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Causal Relationship among Bioethanol Production, Corn Price, and Beef Price in the U.S.

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ABSTRACT : This paper investigates the impact of ethanol mandate on the price relationship between corn and beef using the monthly time-series data from January 2003 through December 2013. In addition, we examine the non-linearity in ethanol, corn, and beef markets. Based on the threshold cointegration test, we find the symmetric relationship in pairs with ethanol production-corn price and ethanol production-beef price whereas there is the asymmetric relationship between prices of corn and beef. Employing the threshold vector error correction and vector error correction models, we also find that the corn price in the U.S is caused by both ethanol production and beef price in a long-run when the beef price is relatively high. On the other hand, the corn price does not cause both ethanol production and beef price in the long run. Findings from this study imply that demanders for corn such as ethanol and beef producers have price leadership on corn producers.

Keywords : Asymmetric relationship, Ethanol production, Price leadership, Threshold vector error correction model, Vector error correction model

JEL 분류 : C22, Q11, Q41

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I. Introduction

The worldwide liquid biofuel production has increased more than five times during the past decade (Condon et al., 2015). According to Renewable Fuel Association (RFA), the United States (U.S.) ethanol production has increased from 1,465 million gallons in 1999 to 14,340 million gallons in 2014. The increased biofuel production such as ethanol and biodiesel is driven by mandates, subsidies, and favorable trade policies. The Energy Policy Act (EPA) of U.S. Renewable Fuel Standard (RFS) in 2005 and the Energy Independence and Security Act (EISA) in 2007 are good examples of the mandates.[1] RFS1, the first RFS program, mandates the usage of 4 billion gallons of biofuel in 2006 and schedules to increase the amount of 7.5 billion gallons in 2012 as a part of EPA. RFS2, which is the expansion of RFS1 in 2007 from EISA, requires to increase the production of biofuel to 36 billion gallons by 2022.

In the U.S., ethanol as the main biofuel product is produced mostly (more than 90%) from corn (U.S. Department of Energy, 2011). U.S. corn production for ethanol increased from 6% in 1999 to 36% in 2014. This implies that demand for U.S. corn has increased from a rise of ethanol production. In this sense, U.S. corn prices show an increasing trend for the years 2003 to 2013, reaching the historical high of about 6.7$/bu in 2012 according to the U.S. Department of Agriculture-National Agricultural Statistical Service of (USDA-NASS). Considering corn is one of the largest feeding crops for livestock in the U.S. covering about 55% of the feed share (Leibtag, 2008), an increase in ethanol production affect corn prices, and in turn, feedstock and meat prices.

According to Serra and Zilberman (2013) that review the previous literature on the biofuel-related price transmission, the previous studies focus on the price transmission between crude oil, biofuels, and feedstock market. Saghaian (2010), Serra et al. (2011),

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[1] The RFS program requires renewable fuel be blended into transportation fuel by rising to 36 billion gallons in 2022 even though RFS, commonly known as RSF1, originated by EPS act of 2005 now is referred to as RSF2.

and Chen and Saghaian (2015), for example, investigate the relationship between biofuel prices and biofuel crop prices. Based on their findings, biofuel prices affect prices of biofuel crops such as corn and soybeans since those crops are the main resources to produce biofuel. Furthermore, they find that biofuel prices affect prices of non-biofuel crops such as rice, tobacco, and alfalfa. Sahm et al. (2013) explain that an expanding the use of energy crops increases land competition and prices for land tenure. Even though findings from the previous studies present a possible price relationship between feedstock prices and meat prices, there are no studies that link the biofuel-related price transmission (crude oil-biofuel-biofuel crop-other crops) with meat prices (Serra and Zilberman, 2013).

To fill a gap in the previous literature on biofuel-related price transmission, this study investigates a causal relationship between ethanol production, corn prices, and beef prices in the U.S since U.S. is one of the largest production countries for ethanol, corn, and beef, and U.S. has a mandate for the corn-based ethanol production.2) Specifically, we investigate three different hypotheses. First, we examine the effect of U.S. ethanol policy on corn prices. In other words, this paper investigates an impact of an increased ethanol production from U.S. policy on a corn price. Second, this paper investigates a causal relationship between corn and beef prices in the U.S. since the main feeding crop for a cow is corn, and beef farmers decide their raising number of cow based on a market price of beef. Third, we test a relationship between ethanol production and beef price in the U.S.

Furthermore, this paper examines a possible asymmetric relationship between U.S. ethanol production, corn prices, and beef prices. Ethanol and beef markets are the demanders of corn, and a corn market is a supplier of ethanol and beef markets. Previous literature such as Awokuse and Wang (2009) and Bakucs, Falkowski, and Ferto (2014) find that a different market power along a supply chain is observed in many cases. They also argue that a different market power is one of the main factors to explain the

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2) Corn is one of the main input for ethanol and feed production, and beef price is a representative of meat price in the U.S.

asymmetric or nonlinear price relationship between supply chains.[3] In addition, high volatilities in corn and beef prices may cause the nonlinearity between ethanol production, corn price, and beef price base on Awokuse and Wang (2009). To investigate a relationship between ethanol production, corn price, and beef price with possible nonlinearity, this study employs the threshold vector error correction model (TVECM) suggested by Serra et al. (2011).

This study makes two key contributions to the previous and existing literature. The first contribution is adapting time-series analysis to investigate the relationship between crop and meat prices in the current context of increased ethanol production, to fill the gap in the existing literature. This study examines the possible long-run price relationship between feeding crops and meat prices based on the ethanol production in the U.S. (large country) from corn. Second, the TVECM model developed by Hansen and Seo (2002) allows to test short- and long-run dynamic price adjustments based on the asymmetric that is originated from a different market power along the supply chain.

Ⅱ. Literature Review

Many developed countries such as U.S. and the European Union (EU) mandate the minimum biofuel requirement in transportation fuels and implement the biofuel tax credit due to the greenhouse gas reduction (de Gorter and Just, 2009). According to the U.S. Energy Independence and Security Act (EISA) in 2007, a new renewable fuel standard (RFS) mandates the use of 15 billion gallons of corn-based ethanol until 2022. For these reasons, many previous studies have focused on the effects of increased ethanol production caused by government policies such as mandates or tax credits. The effects of mandates on U.S. corn prices are discussed by Anderson and Coble (2010), Carter et al. (2016), Drabik et al. (2016), Gehlhar et al. (2010), Oladosu et al. (2012),

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[3] Asymmetric or nonlinear price relationship along vertical chain indicates that each vertical chain has a different price response to shocks.

Roberts and Schlenkera (2013), and Sissine (2010). In addition, some previous studies examine the effect of mandates and tax credits on U.S. corn prices (Bento and Klotz, 2014; Gohin and Tréguer, 2010). The meta-analysis for the impact of ethanol policy on corn prices also has investigated by Condon et al. (2015). They find that the one billion gallon expansion of U.S. corn ethanol from the mandate in 2015 leads three to four percent of the rise in corn prices. Taheripour et al. (2011) also find that U.S. and EU mandates for biofuel cause a reduction of livestock production. Their results also show that the biofuel mandates contribute to an increase in the cropland to compensate for an increase of biofuel and non-biofuel.

Due to the increased production of biofuel based on the mandates or government policies, a price transmission between fossil fuel, biofuel, and crop prices has been extensively investigated. Saghaian (2010) investigates the price relationships between oil, ethanol, corn, and soybean using the vector error correction model (VECM). Serra et al. (2011) examine price relationships between U.S. corn, ethanol, oil, and gasoline using a smooth transition vector error correction model (STVECM). Studies such as Cha and Bae (2011) and Chang and Su (2010) focus on short-run causality between crude oil and feedstock prices using vector autoregressive model (VAR). McPhail (2011) examines the bidirectional causality relationship between crude oil and ethanol prices. Even though Serra and Zilberman (2013) mention the possible relationship between a biofuel induced a change in feedstock and agricultural prices, but to the best of knowledge, no study has addressed the empirical relationship between feedstock and meat prices, except Kim and Mark (2017). They investigate the relationship between prices of imported corn and domestic cattle in South Korea by using the threshold vector autoregressive (TVAR) model.

A few methods such as partial and general equilibrium models for the advent of biofuels on food prices are suggested by Zilberman et al. (2013). Utilizing the partial equilibrium method, Roberts and Schlenkera (2013) find that an introduction of U.S. biofuel mandate causes 30% increase in food prices. Based on the general equilibrium model, Al-Riffai et al. (2010) examine the impact of biofuel mandates of U.S. and EU on final food prices. These two methods derive the results based on simulation.

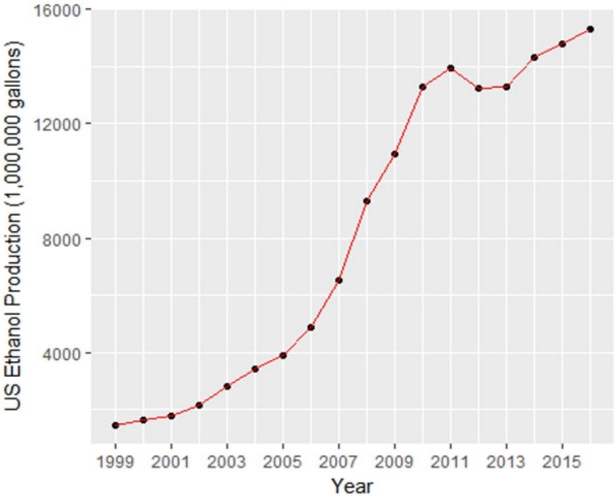
Based on our best knowledge, no study has been conducted previously to investigate the relationship between corn priced and meat prices by incorporating the ethanol production except for Leibtag (2008). Leibtag (2008) investigated the relationship between corn and meat prices in the U.S. since U.S. corn-based ethanol production had increased. The author found that a rise in corn prices has a positive effect on corn-based meats such as chicken and beef. However, the author only considered a symmetry assumption in the analysis that a price passes through to retail meat prices by an increase in feeding costs.

Even though Baier et al. (2009) and Leibtag (2008) tried to investigate the impact of biofuel production on food prices, but they did not provide ex-post relations in their analysis and used the simulation method. The simulation method is one of the ex-ante estimations, but this paper captures the ex-post relations among biofuel production, corn prices, and meat prices by using the time-series analysis. We employ the TVECM model to investigate a possible asymmetric relationship in prices of agricultural products. We also incorporate the ethanol and beef data series because these products are representative of biofuel and meats in the U.S.

Ⅲ. Data Description

This paper uses monthly time-series data for U.S. ethanol production, corn prices, and beef prices from January 2003 to December 2013. The data source for U.S. ethanol production is U.S. energy information administration (EIA), U.S. corn prices come from the NASS of USDA, and U.S. beef prices come from the USDA Economic Research Service (ERS). This study only focuses on the period from 2003 to 2013 that U.S. ethanol production had a rapid growth due to EISA 2005 and 2007 (see. Figure 1). This ethanol growth is due to the RFS program originated by the EPA of 2005 that requires a minimum volume of renewable fuels to reduce greenhouse gases. Moreover, RFS2, an extended program of the RFS by EISA of 2007, specifies the maximum amount of corn-based bio-ethanol and the minimum volume of cellulosic biofuel as 15 billion gallons and 16 billion gallons, respectively. In turn, a growth rate of ethanol production in the U.S. slowed after 2007; however, bio-ethanol production still has an increasing trend (see. Figure 1). Thus, U.S. ethanol production from the mandate could have an impact on corn and beef prices in the U.S.

〈Figure 1〉 Historic U.S. Fuel Ethanol Production



Source: U.S. ethanol production from U.S. energy information administration (EIA)

During the period from 2003 to 2013, prices of U.S. corn and beef show an increasing trend (see. Figure 2). Two possible explanations may support this phenomenon. First, risen in the U.S. corn prices may cause an increase in production costs for U.S. beef since corn is dominant in feeding sources for U.S. cattle.[4] In addition, the change in feeding costs may have an impact on beef supply since the change in supply costs could be

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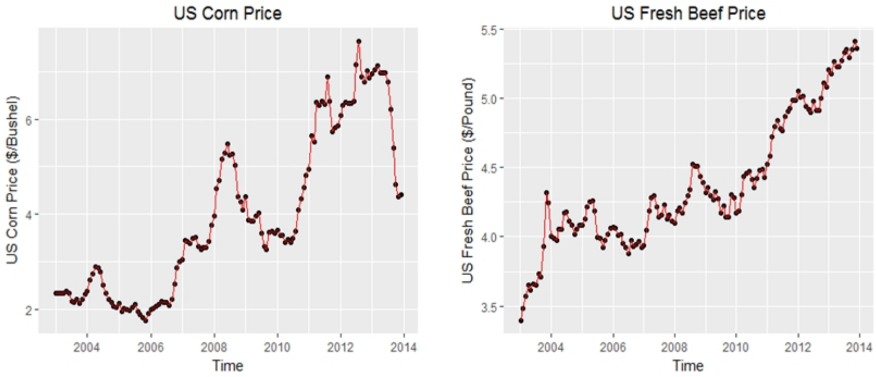
[4] See https://www.ers.usda.gov/webdocs/charts/feedgrainproductionjpg/feedgrainproduction.jpg?v=42809

related to supply itself. Second, a rise in the U.S. beef price may cause an increase in demand for U.S. corn since beef prices are one of the factors to decide the number of cattle produced. According to the estimation result of Arzac and Wilkinson (1979), the retail beef price has a positive effect on cattle and calf on feed. These possible explanations represent that corn is the supply market for beef, and beef is the demand market for corn. In turn, if one of the market prices is changed, then the price of the other market can be changed due to this variation.

〈Figure 2〉 The Historical Trend for U.S. Corn and Fresh Beef Prices



Source: U.S. Corn Price from USDA NASS and U.S. Beef Prices from USDA ERS

The main reason to focus on the ethanol rather than other biofuels is that ethanol has the largest share, by far, in the U.S. biofuel production (see. Table 1). This study also focuses on U.S. beef prices among U.S. meats because of two reasons. First, U.S. beef production in 2016 occupies about 50% share in the red meat market based on the USDA ERS dataset.5) Second, the average lifecycle of beef cattle production is generally longer than other livestock such as pigs and chicken, which indicates that feeding cost for beef production is higher than for others.

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5) https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data/#Red%20meat%20and%20poultry%20production

〈Table 1〉 Summary of the time-series literature on prices of fossil fuel, biofuel, crop, and beef

Author	Period	Country	Methodology	Variables used in the study	Findings
Saghaian (2010)	1996:01-2008:12	U.S.	Directed graph, Granger causality test	Prices of oil, ethanol, corn, soybean, and wheat	Unrelated between energy and crop prices
Serra et al. (2011)	1990:1-2008:12	U.S.	Smooth transition vector error correction model	Prices of ethanol, corn, oil, and gasoline	Non-linear long-run relationship among prices
Cha and Bae (2011)	1986:q1-2008:q4	U.S.	SVAR	Ethanol production, corn demand, prices of oil and corn	The impact of oil price on corn price and demand
Chnag and Su (2010)	2000:01/04-2008:07/04	World	Bivariate EGARCH	Prices of corn, soybean and crude oil	Substitutive effect of oil on corn and soybean prices during the higher oil price period
McPhail (2011)	1994:01-2010:02	U.S.	SVAR	Oil supply, oil price, gasoline retail price	Policy driven ethanol demand reduce crude oil price
Kim and Mark (2017)	2000:01-2014:12	Korea	Threshold VAR	Beef prices of Australia, Korea, and U.S. as well as corn price	Asymmetric short-run corn price effect on beef prices

IV. Methodology and Model Specification

Empirical procedures of this paper are composed of three parts. First part is the unit root and stationary tests, which are performed by the Augmented Dickey-Fuller (ADF) test from Dickey and Fuller (1979) and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test from Kwiatkowski et al. (1992), respectively. These tests are complementary because their null hypotheses are opposite. DeJong et al. (1988) state that the ADF test has a lower power if the alternative hypothesis has roots near unity. The second part is the Johansen cointegration test (Johansen, 1988; Johansen and Juselius, 1990) and the supreme Lagrange Multiplier (*supLM*) test for the linear vector error correction model (VECM) against the TVECM suggested by Hansen and Seo (2002). The third part is for using the VECM and TVECM based on the Johansen cointegration and *supLM* tests.

1. Stationarity Tests with ADF and KPSS

This paper uses the ADF and KPSS unit root tests to check the stationarity. These two unit root tests are complementary with opposite null hypothesis (Chen and Saghaian, 2016). While the null hypothesis of ADF is that a time-series data has a unit root, the null hypothesis of KPSS is that the time-series data is stationary.

The ADF test allows the test for the stationarity in each of the time series of ethanol production, corn prices, and beef prices in the U.S. The ADF test considers the following form:

$$\triangle y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \triangle y_{t-1} + \dots + \delta_{p-1} \triangle y_{t-p+1} + \varepsilon_t \tag{1}$$

where α is constant, β is the time trend coefficient, p is the lag order in the autoregressive process, and ε is a stationary error. The null hypothesis of ADF test is $\gamma = 0$ that indicates the presence of unit roots (i.e., the process is non-stationary). The alternative hypothesis of the ADF test is $\gamma < 0$ that represents the stationarity.

The KPSS test also allows testing for stationarity of each time series with opposite null hypothesis to ADF test. The KPSS test is based on the following equation:

$$y_t = r_t + \beta t + \varepsilon_t \tag{2}$$

where, r_t is a random work ($r_t = r_{t-1} + u_t$ and u_t follows the iid (0, δ_u^2), βt is a deterministic trend, and ε_t is a stationary error. The stationary hypothesis in KPSS test is $\delta_u^2 = 0$, and this test is performed by the LM statistic.

2. Johansen Test and the VECM

The Johansen cointegration test is performed to find the long-run relationship based on trace statistics. A general VAR model is the baseline for the Johansen cointegration test:

$$Y_t = \mu + \sum_{n=1}^{k+1} \Pi_n Y_{t-n} + \varepsilon_t \tag{3}$$

where, $\boldsymbol{Y_t}$ is a $i \times 1$ vector for U.S. ethanol production, corn prices, and beef prices, $\boldsymbol{\mu}$ is a $i \times 1$ constant vector, Π_n is a i × 1 parameter matrix, $k+1$ is the number of lags, and ε_t is the error term. This VAR model is rewritten as the following VECM equation with the error correction term:

$$\triangle Y_t = \mu + \Pi Y_{t-1} + \sum_{n=1}^{k} \Gamma_n \triangle Y_{t-n} + \varepsilon_t \tag{4}$$

where, $\Pi = \Pi_1 + \Pi_2 + \dots + \Pi_k - I$ and $\Gamma_k = -\Sigma_{j=k+1}^{p} \Pi_j$.

The long-run matrix Π can be defined as $\boldsymbol{\alpha\beta'}$, where α is the vector of adjustment parameter ($i \times r$) and $\boldsymbol{\beta}$ is cointegration vector ($r \times i$). Based on the trace statistics from the Johansen cointegration test, we can derive the rank of the cointegration vector (Π). The trace test is performed sequentially until we fail to reject the null hypothesis. First null hypothesis for a trace test is rank(Π) = 0, and the alternative hypothesis is $0 <$ rank (Π) ≤ 1. If the null hypothesis is rejected, then the next null hypothesis is rank(Π)= 1 and the alternative hypothesis is is $1 <$ rank(Π) ≤ 2. This sequential test will be performed until we fail to reject the null hypothesis of rank(Π) = r_0.

If we find the long-run relationship based on the cointegration test, then the error correction term (ECT_{t-1}) can be represented as $\boldsymbol{\beta' Y_{t-1}}$ that indicates the deviation from the long-run equilibrium at the time $t-1$. If we fail to reject that the adjustment parameter (α) is zero, then a long-run weak exogeneity exists in the econometric sense

(Granger, 1988). Γ, ethanol production, ethanol price, corn price, and beef price, indicates a short-run or temporary effect.

3. Hansen and Seo (2002) Test and the TVECM

A *sup-LM* test of a linear VECM against a TVECM with one threshold is suggested by Hansen and Seo (2002). The *sup-LM* maximal value is searched and done only for the case of a bivariate TVECM under the case of unknown cointegration vector (Stigler, 2010). TVECM is then extended for the VECM and is presented by the following equation:

$$\begin{bmatrix}\triangle X_t\\ \triangle Y_t\end{bmatrix}=\begin{cases}\begin{bmatrix}\mu_{XL}\\ \mu_{YL}\end{bmatrix}+\begin{bmatrix}\alpha_{XL}\\ \alpha_{YL}\end{bmatrix}ECT_{L,t-1}+\Pi_{1L}\begin{bmatrix}\triangle X_{t-1}\\ \triangle Y_{t-1}\end{bmatrix}+\ldots+\Pi_{pL}\begin{bmatrix}\triangle X_{t-p}\\ \triangle Y_{t-p}\end{bmatrix}+\varepsilon_{L,t}, ECT_{t-1}\le\nu\\ \begin{bmatrix}\mu_{XH}\\ \mu_{YH}\end{bmatrix}+\begin{bmatrix}\alpha_{XH}\\ \alpha_{YH}\end{bmatrix}ECT_{H,t-1}+\Pi_{1H}\begin{bmatrix}\triangle X_{t-1}\\ \triangle Y_{t-1}\end{bmatrix}+\ldots+\Pi_{pH}\begin{bmatrix}\triangle X_{t-p}\\ \triangle Y_{t-p}\end{bmatrix}+\varepsilon_{H,t}, ECT_{t-1}>\nu\end{cases}\tag{5}$$

where L is the lower-regime, H is the higher-regime, v is the threshold value for the error correction term, and all other subscriptions are identical as equation (4).[6] The TVECM has a long-run adjustment vector α based on a different regime and a temporary effect vector Π.

To check the threshold in the VECM, Hansen and Seo (2002) suggest the *supLM* test. The null hypothesis of the *supLM* test is a linear VECM, and the alternative hypothesis is a TVECM. The *supLM* test can be written as the following equation:

$$supLM=\underset{\nu_u\le\nu\le\nu_L}{supLM}(\tilde{\gamma},\nu)\tag{6}$$

where $\tilde{\gamma}$ is the estimated cointegration vector, v_u is the θ percentile of the error correction term, and v_L is the $(1-\theta)$ percentile of the error correction term. Utilizing a

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[6] We have three pairs which are (ethanol production, corn price), (ethanol production, beef price), and (corn price, beef price).

grid search method, Hansen and Seo (2002) select v that maximizes the *supLM* test statistics. They also suggest two bootstrap approaches with either a fixed-regressor or a residual bootstrap to estimate *supLM* statistics due to no standardize distribution for the *supLM*. If the null hypothesis of Hansen and Seo (2002) test is rejected, then the TVECM is estimated by the conditional least square (CLS) under estimates of cointegration vector $\tilde{\gamma}$ and threshold parameter v. If the null hypothesis of Hansen and Seo (2002) test is not rejected, then we alternatively use the VECM; the alternative hypothesis is the asymmetric long-run relation.

V. Empirical Results

Table 2 presents the results of not only unit root test with ADF and KPSS, but also the stationarity tests with the levels and the first differences. The ADF test for all level data fails to reject the null hypothesis of the unit root at the 10% significant level. The KPSS test for all level data rejects the null hypothesis of non-stationary at the 1% significant level. Since these two stationary tests are complementary, we perform the stationarity tests with first difference data, and we find the time-series data with the first difference is stationary based on ADF.

〈Table 2〉 U.S. Renewable Consumption (Quadrillion Btu)

	2013	2014	2015 E	2016 P
Hydroelectric power	2.562	2.469	2.257	2.415
Geothermal	0.214	0.222	0.226	0.236
Solar	0.305	0.427	0.522	0.624
Wind	1.596	1.729	1.765	2.042
Wood biomass	2.17	2.214	2.041	1.98
Ethanol	1.09	1.107	1.141	1.144
Biodiesel	0.205	0.198	0.222	0.261
Waste biomass	0.496	0.488	0.494	0.502
Total	9.349	9.603	9.432	9.97

Source: Short-Term Energy Outlook Renewables and Carbon Dioxide Emissions
Note: E and P represent Estimated and Forecasted, respectively.

Table 3 shows the pair results of Johansen cointegration test. The null hypothesis of $r = 0$ is that the pair is not cointegrated. The null hypothesis of $r = 1$ is that the pair is cointegrated with the rank 1. Results in Table 3 indicate that all pairs reject the null hypothesis of $r = 0$ at the 10% significant level, but fail to reject the null hypothesis of $r = 1$. Therefore, we conclude that all pairs have a long-run relation with the rank 1.

〈Table 3〉 Results of the Stationarity Tests

Variables		Level			First Difference			
		ADF	KPSS		ADF		KPSS	
US Ethanol Production	With Time Trend	-1.25	0.55	***	-9.51	***	0.11	*
	Without Time Trend	-0.51	4.37	***	-9.55	***	0.12	
US Corn Price	With Time Trend	-1.95	0.23	***	-5.97	***	0.13	*
	Without Time Trend	-1.36	3.58	***	-5.97	***	0.14	
US Beef Price	With Time Trend	-2.64	0.61	***	-8.52	***	0.07	
	Without Time Trend	-0.99	3.73	***	-8.55	***	0.07	

Note: ***, **, * Significant at the 1%, 5%, and 10% level, respectively.

Table 4 presents the VECM results of U.S. ethanol production and corn price series. The pair of U.S. ethanol production and corn price series only shows a linear cointegration relationship because the *supLM* test fails to reject the linear cointegration in this pair. The coefficient for ethanol production's ECT_{t-1} (speed of adjustment) is statistically insignificant, which indicates that U.S. ethanol production does not adjust toward the long-run equilibrium. The coefficient for corn price's speed of adjustment is positive and significant, which means that each period correction in the U.S. corn price makes a deviation from the long-run equilibrium. Specifically, the speed of adjustment coefficient, 0.0251, indicates 2.51% of deviation for each period of correction from the long-run equilibrium corn prices in the U.S. The significant results of adjustment parameters imply that U.S. ethanol production causes U.S. corn price based on the long-run weak exogeneity, but not vice versa (Granger, 1988). The demand factors for corn such as the EPA in 2005, EISA in 2007, and subsidies for biofuels may explain these long-run Granger causalities since U.S. corn production has increased our data period. Thus, we can conclude that the ethanol production leads to a long-run Granger causation of corn prices since U.S. ethanol production is originated from a government policy and depends heavily on corn. To be specific, ethanol producers in the U.S. set their production level based on the policy of the U.S. government, not on corn prices. In other words, U.S. ethanol market has a price leadership on a corn market. The estimated cointegration vector indicates that 1% increase in the U.S. ethanol production will lead to 1.82% increase in the U.S. corn prices in the long-run. This implies that U.S. government policy for biofuels is one of the major factors to explain the recent increasing trend of corn prices.

〈Table 4〉 Johansen Cointegration Test

	Trace Test	
	r = 0	r = 1
US Ethanol Production-Corn Price	20.27^{**}	4.27
US Ethanol Production-Beef Price	20.23^{**}	2.87
US Corn-Beef Prices	19.82^{*}	2.33

Note: ***, **, * Significant at the 1%, 5%, and 10% level, respectively.

Table 5 presents the results of VECM and TVECM for the U.S. corn and beef price pair. Based on the results of the *supLM* test, the null hypothesis of linear VECM is rejected at the 1% significant level, which indicates a potential threshold effect in the U.S. corn and beef price pair. The significance of ECT term in TVECM indicates that beef prices cause corn prices in a long-run only at regime 2.7) These results imply that U.S. beef price is transmitted to U.S. corn prices, but not vice versa. In other words, a beef market in the U.S. has a price leadership on a corn market. It is supported by Baier

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7) Regime 1 and 2 represent the regimes where $ECT \leq 1.8869$ and $ECT > 1.8869$, respectively.

et al. (2009) that find no direct effect of biofuel production on beef prices in the U.S. There are two possible explanations: first, this result implies that feeding costs are not large in the U.S. beef production. Second, U.S. beef producers can change the feedstock from corn to other crops such as soybean and hay. At the regime 2, the coefficient of the speed of adjustment for corn price presents a rapid (57%) adjustment toward the long-run equilibrium each month. The cointegration vector indicates that 1% increase in the U.S. beef prices will lead to 0.91% increase in the U.S. corn prices.

〈Table 5〉 Linear VECM: U.S. Ethanol Production and Corn Price

	$\triangle \text{Ethanol}_t$	$\triangle \text{Corn}_t$
ECT_{t-1}	0.0093	0.0251 ***
	(0.0171)	(0.0115)
Intercept	0.1191 ***	0.0035
	(0.0346)	(0.0233)
$\triangle \text{Ethanol}_{t-1}$	-0.5109 ***	0.0684
	(0.0933)	(0.0628)
$\triangle \text{Ethanol}_{t-2}$	-0.0031	-0.0075
	(0.0928)	(0.0625)
$\triangle \text{Corn}_{t-1}$	-0.0961	0.2905 ***
	(0.1313)	(0.0884)
$\triangle \text{Corn}_{t-2}$	-0.0682	0.1332
	(0.1329)	(0.0895)
Cointegration Vector	(1, -1.816)	
supLM test	14.425	

Notes: ***, **, * Significant at the 1%, 5%, and 10% level, respectively. ( ) is robust standard error.

Specifically, the TVECM estimation method by Hansen and Seo (2002) provides two different regimes depending on the threshold parameter value. The threshold value, 1.8869, indicates the point of nonlinearity between corn and beef prices in ECT since

TVECM allows to find the threshold point in ECT. Regime 1 presents the period that the growth rate of corn prices is relatively low compared to the beef prices (*US Corn Price* $-0.9091\times$*US Beef Price* ≤ 1.8869), and regime 2 indicates the period that the growth rate of corn prices are relatively high compared to the beef prices (*US Corn Price* $-$ $0.9091\times$*US Beef Price* > 1.8869). At regime 2, the beef price of ECT term is significant, which indicates that the U.S. beef price causes corn prices in the long-run only. In other words, an increase in the U.S. beef prices leads to an increase in corn prices in the long-run only when the relative corn prices are high (regime 2). In regime 2, U.S. beef price is high (see Figure 3). To sum up, U.S. beef prices a long-run granger cause corn prices in the long run with high beef prices (regime 2).

〈Figure 3〉 Timing of Threshold Adjustment in the U.S. Corn and Beef Price Pair

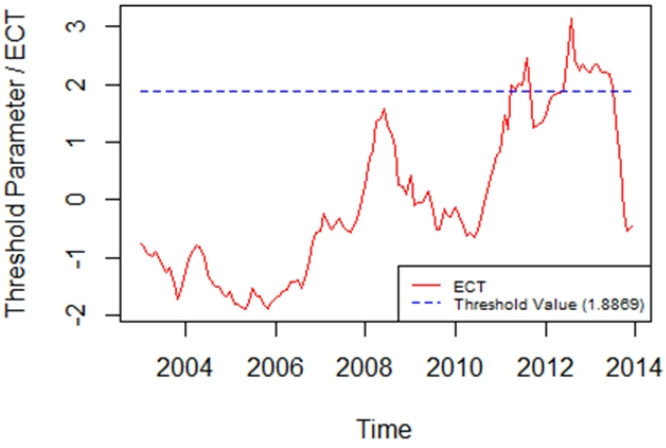

Table 6 presents the results of U.S. ethanol production and beef price pair. The *supLM* test fails to reject the null hypothesis that the pair has a linear cointegration relationship, which leads to using the VECM. Both coefficients of ECT are insignificant, which indicates there is no weak exogeneity and Granger causality in the long-run relationship. This result implies that U.S. ethanol production does not lead U.S. beef prices in a long-run and vice versa. In other words, there is no direct relationship between ethanol and beef markets.

〈Table 6〉 Linear and Threshold VECM: Corn and Beef Prices in the U.S.

	Linear VECM		Threshold VECM			
			Regime 1 (ECT$\leq$1.8869)		Regime 2 (ECT > 1.8869)	
Observations (%)	-		84.5%		15.5%	
	$\triangle\mathrm{Corn}_t$	$\triangle\mathrm{Beef}_t$	$\triangle\mathrm{Corn}_t$	$\triangle\mathrm{Beef}_t$	$\triangle\mathrm{Corn}_t$	$\triangle\mathrm{Beef}_t$
ECT_{t-1}	-0.0223	0.0064	-0.0109	0.0062	-0.5688***	0.0060
	(0.0165)	(0.0051)	(0.6004)	(0.3758)	(0.0062)	(0.9301)
Intercept	0.0120	0.0141***	0.0197	0.0130	1.3935***	0.0395
	(0.0227)	(0.0070)	(0.4087)	(0.1077)	(0.0031)	(0.7998)
$\triangle\mathrm{Corn}_{t-1}$	0.2692***	-0.0039	0.2674***	0.0177	0.3611***	-0.0553
	(0.0878)	(0.0271)	(0.0125)	(0.6185)	(0.0356)	(0.3351)
$\triangle\mathrm{Corn}_{t-2}$	0.1420	0.0175	0.2925***	0.0207	-0.2566	-0.0840
	(0.0888)	(0.0274)	(0.0059)	(0.5573)	(0.1440)	(0.1551)
$\triangle\mathrm{Beef}_{t-1}$	0.2700	0.1758***	0.2993	0.2271***	-2.5796***	-0.4385
	(0.2871)	(0.0887)	(0.2810)	(0.0161)	(0.0109)	(0.1936)
$\triangle\mathrm{Beef}_{t-2}$	-0.5828***	-0.1656**	-0.3703	-0.1940***	-2.7073***	0.0305
	(0.2867)	(0.0886)	(0.1855)	(0.0404)	(0.0026)	(0.9180)
Cointegration Vector	(1, -0.9091)					
supLM Test	26.2666***					
Threshold Paramet	1.88689					

Notes: ***, **, * Significant at the 1%, 5%, and 10% level, respectively. ( ) is robust standard error.

〈Table 7〉 Linear VECM: U.S. Ethanol Production and Beef Prices

	$\triangle \text{Ethanol}_t$		$\triangle \text{Beef}_t$	
ECT_{t-1}	-0.0044		0.0017	
	(0.0108)		(0.0023)	
Intercept	0.1051	***	0.0172	**
	(0.0352)		(0.0074)	
$\triangle \text{Ethanol}_{t-1}$	-0.4790	***	-0.0196	
	(0.0899)		(0.0189)	
$\triangle \text{Ethanol}_{t-2}$	0.0097		-0.0260	
	(0.0894)		(0.0188)	
$\triangle \text{Beef}_{t-1}$	-0.2513		0.1805	**
	(0.4200)		(0.0883)	
$\triangle \text{Beef}_{t-2}$	0.7401	*	-0.1539	*
	(0.4193)		(0.0882)	
Cointegration Vector	(1, -1.7070)			
supLM test	13.39			

Notes: ***, **, * Significant at the 1%, 5%, and 10% level, respectively. ( ) is robust standard error.

VI. Conclusions

This study investigated the possibility of threshold cointegration relationship between U.S. ethanol production, corn prices, and beef prices by using the data from 2003 to 2013 by employing the TVECM method. The results show a threshold cointegration in price pairs of corn and beef in the U.S. On the other hand, we find that a linear cointegration in two pairs: between U.S. ethanol production and corn prices and between ethanol production and U.S. beef prices. According to the results of the linear cointegration based on the VECM, we found that ethanol production causes the corn price in the long-run. This finding is not surprising because increasing ethanol production pushes the demand for corn outward.Base on the TVECM results, we find two different regimes for the threshold parameter value of 1.8896 (=*US Corn Price* −0.9091×*US Beef Price*). In regime 2, when the growth rate of corn prices is relatively high compared to beef prices and beef price is high, we find the existence of the long-run relation between prices of U.S. beef and corn. More specifically, U.S. beef prices cause corn prices in the long-run based on the significant coefficient of the ECT term in regime 2. In other words, increasing in beef price results in increasing in corn price, but not vice versa in regime 2. This result indicates that feeding cost for cow is not a major factor for explaining the beef price in the U.S. However, beef market in the U.S. is large enough to impact on corn prices as a demander of corn especially when the beef price is relatively higher than the corn price.

Our findings provide some contributions and implications. First, most existing studies focus on the relationship between biofuel price and food price (especially crop price). Therefore, findings in this study will fill a gap in previous and existing studies by investigating not only the relationship between ethanol production driven by U.S. government policy but also the relationship between corn (feeding crop) price and beef price. Thus, the policymakers in the U.S. should consider the indirect impact of biofuel policy to evaluate its effectiveness. Second, our results—the positive causation of ethanol production on corn prices in the U.S.—imply that the biomass-based biofuel is more attractive than corn-based biofuel since residue-based biofuel does not have land competition with crops for livestock feeding. In turn, RFS2 is appropriate since RFS2 requires the increased amount of biomass-based biofuel until 2022. Second, this paper finds the asymmetric price relationship between corn and beef. The asymmetric relationship might represent the different market power between corn and beef in the U.S. Based on the result from TVECM, we find that beef price causes corn price in long-run, implying that beef market has price leadership on corn market; in other words, U.S. beef market has a market power on the corn market. Thus, U.S. should assess the overuse of the market power in the beef market in order to maximize social welfare. Third, our results imply that U.S. ethanol market has a price leadership on the corn market based on the unidirectional long-run Granger causation. Thus, U.S. corn market could be considered as a responsive market for corn demanders such as ethanol and beef producers. In other words, the ethanol is produced regardless of corn prices due to the RFS requirements, which implies the imperfect ethanol market in the U.S. Thus, U.S. should improve the policy to make the competitive ethanol market.

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