Dynamics and Price Volatility in Farm-Retail Livestock Price Relationships

by

T. Kesavan, Satheesh Aradhyula, and Stanley Johnson

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1. Introduction

Farm-retail price relationships are commonly studied under a markup type of behavior (see Ward, 1982; Heien; Lyon and Thompson; Powers; and Wohlgenant and Mullen, among others) or under reduced-form specifications (e.g., Gardner; Wohlgenant; and Brorsen et al.). These studies have been extended to understand dynamics and lag adjustments in the price determination process (e.g., Bailey and Brorsen; Schroeder and Goodwin; Babula and Bessler; Brorsen et al.). Most of these studies employ time series procedures to delineate short-run dynamics in the price transmission mechanism. However, a comprehensive analysis of farm-retail price relationships, incorporating economic theory under a more general dynamic framework, has not been performed yet. In this regard, it is desirable to study the retail-to-farm linkages in a framework that accommodates both equilibrium hypotheses (as in Wohlgenant) and the short-run dynamics (as in Brorsen et al.) simultaneously. In this study, a general dynamic model based on an error correction method is developed to study farm-retail price relationships. The error correction model (ECM) has the advantage of combining the long-run, steady-state equilibrium condition dictated by theory with the short-run adjustments that are common in the marketplace.

Another aspect of this study is to explicitly consider volatility in prices within the general dynamic framework through a generalized autoregressive conditional heteroscedastic (GARCH) process. Aradhyula and Holt reported that retail prices for meat commodities have become more volatile in recent periods. Also, there is concern over the issue of structural change in the meat industry brought by factors such as firm concentration within the industry, changes in eating habits, changing demographic structure, and increased health awareness and nutrition education programs. For evaluating the effects of these and related changes in livestock prices, models that can fully accommodate volatility, dynamics, and equilibrium hypotheses are essential. Further, effective modeling of volatility and persistence in variance provides important information for evaluating the effects of external factors or shocks to not only on the conditional mean but also on the conditional variance of prices. Such evaluations are useful in the analysis of many contemporary policy issues.

The purpose of this study is to investigate empirically farm-retail price relationshps by fully accommodating dynamics, the steady-state relationship, and price volatility within a unified framework. The first two aspects are addressed by extending the idea of cointegration and its link to the error correction mechanism specifying a dynamic model that incorporates

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both short- and long-run effects together. Price volatility is incorporated by applying a GARCH process developed by Engle and Bollerslev. The empirical analysis is carried out for beef and pork commodities and is extended to analyze the effect of market concentration on the mean level and variance of farm prices.

The rest of the paper is organized as follows. First, the concepts of cointegration and error correction methods are described in the context of farm-retail price relationships, and a general dynamic model framework is formulated using an error correction framework. Following this, unit root and cointegration tests for farm and retail prices of beef and pork are reported. Then the results of applying both ECM alone and ECM with the GARCH process are presented and discussed. Market concentrations in the pork industry using the estimated ECM/GARCH models are evaluated next. Finally, some implications of the study with possibilities for future work are provided.

2. Cointegration, Error Correction Models, and Dynamics in Prices

Time series models are being used increasingly for analyzing dynamic properties of price systems (Bessler; Bessler and Brandt) and interactions among farm, wholesale, and retail prices (e.g., Brorsen et al.; Babula and Bessler). Models such as vector autoregressions (restricted and Bayesian) and transfer functions are frequently used for forecasting because of their ability to use past information optimally in predicting conditional means of a random process. Generally these approaches operate under the assumption that the underlying series is random and stationary. Typically the procedure involves preprocessing of data such as differencing to achieve these properties. Questions remain, however, about the appropriateness of arbitrary differencing motivated by stationarity requirements, particularly for understanding long-run structure (Granger, 1986; Harvey). To overcome these problems associated with time series analysis, new methods have been suggested that accommodate nonstationarity properties of the series in the form of cointegration systems.

The concept of cointegration states that an individual time series can wander extensively, yet, paired with another series (or a set of series), the pairs will tend to move together consistently (see Granger, 1981 and 1986 for details). This idea of cointegration for time series analysis was linked recently to error correction mechanisms by Engle and Granger. A particularly appealing feature of the ECM is that it can capture the time series properties of the variables together with the steady-state equilibrium relationship suggested by economic theory. Equilibrium in the ECM is represented by a stationary point, which is determined by economic forces which tend to push the system back towards the steady-state solution whenever the system drifts away. The ECM, therefore, attempts to reconcile the time series models and economic theory by merging short- and long-run effects.

A General Dynamic Model for Price Relationships

The static relationship between farm and retail prices for livestock commodities can be specified as

$$y_t = a_0 + b\, x1_t + c\, x2_t, \tag{1}$$

where y_t is the logarithm of farm price; $x1_t$ is the logarithm of retail price; $x2_t$ is the logarithm of the marketing cost index; a_0, b, and c are parameters of interest, and the subscript t refers to time period. This markup type of model[1], augmented with the marketing cost variable is used widely in empirical studies (e.g., Kinnucan and Forker; Wohlgenant and Mullen). Imbedded in this relationship is the assumption that retail prices determine farm prices.

Equation (1) is static in nature, and as such it does not account for the dynamic adjustments involved in farm-retail price relationships. Because lag adjustments in price transmission and price determination are important (see Bessler; Babula and Bessler; Bailey and Brorsen, inter alia), the dynamic aspects can be incorporated in the model through a general distributed lag specification as

$$y_t = a_0 + \sum_{i=1}^{m} a_i\, y_{t-i} + \sum_{j=0}^{n} b_j\, x1_{t-j} + \sum_{k=0}^{p} c_k\, x2_{t-k}. \tag{2}$$

Such an autoregressive, distributed lag model forms the basis for many different dynamic schemes and long-run responses of y, among which the error correction model is becoming increasingly popular (see Hendry et al. for details).

The main idea in the error correction formulation is to transform the general distributed lag model specified in equation (2) to explicitly incorporate the long-run, steady-state relationship between y and the exogeneous variables (x's) along with the short-run dynamics. By repeated substitutions, the steady-state relationship between y and other exogenous variables (x1, x2) can be deduced from (2) as (Harvey)

$$\begin{aligned} Y_t &= a_0^* + \sum_{j=0}^{n} \frac{b_j}{(1-\sum_{i=1}^{m} a_i)}\, x1 + \sum_{k=0}^{p} \frac{c_k}{(1-\sum_{i=1}^{m} a_i)}\, x2 \\ &= \phi_0 + \phi_1\, x1 + \phi_2\, x2. \end{aligned} \tag{3}$$

Maintaining equation (3) as the long-run, steady-state structure, (2) can be algebraically manipulated and rewritten as

$$\begin{aligned}\Delta y_t = &-\sum_{i=2}^{m} a_i \Delta y_{t-i} + b_0\, \Delta x1_t - \sum_{j=2}^{n} b_j\, (x1_{t-1} - x1_{t-j}) \\ &+ c_0\, \Delta x2_t - \sum_{k=2}^{p} c_k\, (x2_{t-1} - x2_{t-k}) \\ &+ (\theta - 1)\, [y_{t-1} - \phi 0 - \phi_1\, x1_{t-1} - \phi_2\, x2_{t-1}] + v_t,\end{aligned} \tag{4}$$

where Δ is the difference operator and v_t is the disturbance term. Equation (4) shows the form of the error correction framework and provides the basic structure for analysis. Intuitively, (4) states that the change in farm price is a function of both levels and differences of dependent (farm price) and independent (retail price and marketing cost) variables. The salient feature of the error correction formulation can be found in the term within the square brackets. This term reflects the deviation of the past period from the steady-state solution given in (3). Under stable conditions, this disequilibrium is corrected back to the steady-state solution; hence, the term within the square bracket represents the mechanism for error correction (see Harvey, Hendry et al.). From the perspective of empirical analysis of livestock price linkages, the ECM specification is appealing: it provides a consistent analytical framework that combines dynamics and the long-run, steady-state relationship between farm and retail prices.

3. Time Series Properties of Livestock Prices

Dynamics in farm and retail price linkages are investigated for beef and pork commodities based on (4) using monthly data from January 1965 to December 1989. Both farm[2] and retail prices were collected from Livestock and Meat Statistics (USDA, 1988, 1983) and Livestock and Poultry Situation (USDA, various issues). Following Wohlgenant and Mullen, a marketing cost index was computed as the average of two indices: the index for wage rates in the meat-processing industry and the producer price index for fuel related products, and power. The data for wage rates were collected from Employment and Earnings (Bureau of Labor Statistics), and data for the fuels products and power index were gathered from Survey of Current Business (Bureau of Labor Statistics).

Before proceeding to the estimation of ECM, the time series properties of the data are examined to ensure the conditions under which ECM can be expressed. The works of Granger and Engle indicate that if two variables are integrated on the order of one and then are cointegrated, they can be modeled as having been generated by an ECM. Since the presence of the unit root implies stochastic nonstationarity, the presumption that the variables are integrated of the order of one can be tested through the unit root hypothesis.

Unit Root Tests

Commonly, presence of the unit root in economic time series is tested through Dickey-Fuller or augmented Dickey-Fuller tests (see Dickey and

Fuller; Fuller; and Perron). Recently, Phillips (also see Phillips and Perron) derived testing procedures for the unit root hypothesis under more general conditions. These tests, referred to as Z tests, were applied in this study to the logarithm of each price series. Accordingly, the presence of the unit root is tested by running the following ordinary least square (OLS) regressions:

$$Y_t = \tilde{\mu} + \tilde{\beta}(t - T/2) + \tilde{\alpha} Y_{t-1} + \tilde{e}_t, \tag{5}$$

$$Y_t = \mu^* + \alpha^* Y_{t-1} + e^*_t, \tag{6}$$

$$Y_t = \hat{\alpha} Y_{t-1} + \hat{e}_t, \tag{7}$$

where Y_t denotes the economic time series and T denotes the sample size. Three hypothesis tests were performed using equation (5). The test statistics $Z(t_{\tilde{\alpha}})$, $Z(\Phi_3)$, and $Z(\Phi_2)$ were computed for the null hypothesis that $\tilde{\alpha} = 1$; $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$; and $\mu = 0$, $\tilde{\beta} = 0$, $\tilde{\alpha} = 1$, respectively. In equation (6), two test statistics were calculated, $Z(t_{\alpha^*})$ and $Z(\Phi_1)$, respectively, for the null hypothesis $\alpha^* = 1$ and $\mu^* = 0$, $\alpha^* = 1$. Finally, the test statistic for the hypothesis that $\hat{\alpha} = 1$ in equation (7) was represented by $Z(t_{\hat{\alpha}})$. For the precise form of the algebraic expressions for these test statistics, see Perron, Table 1.

The Z test results for presence of the unit root in farm and retail prices of beef and pork are presented in Table 1. These results were computed based on the maximum lag of 16 on the autocovariances of the residuals, using a weighting pattern suggested by Newey and West. If the value of the calculated test statistic was less than the critical value, the null hypothesis of the unit root was not rejected. Only four out of the total of 24 statistics reported were significant at the 5 per cent level; thus, the presence of the unit root was rejected in only four instances. In the case of pork, none of the test statistics were significant for the retail price, and only the $Z(t_{\tilde{\alpha}})$ statistics was significant for farm price. In the case of beef, while only one test statistic was significant for the farm price, $Z(t_{\tilde{\alpha}})$, the retail price exhibited two significant unit root test statistics ($Zt_{\hat{\alpha}}$ and $Z\Phi_1$). Overall, the results support the presence of the unit root in the farm and retail prices of both beef and pork.

Cointegration Tests

Engle and Granger have suggested residual-based tests for the presence of cointegration between two time series. Residual-based tests involve running OLS regression as

$$y_t = \lambda_0 + \lambda_1 x1_t + \lambda_2 x2_t + \epsilon_t, \tag{8}$$

where y_t, $x1_t$ and $x2_t$ represent the logarithms of farm price, retail price, and marketing cost, respectively, and ϵ_t indicates the residual and performing unit root tests on the residuals.

Because more than one exogenous variable is involved in this study, the cointegration system is of a higher order than the traditional bivariate case. Engle and Granger recommended the augmented Dickey-Fuller (ADF) test for such higher-order systems. Accordingly, ADF statistics are used in this study to test cointegration between the dependent variable (farm price) and the independent variables (retail prices and marketing cost). The ADF statistics are derived from the residuals based on (8) using the regression

$$\Delta\hat{\epsilon} = -\rho\hat{\epsilon}_{t-1} + \sum_{i=1}^{p} \delta\Delta\hat{\epsilon}_{t-i} + \xi_t. \tag{9}$$

The ADF test statistics are computed by dividing the estimated ρ by its standard error. The null hypothesis of no cointegration between the variables is rejected when the calculated ADF statistics are higher than the critical values. The critical values for the ADF test statistics for higher-order cointegration systems are provided by Engle and Yoo.

The results for cointegration between farm and retail prices are presented in Table 2. There is no theoretical guideline about the choice of lag length in ADF regression (9) although one can decide the lengths by the standard procedures for model selection such as the Akaike information criteria. Alternatively, in this study, ADF statistics are reported for different lag lengths, up to a maximum of three. The ADF statistics for beef indicate that the null hypothesis of no cointegration is rejected at the 5 per cent level of significance. For pork, only one of the ADF statistics is significant; however, the ADF(2) statistic is accepted only marginally. Overall, the test results lend support to the hypothesis of cointegration for the specified farm-retail price relationship. This implies that farm-retail price relationships for pork and beef commodities can be represented via an ECM.

4. ECM and the GARCH Process

Having established the desirable conditions for ECM specification between farm and retail prices, the next step is to identify the appropriate lag lengths for each commodity in equation (3). In choosing the appropriate lags for each commodity, parsimony in representation was kept in mind. The A maximum of 24 lag lengths were considered and those lag coefficients that did not contribute significantly to the statistical performance of the price series were omitted. A model that reasonably reflected the data generating process was identified, and the corresponding ECM specification was derived (corresponding to equation 4). The parameters of ECM were estimated using a maximum likelihood technique and the results for beef and pork are presented Tables 3 and 4, respectively.

The results indicate that retail prices have a positive and significant effect on the long-run farm prices of beef and pork. The long-run elasticities of farm price with respect to retail price, were found to be 0.74 and 1.28 respectively, for beef and pork. These estimates are quite reasonable.[3]

Further information about the validity of the estimated ECM models can be obtained by examining the Box-Pierce portmanteau Q statistics associated with fitted residuals ($\hat{v}_t$). Tables 3 and 4 report the Q statistics for the residuals associated with beef and pork ECMs, respectively. In both cases, the Q statistics were less than the critical value 21.03 (36.42) at 12 (24) degrees of freedom. Thus, the null hypothesis that the residuals from the estimated ECMs are white noise cannot be rejected.

A different picture is presented, however, when squared residuals series, $\hat{v}_t$, are examined. As McLeod and Li report, the portmanteau test statistic Q^2 (m) associated with the first m-squared innovations will be distributed as a Chi-square distribution with m degrees of freedom. In both beef and pork ECMs, Q^2 (12) was significant, while Q^2 (24) was also significant for pork at the 5 per cent level. As Bollerslev suggests, the absence of serial correlation in the conditional first moments, coupled with the presence of serial correlation in the conditional second moments, is one of the indications for the presence of GARCH process. Thus, significant Q^2 statistics reported in tables 3 and 4 suggest that a GARCH process might be appropriate for the innovations associated with the ECMs.

Furthermore, for purposes of evaluating policies and other external factors, added information about price volatility is useful. For certain shocks within the system, the interest is not only in the time required for the farm price to react (as represented by dynamic lag adjustments), but also in the effect on price variability. For instance, evaluation of external factors such as advertising and degree of market concentration should focus on volatility as well as on the mean of the prices. Modeling variance is a key in such analysis.

Modeling Persistence in Variance and the GARCH Process

In order to capture momentum in conditional variance, generalized autoregressive conditional heteroscedasticity (GARCH) models, developed by Bollerslev, are useful. Under GARCH, shocks to variance persist according to an autoregressive moving average (ARMA) structure of the squared residuals of the random process. The GARCH process for a normally distributed innovation series, v_t, is given by

$$v_t \mid \Omega_{t-1} \sim N(0, h_t)\,, \tag{10}$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \, v^2{}_{t-i} + \sum_{j=1}^{p} \beta_j \, h_{t-j}, \tag{11}$$

where

$$p \geq 0, q \geq 0$$
$$\alpha_0 > 0,\ \alpha_i \geq 0, \quad i = 1, \ldots, q, \text{ and}$$
$$\beta_i \geq 0, \quad i = 1, \ldots, p.$$

The conditional variance equation in (10) describes a GARCH (p,q) process, whereby the time-dependent, conditional variance is specified as a function of past behavior of the variability. The persistence effect in variance in a GARCH process can be understood from the β coefficients in equation (10). The β parameters represent the coefficients associated with the lagged variance of the model, suggesting that any shock to the variance does not decay immediately. Although time series methods can be used to facilitate the choice of optimal values of p and q, Bollerslev suggested that a GARCH (1,1) process is probably appropriate in most empirical situations. Accordingly, this study adapts a GARCH (1,1) process for the innovations associated with the farm-retail price relationship in equation (4).

The results of combining the ECM with the GARCH(1,1) process for innovations (referred to as ECM/GARCH) were obtained by estimating the appropriate forms of equations 4, 9, and 10 simultaneously. Maximum likelihood methods were applied to obtain the parameter estimates. The log likelihood function to estimate ECM/GARCH for a sample of T observations is given by,

$$LOG\ L = -T/2 \log(2\Pi) - 0.5\sum_{t=1}^{T} [\log h_t - (v^2{}_t/h_t)]. \qquad (11)$$

Estimation was carried out using the Davidson-Fletcher-Powell (DFP) algorithm and numerical derivatives after imposing conditions for the non-negativity of GARCH parameters.

The results of the ECM/GARCH process for farm prices of beef and pork are presented in Tables 3 and 4, respectively. The estimated long-run parameters differed slightly from those of the ECM model. More important, the persistence parameters in GARCH specification (β's) were statistically significant, indicating that the GARCH process is necessary to modeling the farm-retail price linkage for beef and pork. Also reported are the Box-Pierce Q test statistics for the standardized residuals ($v_t / \surd h_t$) along with the square of the standardized residuals ($v^2{}_t / h_t$) from the estimated ECM/GARCH models. In each case, the estimated values for Q and Q^2 were below the critical values of the Chi-square distribution at the 5 per cent level; thus, no further first- or second-order serial dependence was observed in the estimated ECM/GARCH models.[4] Statistics for the likelihood ratio tests were also computed for formally testing the ECM and ECM/GARCH.[5] This test statistic is distributed as a Chi-square with two degrees of freedom. The calculated likelihood ratio test statistics were 17.34 for beef and 10.25 for pork. These statistics were found to be greater than the critical Chi-square value of 5.99 (at the 0.05 probability level), indicating that use of the ECM alone could be rejected in favor of the ECM/GARCH for both beef and pork farm prices.

5. An Application Using ECM/GARCH

To demonstrate the usefulness of the ECM/GARCH model to empirical investigations of external factors or shocks, the effects on farm price of packer concentration in the meat industry was examined. It has been shown that concentration in markets can effect margins negatively (Ward, 1988), yet it may also provide price stability (Carlton). It is important therefore, to investigate the effect of firm concentration not only on the mean but also on the variance of farm prices. The ECM/GARCH model provides an appropriate tool for such analysis.

In this study, market concentration within the meat industry is measured by four-firm slaughter numbers. The monthly data on this was constructed using figures for the monthly total commercial slaughter and the annual percentage four-firm concentration ratio. Since the market structure for beef industry is complicated by boxed-beef technology, the analysis was carried out only for pork. The number of hogs slaughtered by the top four-firm was introduced on both ECM (the effect at the mean level, equation 4) and GARCH (the effect on variance, equation 10) specifications and the effect of market concentration of farm price of pork was tested. This analysis is exploratory and should be treated as preliminary.

Table 5 summarizes the results of market concentration within pork industry. Complete results are available from the authors. The results point out that market concentration affected mean negatively and variance positively on farm price of pork. A one-tail test on the effect of the market concentration variable on price volatility showed that the estimated coefficients were statistically significant at the 10 per cent level. This suggests that firm concentration within the pork industry has increased volatility of farm prices. This is possible under the "thin" market condition which has resulted from the market concentration. Further analysis is needed of this issue.

The effect of the market concentration variable on the expected value of farm price was also statistically significant (at the 0.05 probability level). Previous studies using margins or farm level prices for beef have shown a negative effect on farm-retail margins or farm prices (e.g., Ward). Until now, however, no study exists that accounted for both the mean and volatility simultaneously. Application of the market concentration on farm price of pork illustrates the use of ECM/GARCH models to evaluate structural effects on both mean and variance of farm prices within the price transmission mechanism. The results, however, should not be viewed as a definite statement about the effects on farm prices of market concentration.

Since market concentration can affect both the farm and retail levels, the markup type model for farm-retail price relationships perhaps capture only the partial effect of market concentration on farm prices. What is needed is a more refined analysis that incorporates the demand and supply shifters in the farm-retail price transmission. Such an analysis is beyond the scope of this study.

6. Conclusion and Implications

This study investigated dynamics in farm-retail price relationships within a general dynamic framework based on an error correction model (ECM). The model merges short-run dynamics with the long-run steady state equilibrium relationship dictated by economic theory. Previous studies in the estimation of farm-retail price relationships have not considered dynamics or incorporated dynamics within a restrictive framework. The error correction model was applied to monthly data for beef and pork and was found to be valid and appropriate for studying farm-retail price linkages. Though not shown here, the fact that ECM provides a consistent framework for merging steady-state equilibrium hypothesis and short run dynamics means it should enable forecasting superior to that of traditional VAR or time series models (Engle and Yoo).

Furthermore, added information regarding price volatility is useful for analyzing the effects of policy changes, market structure, or external shocks such as advertising. The estimated ECM model was extended to model time-varying, conditional variance of prices through the GARCH (1,1) process. The results indicate that the innovations for farm-retail price relationships exhibit the GARCH (1,1) process. This implies that variance of farm prices possess persistent effect, so that any shock to the system relies on the permanency of the shock as it affects not only the mean but also the variance of farm prices.

To demonstrate the usefulness of the dynamic model with the GARCH process in analyzing the effects on mean and variance, an exploratory exercise was conducted based on market concentration in meat industry. The estimated results for the market concentration variable suggest that packer concentration within the pork industry influences farm price levels negatively and variance positively.

In a changing environment like that of the livestock market, a model is needed that can combine the desirable aspects of dynamics, static equilibrium, and price volatility to elucidate and evaluate the effects of alternative pricing systems and policies. The ECM/GARCH model is a step towards such a unified approach.

Endnotes

1. Wohlgenant's specification includes both supply and demand shifters in farm and retail price determination. Our specification is similar to the reduced-form equation in Brorsen et al., with no supply shifters. Since the purpose of this study is to investigate dynamics in farm-retail price linkages, the commonly used form of markup model augmented with marketing cost is used. The analysis can be extended easily to other, more refined models dictated by theory.

2. The data for farm prices are measured by the gross farm value in cents per pound equivalent to one pound of retail weight.

3. In the Wohlgenant study the elasticities of farm price with respect to the retail demand shifter are 1.320 and 1.963 respectively, for beef and pork.

4. The maximum likelihood estimates of GARCH models depend on the existence of the fourth-order moment of v_t. For a GARCH (1,1) process, the fourth-order moment exists if $3\alpha_1^2 + 2\alpha_1\beta_1 + \beta_1^2 < 0$. Checks of the estimated GARCH parameters indicate that the fourth-order moment of v_t exists for each model. The estimated GARCH parameters also satisfy the stationarity conditions. Hence, the asymptotic properties of the maximum likelihood estimates are established.

5. Note that ECM is nested within ECM/GARCH (1,1) when $\alpha_1 = \beta_1 = 0$ in equation (10).

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Table 1. Unit root tests on farm and retail prices for beef and pork

Test statistic	Beef		Pork	
	Farm	Retail	Farm	Retail
$Z(t_{\hat{\alpha}})$	1.64*	2.77*	0.39	1.58
$Z(t_{\alpha^*})$	−1.36	−1.09	−1.96	−1.01
$Z(\Phi_1)$	2.43	4.84*	1.99	1.84
$Z(t_{\tilde{\alpha}})$	−2.94	−1.59	−3.35*	−2.41
$Z(\Phi_2)$	3.78	3.61	3.80	2.79
$Z(\Phi_3)$	4.37	3.82	4.00	3.41

*Significant at the 5% level of significance.

Note: The critical values at the 5% level of significance for 299 degrees of freedom are −1.62, −2.57, 4.63, −3.13, 4.74, and 6.33, respectively, for $Z(t_{\hat{\alpha}})$, $Z(t_{\alpha^*})$, $Z(\Phi_1)$, $Z(t_{\tilde{\alpha}})$, $Z(\Phi_2)$, and $Z(\Phi_3)$.

Table 2. Tests of co-integration between farm and retail prices of beef and pork

Test statistic	Beef	Pork
ADF(1)	−5.76*	−4.36*
ADF(2)	−5.68*	−3.76
ADF(3)	−5.59*	−3.45

*Significant at the 5% level of significance.

Note: The cointegration regression contains an intercept and two exogenous variables. The critical value for ADF statistics at the 5% level of significance for 200 degrees of freedom is −3.78 (Table 3, Engle and Yoo).

Table 3. Maximum likelihood estimates of ECM and ECM/GARCH models for beef

	ECM		ECM/GARCH	
Parameters	Estimated Coefficient	Asymptotic t values	Estimated Coefficient	Asymptotic t values
A_2	-0.009	-0.913	-0.053	-0.913
A_{11}	0.202*	6.186	0.235*	6.186
A_{13}	-0.150*	-4.491	-0.173*	-4.491
B_0	1.286*	10.187	1.141*	10.187
B_2	0.173*	3.396	0.176*	3.396
B_{11}	-0.337*	-5.265	-0.359*	-5.265
B_{13}	0.109	1.653	0.117	1.653
C_0	0.104	0.334	0.273	0.334
C_2	2.645	1.516	1.751	1.516
C_4	-2.167	-1.449	-1.584	-1.449
C_5	1.706	1.647	1.308	1.647
$\theta-1$	-0.100*	-5.269	-0.104*	-5.269
Φ_0	-0.073	-0.071	-0.031	-0.071
Φ_1	0.740*	2.141	0.668*	2.141
Φ_2	0.238	1.111	0.308	1.111
α_0	0.001		0.001*	2.109
α_1			0.086*	2.449
β_1			0.848*	18.056
Log L[a]	848.867		857.537	
Q Statistics[b]				
Q(12)	11.42		10.96	
Q(24)	27.09		29.18	
Q^2((12)	46.35*		23.92	
$Q^2(24)$	53.43*		28.94	

*Significant at the 0.05 probability level.

[a]Log L denotes the log-likelihood values which is upto a constant.

[b]The Q statistics denote Box-Pierce-Ljung portmanteau tests for autocorrelation, which are distributed as Chi-square with degrees of freedom equal to the lag provided within the parentheses. The critical values at the 5% level of significance are 21.03 and 36.42, respectively, for 12 and 24 degrees of freedom.

Table 4. Maximum likelihood estimates of ECM and ECM/GARCH models for pork

	ECM		ECM/GARCH	
Parameters	Estimated Coefficient	Asymptotic t values	Estimated Coefficient	Asymptotic t values
A_4	-0.016	-0.380	-0.001	-0.012
A_5	0.087*	2.208	0.056	1.355
A_{11}	0.151*	2.596	0.186*	3.076
A_{12}	0.036	0.497	0.042	0.578
A_{13}	-0.153*	-2.699	-0.120*	-2.005
B_0	2.209*	16.630	2.284*	16.584
B_4	-0.206	-1.054	-0.321	-1.689
B_{12}	-0.272	-1.065	-0.248	-1.013
B_{13}	0.422*	2.886	0.391*	2.847
C_0	-2.345	-1.657	-2.706	-1.920
C_2	1.464	0.734	1.319	0.677
C_4	-1.581	-0.871	-1.286	-0.660
C_5	0.527	0.426	0.406	0.296
$\theta-1$	-0.208*	-3.772	-0.211*	-3.862
Φ_0	-0.335	-1.072	-0.016	-0.461
Φ_1	1.284*	6.771	1.206*	6.281
Φ_2	-0.403*	-2.669	-0.353*	-2.368
α_0	0.003*	13.714	0.001	1.893
α_1			0.106	1.620
β_1			0.718*	5.649
Log L[a]	698.623		703.750	
<u>Q Statistics</u>[b]				
Q(12)	19.02		14.45	
Q(24)	28.26		25.31	
$Q^2(12)$	21.36*		4.73	
$Q^2(24)$	27.87		9.74	

[a]Log L denotes the log-likelihood value which is upto a constant.

[b]The Q statistics denote Box-Pierce-Ljung Portmanteau tests for autocorrelation which are distributed Chi-square with degrees of freedom equal to the lag provided within the parentheses. The critical values at 5% level of significance are 21.03 and 36.42, respectively, for 12 and 24 degrees of freedom.

*indicates significant at 0.05 probability level.

Table 5. Effects of market concentration on farm price of pork using ECM/GARCH model

Tests/ parameter	Coefficient	t-value
Effect on		
Mean (ECM)	-5.824**	-4.316
Variance (GARCH)	0.007[a]	1.416

**Significant at 0.01 probability level.

[a]Significant at the 10% level of significance, based on one tailed test.