Examination of asymmetric supply response in the U.S. livestock industry

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Abstract

This paper aims to investigate asymmetric supply response in the U.S. cattle, hog, and chicken industries. This investigation can be described in the context of structural change of the U.S. livestock industry. That is, the move to larger operations that occurred from the economies of scale that exist in many of these sectors today results in an inability to adjust to low profitability because of the high capital outlays associated with the large facilities. These same economies of scale allow for quick expansion in periods of high profitability. For this purpose, the threshold autoregressive (TAR) model and the momentum threshold autoregressive (M-TAR) models are used to analyze these industries. The empirical results of the M-TAR model suggest that there is evidence in support of the presence of asymmetric supply response in the hog and chicken industries. In contrast, there is presence of symmetric supply response for cattle. The finding for the hog industry is consistent with a priori that the positive discrepancy from the long-run equilibrium made by the producers' expectation of high profitability may more quickly adjust to equilibrium while the negative discrepancy created by the producers' expectation of low profitability tends to persist. Overall, the empirical results suggest that there is evidence in support of symmetric supply response for the cattle industry, while there is the presence of asymmetric supply response for both the hog and chicken industries. These findings imply that the recent structural change in the cattle industry has contributed to improving the production efficiency for cattle, but in the hog industry and the chicken industry, there might exist potential production inefficiencies that should be corrected.

1. Introduction

Information on agricultural supply response can be regarded as an important indicator for policymakers to establish agricultural policies in assessing efficiency in agricultural production because the price elasticity of supply can quantify the response of producers to changes in economic factors and the introduction of associated policy (Albayrak, 1997). In addition, the extent of the agricultural supply response is very informative to judge whether there exist efficiencies in the current facilities of production in handling the expected quantities, or whether it is desirable for the existing policy of products for growth in the agricultural industry.

In microeconomics, the definition of agricultural supply response is how much change in agricultural output occurs with respect to changes in the output price, holding other factors fixed. This notion implicitly assumes that the change in output in absolute value is the same regardless of whether output prices increase or decrease. In this sense, agricultural supply is said to be symmetric or reversible (Mamingi, 1996). The estimates of the agricultural supply response in many previous studies are based on this assumption. Conversely, asymmetric or irreversible supply response is described as occurring when increases or decreases in prices do not lead to the same change in agricultural output. With regard to this, Heady et al. (1958) mention that this phenomenon in the agricultural sector, in reality the imbalanced changes in output to price increases and price decreases, are mainly attributed to sticky assets such as land, buildings or equipment. Although these facilities for agricultural production are introduced in the periods of high output prices, producers have few options but to retain the production facilities even in periods of low output prices. Consequently, due to practical constraints, decreases in output to falling prices do not proportionally match increases in output to rising prices.

This concern can be found in the context of structural change of the U.S. livestock industries. The structures of the livestock industries in the U.S. have changed into efficient systems for livestock production by increasing size, specialization of operations and technological innovation in production. Specifically, concentration in cattle, hog and chicken slaughter has intensified over time. According to the fact sheet in the National Farmers Union (2014) and Hendrickson and Heffernan (2007), concentration in steer and heifer slaughter has increased since 1990 with some small firms being acquired by the top four firms and the share of hog slaughter by the four largest firms has increased from 59 percent in 2001 to about 63 percent in 2013. Moreover, the chicken industry has grown to combine production stages into large vertically integrated firms that can take advantage of technological advancement (National Chicken Council, 2016). In this situation, the ability to attain economies of scale might be highly relevant to the success of a large-scale operation. Theoretically, it may be feasible when economies of scale are realized so that producers will have a better chance to reduce its costs by spreading the cost of the inputs over an increase in its production units. In this sense, concentration of the livestock supply by a small number of the large-scale livestock producers with the recent structural changes enables them to realize cost savings and to allow them to be more competitive than small-scale farm operators (Dyck and Nelson, 2003).

However, despite the fact that large-scale livestock producers have taken advantage of economies of scale for livestock production, many of them might be suffering from financial difficulty due to decreases in the real price of livestock for decades (Food & Water Watch, 2015). This issue might be highly relevant with the fact that the extent to which livestock production has adjusted to a change in output prices under given fixed costs. According to USDA_GIPSA (2008), since 2000, the proportion of operating income to sales of the larger packers, in spite of having a lower operating expenses ratio, have trended downward due to high fixed cost for livestock production and weak output prices. Producers may supply livestock for slaughter to the market at the expense of the loss to cover the high capital outlays only if the fixed costs are lower than the loss. Specifically, in periods of high prices, if prices are enough to cover the average costs of livestock production, the large facilities that have resulted from the economies of scale are likely to respond promptly. However, the period of low prices discourages producers to expand the supply of livestock. That is, the move to larger operations that have resulted from the economies of scale that exist in many of these sectors today results in an inability to adjust to low profitability because of the high capital outlays associated with the large facilities yet these same economies of scale allow for quick expansion in periods of high profitability. With such issues on the U.S. livestock industry, it can be hypothesized that the livestock supply response to changes in the economic factors, especially prices, might not be identical as prices increase or decrease.

The objective of this study is to examine the asymmetric supply response of the U.S. livestock industry and the price elasticity of supply for livestock. In particular, the focus of analysis is on investigating the empirical evidence in support of the asymmetric supply behavior of livestock producers as shown in the form of relatively more persistent response to change in a price fall than in response to a price increase.

Most of the empirical studies on asymmetric agricultural supply response are applied with an asymmetric generalized autoregressive conditional heteroskedasticity (GARCH) model to characterize the conditional variances of the time series processes (Holt and Aradhyula, 1990; Rezitis and Stavropoulos, 2009). The main purpose of these studies is to examine the effect of price uncertainty or volatility in agricultural supply response and to provide the appropriate forecasting techniques for quantity supplied and price. On the other hand, from the viewpoint of the residual based co-integration analysis examining long-run equilibrium properties, relationships among the conditional means of the series of the dynamic process is more informative. In other words, residuals, namely discrepancies between the actual values and the fitted values, have more useful information because the series process will revert back to long-run equilibrium on average (Albayrak 1997). In this sense, the threshold autoregressive (TAR) and the momentum threshold autoregressive (M-TAR) model can be considered as an alternative method to test for asymmetric supply response. The TAR model can capture the magnitude of adjustment to restore the long-run equilibrium and the M-TAR model can capture asymmetrically differing amounts of adjustment towards the long-run equilibrium. Therefore, the empirical results will be helpful to gauge the contribution of the recent structural changes in livestock production and to judge whether there is the presence of potential production efficiencies in the U.S. livestock industries from a normative perspective.

This study is arranged in the following manner. Section 2 provides a brief review of literature associated with agricultural supply response and application of the TAR and M-TAR models. Section 3 highlights the econometric methods used while section 4 introduces data to be analyzed in this study. Section 5 presents the empirical results and section 6 provides conclusions.

2. Literature Review

This study aims to examine asymmetric supply response of livestock with respect to economic variables such as output price and feed cost. The fundamental idea of this work is based on the long-run relationship between a set of variables. The residuals, representing the disequilibrium from the co-integrating equation can be applied in assessing both the long-run relationship between variables and patterns of supply response. Threshold co-integrating analysis is a very important part for this purpose and can assist in discovering empirical evidence on the hypothesis of this study.

Prior to discussion of the TAR and the M-TAR models, discussion on some advantages of application of co-integration analysis in studying agricultural supply response should be made. Assuring a co-integrated relationship between variables is a prerequisite for proceeding to the estimation of the error correction model (ECM). There are many studies that applied the co-integration analysis and ECM to examine agricultural supply response (Hallam and Zanoli, 1993; Albayrak, 1997; Mckay et al., 1998: Alemu et al., 2003; Tripathi, 2008). The application of both the co-integrating test and the ECM in supply response analysis is to ensure that one would obtain a consistent estimate of both the short-run and long-run elasticities by using stationary series. Accordingly, the error correction model is widely perceived as an alternative method to overcome the spurious regression problem caused by the conventional Nerlovian approach by using non-stationary series (partial adjustments in actual output and adaptive expectations of output price as seen in Nerlove, (1956, 1958), Askari and Cummings (1977), Sunil Kanwar (2004). Thus, without considering stationary issues in data series, the value of parameters in the conventional model may provide inconsistent estimates.

Application of the threshold co-integration analysis by using the TAR and the M-TAR models can be understood in the same context with the importance of conventional co-integration analysis. There is no empirical study applied with the TAR and the M-TAR model to test for asymmetric agricultural supply response. Since the quantification of a price rise and fall is quite difficult in the regression model, the notion of irreversible supply response to a change in price has been applied less in empirical study (Mamingi, 1996). Most of the studies on asymmetric price transmission in a spatial or vertical context are conducted using the TAR and the M-TAR model.

Although the scope of analysis and policy implications of the results between asymmetric price transmission and asymmetric supply response are different, knowledge on statistical techniques and analytic procedures of the TAR and M-TAR model applied in price transmission studies is useful in testing for the adjustment pattern of supply response in this paper.

There are several studies that have utilized the threshold co-integration model that explain the potential for nonlinear and threshold type adjustment in time series data. The study by Goodwin and Holt (1999) examines the vertically asymmetric price transmission through the market channel for U.S. beef prices while another study by Goodwin and Harper (2000) investigates price transmission among farm, wholesale and retail U.S. pork sectors. In order to estimate the threshold between 5% and 95% of the largest negative residuals or positive residuals both studies used a two-dimensional grid search proposed by Balke and Fomby (1997). The results of the former study supported the evidence of asymmetric price transmission that tends to be transmitted one way from farm to wholesale to retail levels but not vice versa. In the latter, they find that threshold effects and asymmetric adjustment are significant. In addition, price is unidirectionally transmitted from farm gate to wholesale, and to retail levels.

More recently, other methods for investigating asymmetric price adjustment include the TAR model and the M-TAR model introduced by Enders and Granger (1998). Abdulai (2002) examines asymmetric price transmission in the Swiss pork market using threshold co-integration method. The results suggest that price transmission between the producer and retail market showed asymmetric adjustment behavior. Another study by Awokuse and Wang (2009) investigate asymmetric price transmission in U.S. dairy markets. The findings of this study suggest that there is the presence of asymmetric price adjustment from farm gate to retail stages for only butter and fluid milk.

Further, the study by Ghoshray (2002) examined asymmetric price transmission in the global wheat markets by applying the TAR model and the M-TAR model. The empirical results in this study show that the international wheat market appears to be greatly unitary and that there is lack of evidence for asymmetric price adjustment. However, some results of asymmetric adjustment may attribute to the quality difference of wheat reflecting different end-uses. Another study by Goychuk and Meyers (2014) was conducted to investigate price integration between the Black Sea and international wheat markets. To do this, the Johansen ML test and Engle-Granger co-integration test are used. In addition, the TAR and the M-TAR model for testing asymmetric price transmission are employed as well. The results of this study indicates that co-integrating relationships between Russian wheat prices and EU wheat prices and U.S. wheat prices are valid. In addition, the Ukrainian wheat prices are co-integrated with the French wheat price. The study concludes that there is the existence of symmetric price transmission in the world wheat market.

Some findings from previous studies on the application of co-integration analysis are important to understand. The first issue is non-stationarity, which will frequently be apparent in time series analysis. The spurious regression problem may arise with nonstationary time series. As pointed out by Tripathi (2008), this is an important question that econometric methods for estimating the supply elasticities should take into account to avoid spurious regression problems that can arise when one uses nonstationary series in a conventional model approach.

Second, the specification of the co-integrating equation should be based on the static regression framework, which means that variables in the right-hand side of the regression model should contain variables that are contemporaneous. Thus, the Engle-Granger approach and the threshold co-integration test allows us to directly test for the null hypothesis that the residuals obtained from the static regression model have a unit root.

Finally, the Engle-Granger two step procedure is designed to test for pair wise long-run co-integrating relationships. However, a simple static regression model may lead to low power of co-integrating statistics and biased long-run estimates (Albayrak, 1997) because, in economic theory, the economic relationship of the agricultural supply generally requires more than two variables (Albayrak, 1997). Therefore, specifying a static co-integrating equation with more than two explanatory variables would be better to avoid the possible drawbacks of a simply specified model in the sense that it is necessary to check multiple co-integrating relationships.

Until recently, no previous study has investigated asymmetric supply response by considering the notion of convergence of a long-run relationship between variables. The contribution of this study is to take a new attempt by applying the threshold co-integration analysis in investigating asymmetric supply response in the U.S. livestock industry. The findings from the TAR and the M-TAR model will provide useful information in signaling potential inefficiency of livestock production in the context of the recent structural change in the U.S. livestock industry. Detailed discussions on the econometric methods are included in the next section.

3. Econometric methodology

Before testing the co-integration relationship between the meat quantity and the relevant prices, test for stationarity of the time series should be required. By doing so, three methods including the Augmented Dickey-Fuller (ADF), the Phillips-Perron (PP), and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) are applied. The appropriate lags can be determined in selecting the minimum Bayesian Information Criterion (BIC). The KPSS has some advantages over the ADF and PP tests in that it assumes stationarity of the time series, as opposed to the null assumed by the ADF and PP. Since the ADF and PP test assume the null hypothesis of non-stationarity of the series, if there is no strong evidence for stationarity of time series, the ADF and

PP might have a low power to reject the null, which might result in a Type II error. Consequently, testing a unit root of the time series throughout these three approaches would be a good strategy in terms of a robustness check of the characteristic of the time series.

In this paper, two approaches are followed to test for co-integration assuming symmetric adjustment of the series; the Engle-Granger and the Johansen co-integrating test are applied. The Engle and Granger approach is composed of two steps. Initially, the co-integrating equation for supply response is estimated by equation (1)~(3) below;

$$Cattle: \ lnSHSLT_t = a_0 + \sum_{i=1}^{3} a_i D_{it} + a_4 lnTR_T + a_5 lnPB_t + a_6 lnFCB_t + \varepsilon_t \quad (1)$$

$$Hog: \ lnBGSLT_t = b_0 + \sum_{i=1}^{3} b_i D_{it} + b_4 lnTR_T + b_5 lnPRH_t + \mu_t \quad (2)$$

$$Chicken: lnCQ_t = c_0 + \sum_{i=1}^{3} c_i D_{it} + c_4 lnTR_T + c_5 lnPRC_t + \omega_t \quad (3)$$

where $SHSLT_t$ is the cattle (steer and heifer) slaughter at time t, D_{it} is a quarterly dummy variable ($i = 1, 2,3$), which is used to capture the monthly seasonality effect of cattle slaughter, TR_T is a trend component is used to capture technological change in the production process, PB_t and $FCB_t$are cattle price and feed cost, respectively, and ε_t is error terms. $BGSLT_t$ and CQ_t stand for hog slaughter and chicken production, respectively, PRH_t is the ratio of hog price to feed cost, and PRC_t represent the ratio of chicken price to feed cost. μ_t and ω_t are error terms. Second, the unit root tests (ADF, PP, KPSS) for stationarity of residuals from Equations (1)~(3) are conducted. If the test result is that the residuals are stationary, the variables are said to be co-integrated.

The Johansen ML procedure is well suited for the co-integration test to multivariate series by obtaining more than one co-integration relationship. This paper cites the representation of the Johansen ML method described in the study by Weliwita and Govindasamy (1997). Johansen's approach initially takes its starting point in the general VAR(p) model of order of the lower case of p given by

$$Z_t = \alpha_0 + \alpha_1 Z_{t-1} + \cdots + \alpha_p Z_{t-p} + \varepsilon_t \qquad t = 1, \ldots, T \quad (4)$$

where Z_t is an $\mathrm{n} \times 1$ vector of variables, and α is the coefficient matrix, ε_t is stochastic terms, which are identically and independently normally distributed. This VAR can be re-written as the following vector ECM;

$$\Delta Z_t = \alpha_0 + \Pi Z_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta Z_{t-1} + \varepsilon_t \quad (5)$$

where Δ denotes first difference, Π indicates the long-run effects, Γ_i stands for the dynamic effects. The term of ΠZ_{t-1} has information on the co-integrating relationship among variables in Z_t. Thus, the Johansen co-integration test mainly aims to estimate the rank (r) of Π. If its rank is $0 < \mathrm{r} < \mathrm{n}$, then there exist $\mathrm{n} \times \mathrm{r}$ matrices α and β with rank r such that $\Pi = \alpha\beta'$ and $\beta' Z_t$ is stationary, where α represents the adjustment parameter, and β stands for a co-integrating vector. The r indicates the number of co-integration relationships.

Enders and Granger (1998), on the other hand, indicate that the inconsistent results of co-integration might be derived due to asymmetric adjustment of series. Thus, they suggest an alternative specification allowing for asymmetric adjustment, known as the threshold autoregressive (TAR) model, and it can be written as:

$$\Delta\hat{\varepsilon}_t = I_t \gamma_1 \hat{\varepsilon}_{t-1} + (1 - I_t)\gamma_2 \hat{\varepsilon}_{t-1} + \omega_t \quad (6)$$

where $\Delta\hat{\varepsilon}_t$ stands for the first differenced error term from Equations (1)~(3), γ_1 and γ_2 are parameter value of the positive shock and the negative shock, I_t stands for the Heaviside indicator function as shown below:

$$I_t = \begin{cases} 1 & if \quad \hat{\varepsilon}_{t-1} \geq \tau \\ 0 & if \quad \hat{\varepsilon}_{t-1} < \tau \end{cases} \qquad (7)$$

$$I_t = \begin{cases} 1 & if \quad \Delta\hat{\varepsilon}_{t-1} \geq \tau \\ 0 & if \quad \Delta\,\hat{\varepsilon}_{t-1} < \tau \end{cases} \qquad (8)$$

τ stands for threshold value proposed by Chan (1993).

According to Tong (1983), the estimate of the sample mean for the residuals may be biased if adjustment of series is asymmetric. For this reason, Chan (1993) suggests that it is necessary to find the possible long-run equilibrium values to minimize the sum of squared errors from the fitted model as a super-consistent estimate of threshold. The estimation procedures of the threshold proposed by Chan (1993) utilize the following steps: first, residual series ($\Delta\hat{\varepsilon}_t$) from co-integrating equation are arranged in ascending sort, second, 15 percent of the minimum and maximum observations are excluded, and then 70 percent of the observations are used as a potential threshold. Finally, the equation is estimated with Equations (7) and (8) for each potential threshold value, then the equation with the lowest Schwarz criterion (SBC) is chosen. Therefore, it can be considered as the best estimate threshold parameter (τ).

The combination of equations (6) and (7) is referred to as the TAR model and the combination of the equations (6) and (8) is said to be the M-TAR model. According to Enders and Granger (1998), the TAR model and the M-TAR model capture “deep” and “sharp” movements of the residual series, respectively[1]. In the M-TAR model, the potential thresholds are based on the change in ε_{t-1}. To interpret the adjustment rate of γ_1 and γ_2, if for example, $-1 < \gamma_1 < \gamma_2 < 0$, the TAR model represents that the positive discrepancies of the $\hat{\varepsilon}_t$ series will tend to return rapidly to the long-run equilibrium relative to the negative discrepancies of the residual series. Furthermore, if, for example, $|\gamma_1| < |\gamma_2|$, the M-TAR model suggests that the negative $\Delta\hat{\varepsilon}_{t-1}$ is in substantial decay, while the positive $\Delta\hat{\varepsilon}_{t-1}$ moves relatively slowly back to the attractor. In this paper, given the possible economic behavior of producers for supply response as to profitability, two terms are defined that the positive shocks ($\boldsymbol{\gamma_1}$) from the long-run equilibrium is made by producers' expectation of higher profitability in the future and the negative shocks ($\boldsymbol{\gamma_1}$) from the long-run equilibrium is generated by their expectation of lower profitability in the future.

Two hypotheses are tested by estimating the TAR and the M-TAR model. First, the null hypothesis of no co-integration ($H_0\colon \gamma_1 = \gamma_2 = 0$) is tested. In this test, the Φ-statistic is used instead of the F-statistic with a non-standard distribution for the null mentioned above. If the null hypothesis is rejected, the co-integration of the series is proven. Confirmation of the co-integration of the series allows us to test the null hypothesis that there is symmetric adjustment ($H_0\colon \gamma_1 = \gamma_2$). In this test, standard F-statistics is recorded and used to test the hypothesis that two parameter values are equal. If the null fails to reject, it supports the evidence of symmetric supply adjustment. Rejecting the null, on the other hand, would indicate that adjustment of supply to the long-run equilibrium is different for a positive shock or negative shock. Diagnostic checking for a white noise process for the residuals ω_t is performed by using the Ljung-Box test, the Breusch–Godfrey

[1]The definition of the two terms "deep" and "sharp" as described by Ghoshray (2002, p 301) shows "deepness indicates the asymmetry in the magnitude of peaks and troughs and sharpness represents the asymmetry in the form of differing speeds at which peaks and troughs are approached".

test, and Durbin Watson test. If the residuals are serially correlated, the threshold models (the TAR and the M-TAR) should be re-specified by adding the additional lags of $\Delta\hat{\varepsilon}_t$ in the form:

$$\Delta\hat{\varepsilon}_t = I_t\gamma_1\hat{\varepsilon}_{t-1} + (1 - I_t)\gamma_2\hat{\varepsilon}_{t-1} + \sum_{i=1}^{p}\theta_i\,\Delta\hat{\varepsilon}_{t-1} + \omega_t \qquad (9)$$

4. Data

The three sectors in this study are the cattle, hog and chicken industries. In this empirical investigation, the following quarterly time series data is used: slaughter of cattle (SHSLT, thousand head), slaughter of hog (BGSLT, thousand head), production of chicken (CQ, million pound), fed steer price (PB, dollar per cwt), price ratio of the hog price to the feed cost (PRH, dollars per pound), price ratio of the chicken price to the feed cost (RPC, dollars per pound), where the hog price is for barrows and gilts and the chicken price is the wholesale price. All price terms in the cattle supply function are deflated by the Producer Price Index (PPI) sourced from the U.S. Bureau of Labor Statistics. Feed cost consists of corn price received by producers (dollars per bushel) and 48% soybean meal price (dollars per ton). These prices are converted into dollars per cwt, and then a feed cost is calculated by applying a weighted average of the corn and soybean meal prices where the weights are 0.9 and 0.1 for cattle, 0.8 and 0.2 for hog, and 0.7 and 0.3 for chicken, respectively. All variables in each supply function are expressed in logarithm. The time periods of the analysis is from quarter 1, 1990 to quarter 4, 2015. Descriptive statistics and characteristic of each data series are represented in Table 1.

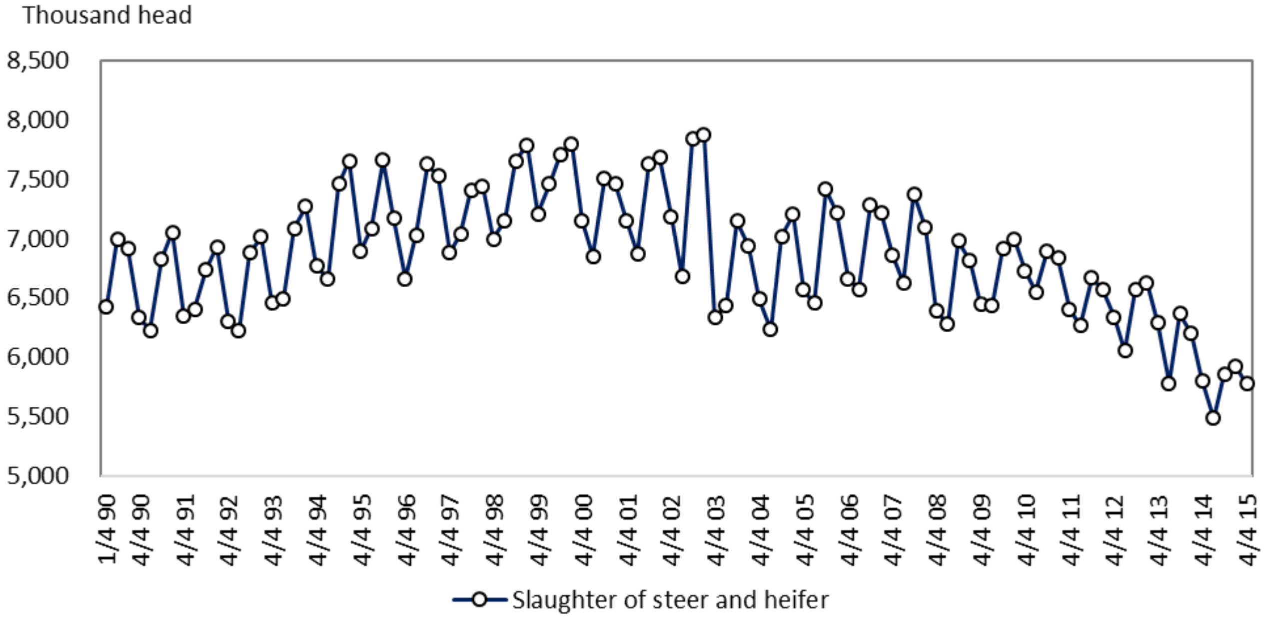
Table 1. Basic statistical measures of the data series in levels

Variable	Obs	Min	Max	Mean	SD	Variance	Skewness	Kurtosis
SHSLT	104	5,485.36	7,870.31	6,844.99	521.39	271,849.00	-0.09	-0.42
BGSLT	104	19,102.70	29,587.80	24,590.47	2,512.00	6,308,381.00	0.03	-0.65
CQ	104	4,494.76	10,372.47	7,780.01	1,585.00	2,512,537.00	-0.51	-0.94
PB	104	46.60	85.07	57.45	8.24	67.87	1.20	1.36
FCB	104	84.15	254.81	146.03	37.33	1,394.00	0.85	0.50
PRH	104	0.22	0.68	0.43	0.12	0.01	0.06	-0.91
PRC	104	0.54	1.64	1.08	0.24	0.06	0.20	-0.50

Notes: SHSLT is cattle slaughter (thousand head), BGSLT is hog slaughter (thousand head), CQ is chicken production (million pound), PB is fed steer price (dollar per cwt), FCB is cattle feed cost (dollar per cwt), PRH is the price ratio of the hog price to feed cost (dollar per pound), and PRC is the price ratio of the chicken price to feed cost (dollar per pound).

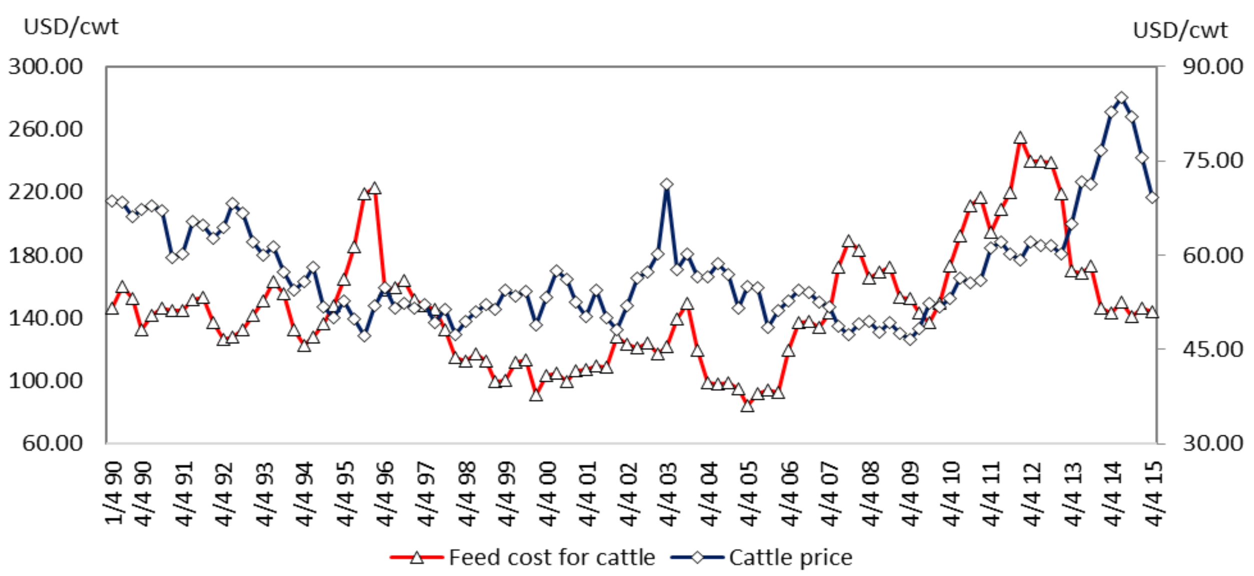
The visualized plots of data series analyzed in this study are shown in Figures 1~4. According to the graphs, the quantity of the cattle slaughter series presents a slightly negative trend, while the quantity series of hog slaughter and chicken production have positive trends over time. The chicken production series has an apparently stronger upward trend. All price series seem to have an increasing trend over time and volatility is intensified at the end of the sample period in the sense that all price series are likely to be non-stationary. In particular, the existence of a trend component impacts the stationarity results for some quantity series, and the presence of trends will affect the long-run relationship. Therefore, it is necessary to check which series should be modeled with a trend.

Figure 1. The plot of cattle slaughter



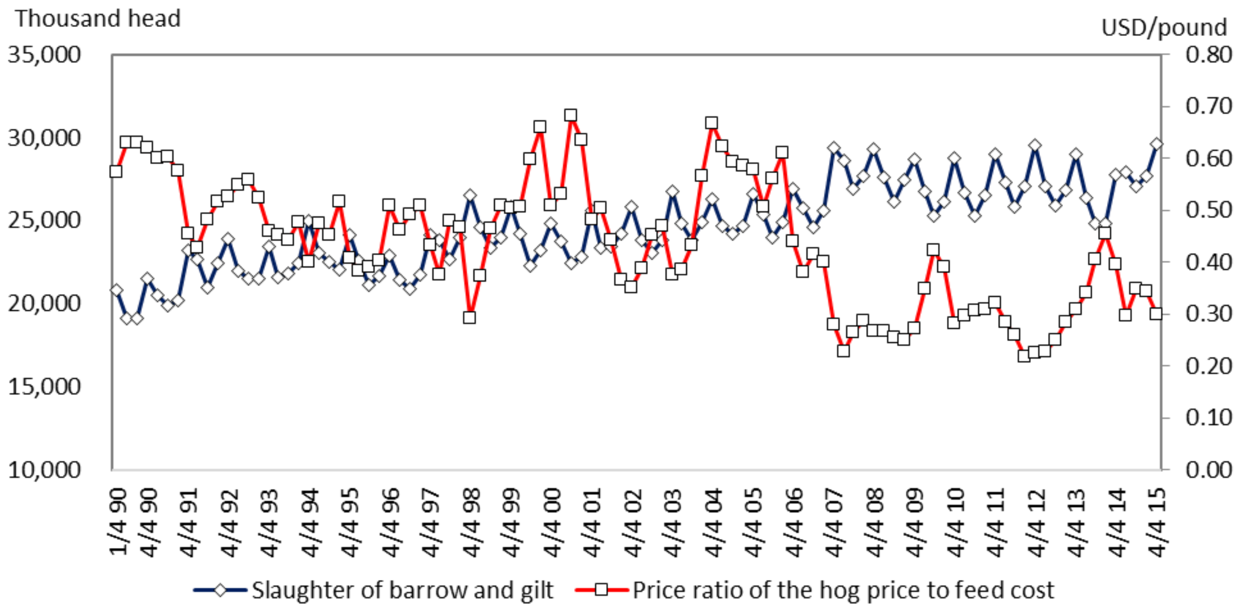
Source: USDA/ERS LDP.

Figure 2. The plot of cattle price and feed cost



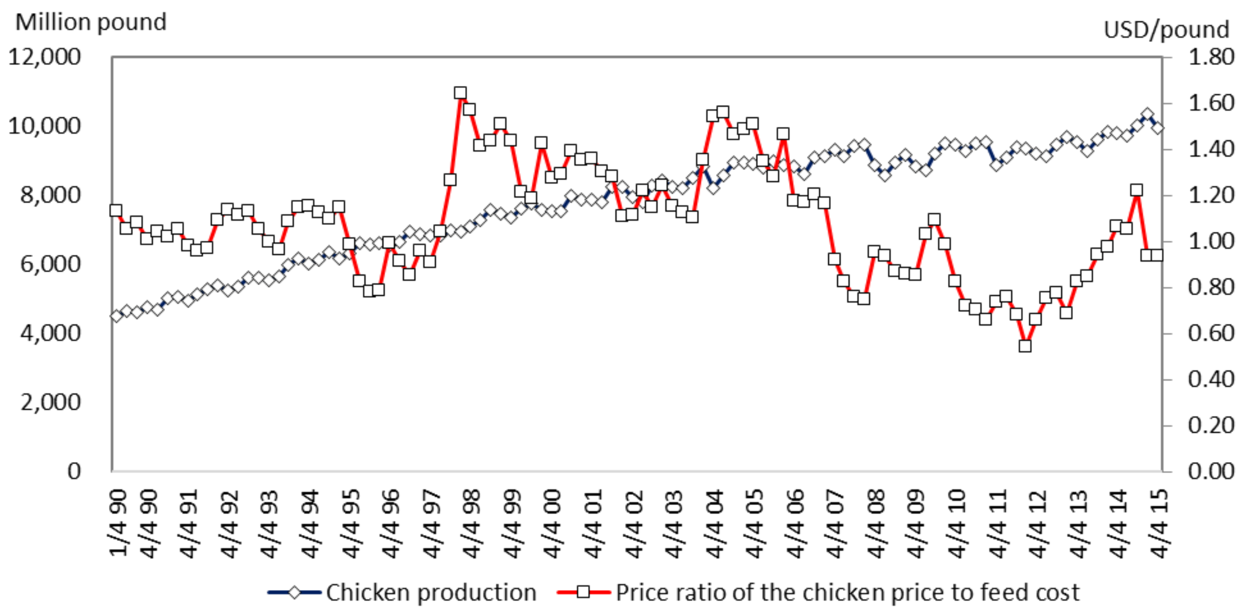
Source: Output price is from USDA/ERS LDP and corn farm price and 48% soybean meal price are USDA/NASS Ag Prices Publication and USDA/AMS monthly feedstuff prices, respectively.

Figure 3. The plot of hog slaughter and price ratio



Source: Hog slaughter and output price are from USDA/ERS LDP, corn farm price and 48% soybean meal price are USDA/NASS Ag Prices Publication and USDA/AMS monthly feedstuff prices respectively.

Figure 4. The plot of chicken production and price ratio



Source: Chicken production is from USDA/ERS LDP, chicken wholesale price is USDA/AMS Livestock, Dairy and Poultry Situation and Outlook, and corn farm price and 48% soybean meal price are USDA/NASS Ag Prices Publication and USDA/AMS monthly feedstuff prices respectively.

5. Empirical results

5.1. Testing for a unit root

Before conducting the co-integrating test, the time series to be analyzed in this study is required to be examined to determine whether these series have a unit root. For this purpose, three testing methods are employed: ADF, PP, and KPSS. Table 2 and Table 3 show the results of stationary tests for the logged and the logged first difference series, respectively. The null hypothesis of the ADF and the PP test is that the series is non-stationary. In contrast, the KPSS test is conducted for the null hypothesis for stationarity of the series. For each test, the appropriate length of lag for the test of a unit root is determined to find the minimum value of the Bayesian Information Criteria (BIC). Concluding whether the series analyzed has a unit root is made by rejecting the null hypothesis for the two of the three results (ADF, PP and KPSS).

The results in Table 2 shows that all data series analyzed have the unit root in levels based on the results from the three tests. This implies that all series are integrated of order one, I(1) because they have a unit root in their log-levels. It implies that taking the first difference of all variables is needed to assure stationarity of these series.

On the basis of the results in Table 3, all three tests confirm that all the first differenced series do not have the unit root, which means that all series in their first difference are stationary. This allows for the conclusion that it is possible that there is the presence of a co-integrating relationship among the variables. Therefore, the results allow us to proceed with the tests for co-integration on all the series using the Johansen and the Engle-Granger co-integration test.

Table 2. Results of the stationary tests in levels

	No. of lags	ADF		PP		KPSS	
		with drift	with drift and trend	with drift	with drift and trend	with drift	with trend
SHSLT	4	-0.10	-1.10	-4.55**	-5.34**	0.84**	0.42**
BGSLT	3	-1.49	-2.41	-2.31	-6.94**	2.45**	0.12*
CQ	1	-2.22	-2.33	-2.38	-2.57	4.84**	1.17**
PB	1	-2.04	-2.14	-2.19	-2.27	0.73**	0.70**
FCB	1	-2.54	-2.72	-2.22	-2.32	0.99**	0.63**
PRP	3	-2.29	-3.00	-2.47	-3.43*	1.38**	0.15**
PRC	1	-2.56	-2.78	-2.48	-2.65	1.18**	0.60**

Notes: Asterisks stand for significance levels (* for 10%, ** for 5%). The critical value of ADF and PP tests at 5% and 10% significance level are obtained from the R. Davidson and J.G. Mackinnon (1993), *Estimation and Inference in Econometrics*. The critical values of test with a drift and with a drift and a trend for ADF and PP tests at 5% significant are -2.86 and -3.41, respectively and at 10% significant are -2.57 and -3.13, respectively. In the KPSS tests, the critical values with a drift and with a trend at 5% significant are 0.463 and 0.146, respectively and at 10% significant are 0.347 and 0.119, respectively.

Table 3. Results of the stationary tests in the first differenced series

	No. of lags	ADF		PP		KPSS	
		with drift	with drift and trend	with drift	with drift and trend	with drift	with trend
SHSLT	3	-5.58**	-6.20**	-19.55**	-20.09**	0.43*	0.07
BGSLT	2	-4.74**	-4.70**	-12.76**	-12.69**	0.02	0.02
CQ	2	-9.87**	-11.20**	-12.03**	-12.52**	0.50**	0.03
PB	1	-8.98**	-9.20**	-11.02**	-11.14**	0.17	0.03
FCB	1	-8.04**	-8.00**	-8.28**	-8.24**	0.05	0.05
PRP	2	-6.62**	-6.59**	-9.27**	-9.22**	0.03	0.03
PRC	1	-7.83**	-7.79**	-9.45**	-9.4**	0.04	0.04

Notes: Asterisks indicate significance levels (* for 10%, ** for 5%). The critical value of ADF and PP tests at 5% and 10% significance level are obtained from the R. Davidson and J.G. Mackinnon (1993), *Estimation and Inference in Econometrics*. The critical values of test with a drift and with a drift and a trend for ADF and PP tests at 5% significant are -2.86 and -3.41, respectively and at 10% significant are -2.57 and -3.13, respectively. For the KPSS tests, the critical values with a drift and with a trend at 5% significant are 0.463 and 0.146, respectively and at 10% significant are 0.347 and 0.119, respectively.

5.2. Testing for co-integration under symmetric adjustment of series

Having established that all data series are confirmed to be integrated of the same order of one from the previous section, two approaches are conducted to test for co-integrating relationships among the variables. In order to do this, first, in the light of the key relationship between supply and price terms, a pair-wise co-integrating test for the supply response of cattle and hog slaughter and chicken production to own price and feed cost for cattle or the output/feed price ratio for hogs and chicken is conducted with Johansen ML approach. Second, the residual-based procedures proposed by Engle-Granger is applied by estimating each co-integrating equation (1) ~ (3) mentioned above, and then residuals obtained from each equation are used for the co-integrating relationship. The unit root test of the residuals is conducted with ADF, PP, and KPSS as well.

Tables 4 and 5 show the results of the Johansen ML co-integrating test. For cattle, since the supply function is specified with separate price terms for own price and feed cost it is necessary to identify the maximum co-integrating relationships among the variables. The results presented in Table 4 indicate that the null hypothesis that there is no co-integrating relationship should be rejected at a significance level of 5%, while one co-integrating relationship among variables is retained. These results suggest that there is one or two long-run relationships among the variables. In addition, according to the results of the Johansen pairwise co-integrating test (Table 4), all bivariate combinations of series are co-integrated by rejecting the null hypothesis that there is no long-run co-integrating relationship between two variables.

Table 4. Johansen co-integration rank test using the trace for cattle slaughter supply

$H_0: Rank = r$	$H_1: Rank > r$	Trace
0	0	49.42 (0.00)
1	1	10.20 (0.27)
2	2	3.81 (0.05)

Note: The p-values are presented in parenthesis. The r presents the number of co-integrating relationship.

Table 5. Johansen co-integration rank test for each pairs of series

	No. of lags	$H_0: Rank = r$	$H_1: Rank > r$	Trace
SHSLT – PB	2	0	0	45.40 (0.00)
		1	1	4.41 (0.04)
SHSLT – FCB	1	0	0	28.31 (0.00)
		1	1	3.65 (0.06)
BGSLT – PRP	4	0	0	18.55 (0.08)
		1	1	7.26 (0.11)
CQ – PRC	3	0	0	20.20 (0.01)
		1	1	5.14 (0.02)

Note: The p-values are presented in parenthesis. The r represents the number of co-integrating relationship.

Table 6. Engle-Granger co-integration tests

Dependent variable	No. of lags	ADF		PP		KPSS	
		w/drift	w/drift and trend	w/drift	w/drift and trend	w/drift	w/trend
SHSLT	1	-3.67**	-3.64**	-4.24**	-4.22**	0.29	0.29**
BGSLT	3	-3.62**	-3.65**	-3.52**	-3.50**	0.20	0.20**
CQ	1	-3.01**	-3.02	-3.16**	-3.12*	0.82**	0.81**

Note: Asterisks represent levels of significance (* for 10%, ** for 5%). The *t*-statistic is stated in parenthesis. The critical value of ADF and PP tests at 5% and 10% significance level are obtained from the R. Davidson and J.G. Mackinnon (1993), *Estimation and Inference in Econometrics*. The critical values of test with a drift and with a drift and a trend for ADF and PP tests at 5% significant are -2.86 and -3.41, respectively and at 10% significant are -2.57 and -3.13, respectively. For the KPSS tests, the critical values with a drift and with a trend at 5% significant are 0.463 and 0.146, respectively and at 10% significant are 0.347 and 0.119, respectively.

According to the results of the Engle-Granger co-integration test (Table 6), the ADF and the PP test support the validity of rejecting the null hypothesis that residuals in the static regression on the supply models are non-stationary. Despite the results of the KPSS representing insufficient evidence of stationarity of series, since the presence of a co-integrating relationship is confirmed by two of the three test results it can be accepted that there is the existence of the long-run equilibrium relationship with co-integration established in all tests. Concluding the existence of long-run equilibrium relationships allows us to use the residuals in specifying the TAR and the M-TAR model to test for asymmetric supply response.

5.3. Testing for co-integration under asymmetric adjustment of series

As mentioned above, both the TAR and the M-TAR models are designed to examine whether variables in the supply models presented in the previous section have a co-integrating relationship with the threshold adjustment and to check the asymmetric pattern of adjustment. For this purpose, the discrepancies obtained from each co-integrating equation estimated by the static regression are employed to test for both stationarity of residuals and asymmetric supply. By applying the statement on the TAR and the M-TAR models described in Ghoshray (2002), in this study the TAR model allows the extent of adjustment to the long-run equilibrium to depend on the quantity discrepancies. The M-TAR model allows the quantity deviations to show differing levels of adjustment.

Table 7 represents the estimated results of the TAR model. The coefficients of γ_1 and γ_2 should be negative, implying the convergence of the TAR model (Ghoshray, 2002). The estimate of γ_1 represents the adjustment rate of the positive deviation from the long-run equilibrium and the estimate of γ_2 stands for the adjustment rate of the negative discrepancy from the long-run equilibrium. The estimate of γ_1 for both SHSLT and CQ are significant at a significance level of

5%, and the estimate of γ_2 for SHSLT and CQ is significant at the 10% significance level. Both estimates of γ_1 and γ_2 for BGSLT are significant at the 5% significance level, respectively. To interpret the estimates of γ_1 and γ_2, the example of SHSLT, -0.43 of γ_1 shows that about 43 percent of the positive discrepancy from the long-run equilibrium is corrected in a quarter, and the estimate of γ_2 (-0.19) represents that about 19 percent of the negative discrepancy from the long-run equilibrium is corrected within a quarter. Additionally, for both BGSLT and CQ, the positive adjustment rate to the long-run equilibrium within a quarter is 27 percent and 23 percent, respectively. Additionally, approximately 17 percent of the negative deviation for BGSLT and 12 percent of the negative deviation of CQ revert back to the long-run equilibrium within a quarter, respectively.

In comparison of each sector, both the positive shock and the negative shock for SHSLT is likely to return more quickly to equilibrium than the case of BGSLT and CQ. However, in the case of CQ, both the positive and negative shocks tend to be relatively more persistent than the other sectors. This implies that producers in the cattle industry may be able to respond more efficiently to increases or decreases in their expectation of profitability than those in other sectors. The possible explanation is that this result may attribute to relatively larger economic scales of cattle industry and a relatively long time period of adjustment for the quantity of cattle slaughter due to the biological nature of cattle.

In order to test for the null hypothesis that there is no co-integration ($H_0 : \gamma_1 = \gamma_2 = 0$), it is necessary to compare the Φ-statistic recorded to the critical value computed by Enders and Granger (1998) instead of the F-statistic. The critical values at the 5% and 10% significance level for 100 observations are 5.02 and 4.11, respectively. The results indicate that the null hypothesis of no co-integration is rejected in all cases at the 5% significance level. These results are consistent with the results of co-integration test under symmetric adjustment presented in the previous section. The null hypothesis that there is symmetric adjustment ($H_0 : \gamma_1 = \gamma_2$) is tested by using the F-statistic. P-values corresponding to the F-statistic are stated in the parenthesis. The results present that the null hypothesis is rejected in all cases. This implies that there is no empirical evidence in support of asymmetric supply adjustment in estimated results of the TAR model.

Diagnostic checking of serial correlation of the residuals of the TAR model is performed by using the Breusch–Godfrey test, the Ljung-Box test, and Durbin Watson test. The results indicate that there is no serial correlation of residuals, which implies that the residuals follow a white noise process. This implies that there is no need to take the additional lagged terms of $\Delta\hat{\varepsilon}_t$ in the TAR model to correct the autocorrelation of residuals. The consistent estimate of threshold proposed by Chan (1993) for SHSLT, BGSLT, and CQ is 0.0243, 0.0174, and -0.0328, respectively.

Table 7. The results of TAR model

Variable	SHSLT	BGSLT	CQ
γ_1	-0.43 [-4.26]**	-0.27 [-2.82]**	-0.23 [-2.94]**
γ_2	-0.19 [-1.91]*	-0.17 [2.13]**	-0.12 [-1.70]*
$H_0 : \gamma_1 = \gamma_2 = 0$ (Φ)	10.89**	6.24**	5.77**
$H_0 : \gamma_1 = \gamma_2$ (F)	2.71 (0.10)	0.59 (0.44)	1.11 (0.29)
τ	0.0243	0.0174	-0.0328
LM_{test}	0.32 (0.57)	0.09 (0.76)	0.21 (0.65)
DW	2.07	1.99	2.06
$Q(6)$	17.40 (0.01)	2.35 (0.88)	6.50 (0.37)
F_{test}	10.89 (0.00)	6.24 (0.00)	5.77 (0.00)
SBC	-470.22	-517.56	-425.90

Notes: Asterisks stand for levels of significance (* for 10%, ** for 5%). γ_1 and γ_2 stand for the coefficients of adjustment and t-statistics is in bracket for the null hypothesis $\gamma_1 = 0$ and $\gamma_2 = 0$, respectively. Values of Φ-statistic for the TAR model with n $= 100$ for the null hypothesis $\gamma_1 = \gamma_2 = 0$ at 5% and 10% significance level are 4.64 and 3.79, respectively. Critical values for Φ-statistic are calculated by Enders and Granger (1998). P-values are stated in the parenthesis.

Table 8. The results of M-TAR model

Variable	SHSLT	BGSLT	CQ
γ_1	-0.45 [-4.07]**	-0.43 [-4.09]**	-0.05 [0.66]
γ_2	-0.21 [-2.23]**	-0.12 [-1.69]*	-0.26 [-3.76]**
$H_0 : \gamma_1 = \gamma_2 = 0\ (\Phi)$	10.75**	9.81**	7.27**
$H_0 : \gamma_1 = \gamma_2\ (F)$	2.59 (0.11)	6.04 (0.02)	3.76 (0.06)
τ	0.0179	0.0098	0.006
LM_{test}	0.44 (0.51)	0.61 (0.44)	0.27 (0.61)
DW	2.09	2.07	2.07
$Q(6)$	18.72 (0.00)	4.09 (0.66)	7.06 (0.32)
F_{test}	10.75 (0.00)	9.81 (0.00)	7.27 (0.00)
SBC	-464.57	-521.65	-423.59

Notes: Asterisks stand for levels of significance (* for 10%, ** for 5%). γ_1 and γ_2 stand for the coefficients of adjustment and t-statistics is in bracket for the null hypothesis $\gamma_1 = 0$ and $\gamma_2 = 0$, respectively. Values of Φ-statistic for the M-TAR model with $n = 100$ for the null hypothesis $\gamma_1 = \gamma_2 = 0$ at 5% and 10% significance level are 5.02 and 4.11, respectively. Critical values for Φ-statistic are calculated by Enders and Granger (1998). P-values are stated in the parenthesis.

Second, from Table 8, the estimated adjustment rate of γ_1 and γ_2 should be negative representing convergence for the M-TAR model. The value of both γ_1 and γ_2 for SHSLT are -0.45 and -0.21, respectively, and they are significant at the 5% significance level. For BGSLT, the estimate of γ_1 (-0.43) and γ_2 (-0.12) are significant at the significance level of 5% and 10%, respectively. However, for CQ, only the estimate of γ_2 is significant at the significance level of 5%. The rate of adjustment estimated from the M-TAR model is quite different from that of the TAR model. For the sharp movement in the quantity discrepancy, in the case of SHSLT and BGSLT, the adjustment rate of the positive deviation to the long-run equilibrium shows a similar fashion corresponding to -0.45 of SHSLT and -0.43 of BGSLT, respectively. In the case of CQ, on the other hand, the negative shock tends to quickly revert to the attractor as compared to other sectors.

To test for the null hypothesis of no co-integration ($H_0 : \gamma_1 = \gamma_2 = 0$), comparing Φ-statistic with the critical values in the case of the M-TAR is required. The results indicate that the null hypothesis is rejected at the significance level of 5% in all cases. This implies that there is empirical evidence of a co-integration relationship among the series. The co-integrating test by the M-TAR model also comes to the same results with the case of symmetric adjustment. Next, the F-statistic for testing the null hypothesis that adjustment is symmetric ($H_0 : \gamma_1 = \gamma_2$) indicates that the null hypothesis is not rejected for SHSLT, which indicates that the supply response of SHSLT may be adjusted symmetrically. However, the null hypothesis of symmetric supply adjustment is rejected at the significance levels of 5% and 10%, respectively, in the case of both BGSLT and CQ, as opposed to the results of the TAR model. These findings suggest that there is empirical evidence in support of the presence of asymmetric supply response in the hog and chicken sectors.

The Breusch–Godfrey test, the Ljung-Box test, and the Durbin Watson test are conducted to check a serial correlation of the residuals of the M-TAR model. The results show that residuals are not serially correlated with each other, which means that the residuals are a white noise process. With this result, the M-TAR model can be specified without the additional lagged terms of $\Delta\hat{\varepsilon}_t$. The consistent estimate of threshold proposed by Chan (1993) for SHSLT, BGSLT, and CQ is 0.0179, 0.0098, and 0.006, respectively.

Finally, there are some suggestions on selecting a model between the TAR and the M-TAR model proposed by the previous studies. First, Goychuk and Meyers (2014) demonstrate that asymmetric adjustment can be considered in the series analyzed if one of two models fails to confirm the null hypothesis of symmetric adjustment. Second, Enders and Granger (1998) mention that the model with the best overall fit can be selected by using the SBC or the Akaike information criterion (AIC) test if both the TAR and M-TAR models show asymmetric or symmetric adjustment. In this sense, in the case of SHSLT, the TAR model with the lower value of the SBC is preferable to the M-TAR model to represent the symmetric pattern of adjustment. In addition, the results of the M-TAR models exhibiting the asymmetric type of adjustment in the cases of both BGSLT and CQ support the presence of asymmetric supply adjustment in the hog and chicken sectors.

5.4. Interpretation of the long-run adjustment

Focusing on the point estimates of γ_1 and γ_2 estimated by the M-TAR model, this section discusses the long-run adjustment of supply in each livestock sector. The calculation of how many quarters are required to adjust under a proportion of probability (p) of the disequilibrium is made by the following formula presented in the study by Ghoshray (2002).

$$n = \frac{\log(1-p)}{\log(1-\gamma)} \quad (10)$$

where n stands for the number of quarters, p is a proportional probability of the disequilibrium to be restored, and γ is the adjustment rate to long-run equilibrium.

In the case of SHSLT, the M-TAR model confirms the mechanism of symmetric adjustment with γ_1 of 0.45 and γ_2 of 0.21. By using the formula above, it will take approximately 4~10 quarters to adjust the cattle supply to correct 90 percent of the disequilibrium to positive or negative shock. In both cases of BGSLT and CQ, there might be mechanism of asymmetric supply adjustment. In the hog case, the absolute value of γ_1 is larger than that of γ_2. This implies the positive discrepancy from the long-run equilibrium generated by the producers' expectation of high profitability may more quickly adjust to equilibrium while the negative discrepancy created by the producers' expectation of low profitability tends to persist. By using the same formula, adjustment of hog supply to correct 90 percent of the disequilibrium to a positive shock may be required to take approximately 4 quarters, while a negative shock will be corrected in 18 quarters. In contrast, for chicken, the point estimate of γ_2 is larger than that of γ_1. This indicates that the M-TAR model shows fast speed of adjustment toward the long-run equilibrium to a negative shock, but slow decay toward equilibrium to a positive shock. Taken together, the conclusion can be reached that the recent structural changes of cattle industry might improve the cattle production system, while there might exist potential production inefficiencies that should be corrected in both the hog and chicken industries.

6. Conclusion

This study aims to examine asymmetric supply response of the U.S. cattle, hog and chicken sectors. This concern can be found in the context of structural change of the U.S. livestock industries. That is, the move to larger operations that have resulted from the economies of scale that exist in many of these sectors today results in an inability to adjust to low profitability because of the high capital outlays associated with the large facilities, yet these same economies of scale allow for quick expansion in periods of high profitability. In this sense, the empirical evidence in support of asymmetric supply adjustment would be important information for both researchers and policymakers who might need to have insights into the potential inefficiencies of the livestock industry that must be understood.

For this purpose, as a part of the preliminary analysis, the stationary test (ADF, PP, and KPSS) for the data series and Johansen and Engle-Granger co-integration test are conducted and to test for the presence of asymmetric adjustment, the threshold autoregressive (TAR) and the momentum threshold autoregressive (M-TAR) models are applied to quarterly time series data for the quantity of slaughter (cattle and hog) and production (chicken), and price over the 1990-2015 sample period. The results of co-integrating test indicates that there is the existence of the long-run equilibrium relationship with co-integration established in all sectors.

Concluding the existence of long-run equilibrium relationships allows us to use the residuals in specifying the TAR and the M-TAR models to test for asymmetric supply response. The findings provided from the TAR model suggests that there is a co-integrating relationship among variables in all cases and the supply response in all cases is symmetrically adjusted. Additionally, both the positive and the negative discrepancies for cattle slaughter appear to more rapidly revert to the equilibrium than hog slaughter or chicken production. This implies that producers in the cattle industry may more efficiently respond to an increase or a decrease in their expectation of profitability than those who are engaged in the other sectors.

In contrast, the results of the M-TAR models exhibiting the asymmetric type of adjustment in the cases of both hog slaughter and chicken production support the presence of asymmetric supply adjustment in both the hog and chicken sectors. The empirical results for the hog industry would be meaningful in the sense that the positive deviation from the long-run equilibrium created by the producers' expectation of high profitability may quickly adjust to equilibrium while the negative discrepancy created by the producers' expectation of low profitability tend to persist. Overall, the empirical results suggest that there is evidence in support of symmetric supply response for the cattle industry, while there is the presence of asymmetric supply response for the hog and chicken industries. These findings imply that the recent structural change in the cattle industry contributes to improving the production efficiency for cattle, but in the hog and chicken industries, there might exist potential production inefficiencies.

Finally, the results of this study could be a useful reference material for future studies on estimating supply response using time series data, the structure of the livestock industry, and policy programs associated with price and cost of production. Notably, information on asymmetric supply adjustment obtained from this study would be a useful source in estimating supply function by using time series data. In addition, further studies in this field are needed to investigate the exact causes resulting in an asymmetric pattern of supply adjustment in the U.S. livestock industry.

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