportation limitations and lack of export infrastructure. However, if ethylene production and export facilities are added, it is expected to increase supply in the US and global markets. By 2018, the US had only one ethylene export terminal, but two were expected to be added in 2020. Indeed, in January 2020, a new terminal built by Enterprise Products Partners and Navigator Holdings' joint venture was reported to have departed ethylene from the US for a Japanese trading company. In the medium to long term, the US would have export competitiveness based on cheap natural gas and ethane in the global market.

5. Conclusions

This study analyzes the change in the ethylene market and ethylene prices originating from the US. First, the shifting vertical relationship between raw materials (crude oil and natural gas) in the US; second, the horizontal price gap between the US and other regions (Japan and Northwest Europe). The structural changes in each relationship for the period 2010 to 2018 were detected and the

cointegration relationship was identified based on the resulting structural breaks, and the ECM with time-varying cointegration equations was estimated to provide short- and long-term relationships.

The results indicate that all relationships investigated have four structural breaks between 2010 and 2018, and the cointegration relationships also have varied passing resulting structural breakpoints. When cointegration equations were estimated by taking temporal changes into consideration, the effect of crude oil on US ethylene price declined, while that of natural gas rose. When it comes to regional prices, the US and Japan have continued to comove despite the gap since 2014, whereas the US and Northwest European prices have gradually weakened over time. Lastly, the estimated ECM with time-varying cointegration equations shows that the variables have properties that allow a swift recovery to a new equilibrium at each time in the long term, and while doing so, they adjust themselves by going up and down with lags in the short term.

Such findings have several policy implications. Due to the gap between oil and natural gas prices and the production of shale resources in the US, the difference in regional feedstock prices between oil-based NCC and gas-based ECC is expanding. The results of this study show that the relationship with the natural gas price is gradually increasing in the United States rather than with the crude oil price. When US natural gas and ethane prices continue to remain low, the US will emerge as a strong competitor in the global ethylene market with higher margins of ECCs than those of NCCs in Europe and Asia. The US natural gas is playing a more determinant role of ethylene prices than in the past, and the construction of ethylene facilities is accelerating the entry of the US into the global ethylene markets. Although it is unlikely that the US ethane-based products will dominate the Asian and European markets in the short run, it can lead to global oversupply and lower prices, and the volume of exports to Asian markets could increase. The US could take advantage of these opportunities, and Asia and Europe need to be prepared against intensifying supply competition by diversifying from naphtha- to ethane-based feedstocks, expanding natural-gas-using facilities, differentiating into high-value added products, etc. This study is significant in detecting such shifting structural trends and sheds light on the widening gap among local ethylene markets.

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