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The Transmission of Price Volatility in the Beef Markets: A Multivariate Approach

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Abstract (Extended)

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The literature addressing the implications and measurement of price volatility in asset markets is vast (e.g. Weaver and Banerjee (J. of Futures Markets 1990); Nezt (AJAE 1995); Cho and Frees (J. of Fin. 1988)). While the research in this area is notable, less work has addressed the issue of temporal and spatial transmission of volatility. Transmission is the idea that volatility in one market is transferable across markets through the arbitrage of goods between markets. These markets can be distinguished temporally, spatially, or vertically.

The topic of temporal and spatial volatility transmission raises the issue of market efficiency. An efficient market is one where all information available at time *t* is reflected in current prices. Price changes will occur only when new, unanticipated information enters the market. But if volatility is transmitted across markets over the long-run for heterogeneous assets, this implies the markets are cointegrated. Goodwin and Schroeder (J. of Futures Markets 1991) define cointegration as two markets whose prices are each non-stationary by themselves but possess a long-run equilibrium relationship which is stationary. Spatial cointegration contradicts the efficient market hypothesis (EMH) because price information in one market could improve on the prediction of future prices in another market.

Another type of volatility transmission is temporal, i.e. persistence. That is, it is not uncommon for a shock to occur in a market, which induces price fluctuations. These fluctuations should be temporary if the markets are efficient but in some instances the volatility persists. Persistence of volatility is significant for various market participants. Producers and consumers are directly impacted by volatility persistence because it augments the uncertainty in the market. If the volatility persists as opposed to being centralized shocks, the level of uncertainty and risk will also persist. Therefore, it is critical for agents to not only be aware of the level of volatility but also its duration so appropriate temporal hedging strategies may be implemented.

Testing for efficient and temporal market integration until recently has focused on the conditional mean of price distributions. This paper investigates the transmission of information in the beef market by estimating both the conditional mean and conditional variance of various price series over a thirty-year period through advanced times series techniques. This approach of estimating the conditional first and second moments affords an approach to more completely describe the information flow over the specified sample period and ultimately commenting on market efficiency.

The definition of an efficient market suggests that it is impossible to make economic profits by trading on some information set since all information is fully reflected in the assets price. Therefore the asset price must fully reflect all information concerning

the second moment of the distribution. This suggests that since assets in structurally related markets share a common information set, price volatility should be instantaneously transmitted. Alternatively, if the rate of transmission is not immediate then information in one market can be used to anticipate prices in related markets thus violating the EMH.

The approach used in this paper to measure volatility transmission involves both a generalized autoregressive conditional heteroskedasticity (GARCH) model (see Engle (Econometrica 1982) and Engle and Bollerslev (Econometric R. 1986)) and a vector autoregressive (VAR) model. The GARCH model provides a parsimonious representation of the conditional variance, which is used to measure the intertemporal shock to volatility. Furthermore, the estimated conditional variance is implemented into a VAR model to explore the volatility relationship between markets. Finally, the data used in this study consists of monthly observations for various beef products for the period January, 1970 - December, 1998. These prices include the average US monthly wholesale and retail price of choice beef along with the average monthly Oklahoma City cash price for feeder cattle and the average choice cash price for Texas/Oklahoma City live cattle. The wholesale and retail prices represent monthly geographic average prices for choice beef as reported by U.S.D.A. The paper focuses on both levels and first differences since each series are found to be nonstationary.

The results from the cointegration analysis suggests the markets are integrated by arbitrage establishing long-term relationships. Furthermore, we find evidence that prices are interrelated even in the short-run with indication that the links closest to the production side are weakest. The results from the conditional variance estimation implies that shocks to the unexplained portion of prices do not persist in any of the beef markets suggesting the markets are operating efficiently. Finally, the results from the VAR model reveals relationships exist among the conditional variances with the most significant being the own conditional variance lag. However, in general, lag length is very short, indicating adjustment is rapid to changing market conditions.

The Transmission of Price Volatility in the Beef Market: A Multivariate Approach

Over the past twenty years the U.S. beef industry has experienced significant structural changes and increased market concentration in beef packing. This concentration has led researchers ask whether market power is being exercised by industry participants to determine if the market is operating in a competitive manner. Concentration alone in an industry does not imply noncompetitive behavior. For example, Feather and Sherrick (1992) note that firms may choose to vertically integrate to reduce the risk of supply uncertainty and to increase the efficiency of the firm by reducing cost in the production process. Therefore, vertical integration may be chosen by firms as a means to reduce uncertainty as opposed to noncompetitive behavior. Nonetheless, a high degree of concentration does raise concerns that natural barriers to entry and noncompetitive pricing may exist.

Empirical examination of the efficiency of markets has most often involved evidence from estimated conditional means of prices. The definition of an efficient market suggests that it is impossible to make economic profits by trading on the full information set since all information will be instantaneously exploited by arbitrage and reflected by independent, identically distributed (iid) changes in prices. The implications of this for the first moment of price series has received considerable attention. Given the nonstationarity of many commodity series, numerous studies noted the need to reconsider regression based methods that examined the existence of instantaneous linear relationships between prices in spatially separated markets (see e.g. Goodwin(1992)) or between futures and cash markets (see e.g. Chowdhury (1991)). This work led the literature to consider the usefulness of cointegration as a means of examining market efficiency.

This paper investigates market efficiency within vertically linked markets by considering its implications for both the conditional means and variance of price series. Estimation of the conditional means and variance jointly affords measurement of both the extent of and the intertemporal persistence of distortions in intertemporal arbitrage equilibrium. The paper is part of a stream of ongoing research by the authors that examines the implications for second moments, or price volatility, see e.g. Weaver, et al. (1989) and Loy and Weaver (1998). In this paper, we consider the persistence of transmission of levels and innovations in price and volatility across vertically linked markets as empirical evidence and its relevance for evaluation of market efficiency. Persistence in levels is considered using cointegration test and vector error correction models. Interpreting the innovation in price as unanticipated change we consider the Granger causal structure of transmission of these innovations. Volatility persistence is considered within the framework of a generalized autoregressive conditional heteroskedasticity (GARCH) model (see Engle (1982) and Engle and Bollerslev (1986)).

The data used in this study consists of monthly average prices for various beef products for the period 1/70 - 12/98. Products for which prices are analyzed include feeder cattle, live cattle, and the wholesale and retail price of choice beef. The monthly frequency of the observations allow analysis of beef prices through the vertical chain where each is sampled at the same frequency. The vertical structure of the data set begins with feeder cattle followed by live cattle, wholesale and retail levels.

Time Series Approaches

As an alternative to structural, parametric or nonparametric approaches, researchers have employed various time series techniques to study competitiveness in markets including the livestock industry. Again, while extensive work has focused on conditional means, less has considered implications for conditional higher moments. Weaver et al. (1989) considered the impact of local market structure on the speed of transmission of price change within retail grocery markets. Loy and Weaver (1998) considered transmission of volatility in food prices across space in Russia. Recent literature considering livestock includes Khan and Helmers (1997) who investigated the relationship between the input price of corn and livestock prices over three regimes within a VAR framework. Schroeder (1996) used a VAR model to investigate spatial price integration among 28 beef packing plants.

Spatial efficiency in markets implies convergence of prices in separated markets to one price (law of one price, LOP). In this case, spatial arbitrage with free entry and atomistic traders will result in uniform prices for homogeneous commodities in spatially separated markets once prices are adjusted for transportation costs and exchange rates. Explanations of incomplete spatial arbitrage (see e.g. Sexton et al., 1991) may include technological infeasibility, or regulatory or noncompetitive entry barriers may exist. Like those for the EMH, tests of the LOP hypothesis have examined evidence of randomness in price difference.[1] Although simple to conduct, results of this approach are biased and

[1] e.g. by estimation of the regression, $p_{1,t}=\alpha_0+ \beta_1 p_{2,t} + \varepsilon_t$ where $p_{1,t}$ represents a price series generated in one market while p2,t are prices in another market and testing whether the parameter estimate β_1 is significantly different from unity.

inconsistent if price series are nonstationary (Chowdury 1991). In this case, cointegration can be examined to establish evidence of long-run co-movement.[2] Cointegration has direct implications for market efficiency since if the prices for two homogeneous assets in distinct markets are not cointegrated, then they will tend to drift apart without bound. This divergence property is inconsistent with the implication of the EMH that arbitrage will bind prices into a long-run relationship. Chowdhury used the cointegration approach to reject the EMH in the cash and futures markets of four nonferrous metals. Fanchon and Wendel looked at cointegration of corn and feeder cattle prices finding that 1) both price levels were I(1), 2) monthly average, CPI deflated feeder cattle prices across weight classes (K.C. 400-500lb, 600-700lb. and Omaha 1000lb. steers) are co-integrated, and 3) these cattle prices are co-integrated with corn price (Omaha Y#2). Goodwin (1992) found supporting evidence for the LOP in the international wheat markets by employing a multivariate cointegration test.

Evidence of time varying volatility in commodity markets is extensive, see e.g. Baillie and Myers, and Holt and Aradhyula (1998). The possibility that price dynamics such as volatility are different under competitive vs. noncompetitive pricing was explored by Weaver et al. (1989) and, more recently, by Loy and Weaver (1998). Both the regression and the cointegration approaches used to examine market efficiency rely on the behavior of the conditional mean of the series to provide insight into the structure of the markets. However, the EMH has implications for both the level and transmission of volatility.

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[2] In a bivariate case, market prices would be cointegrated if $[\mathbf{p_1} \quad \mathbf{p_2}]\eta = \mathbf{p}_1 - \eta_2\mathbf{p}_2 = 0$ where η is called the cointegrating vector.

Market Efficiency in Vertically Linked Beef Markets

In this paper, we explore time series evidence concerning market efficiency in cattle markets based on a limited data set of monthly average cash prices for the period of 1/70 - 12/98. These prices include the average US monthly wholesale (WHOLESALE) and retail (RETAIL) price of choice beef along with the average monthly Oklahoma City cash price for feeder cattle (FCATTLE) and the average choice cash price for Texas/Oklahoma City live cattle (LCATTLE). The wholesale and retail prices represent monthly geographic average prices for choice beef as reported by U.S.D.A.

Figure 1 provides graphs of the four price series. Descriptive statistics for each series are presented in table 1. Results from the Jarque-Bera test suggest the beef prices in each market are characterized by a non-normal distributions.[3] Augmented Dickey-Fuller (1979) (ADF) tests indicate each series are nonstationary I(1). Although there existed no *a priori* hypothesis concerning the data generating process the presence of an apparent trend in each series resulted in both a constant term and trend term imposed in the estimated ADF equations. The optimal lag length was determined by minimizing the AIC criteria. First differences of each series were found to be stationary, I(0). Results are available from the authors.

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[3] This test provides an approach to determine if $Y_t \sim N(.)$. The test is based on measuring the skewness (third moment) and the kurtosis (fourth moment) of the data.

$$\text{Skewness}=S=1/T \sum(y_t-\mu)^3/\sigma^3$$

$$\text{Kurtosis}=K=1/T \sum(y_t-\mu)^4/\sigma^4$$

$$\text{Test:} \quad (T-K)/6\ [S^2 + 1/4(K-3)^2] \sim \chi^2_2$$

Implementing the above test statistic, the null hypothesis is

$$H_o: y_t \sim N(.)$$

Therefore, if the test statistic exceeds the critical value from a χ^2_2 distribution then there is evidence for

The results from the ADF tests motivated the use of cointegration tests to determine if a long run relationship exists across the commodity prices. To examine these relationships, bivariate and multivariate Johansen (1988, 1991) cointegration tests were conducted on price levels for each market. The results are presented in Table 2 for the multivariate case. The test was performed by only imposing a restriction on the intercept in the cointegrating relationship. The results from both the bivariate tests and the multivariate test indicate that there exist three cointegrating vectors in the model. This suggests the markets are integrated by arbitrage establishing long-term relationships. However, the cointegration results also suggest possible inertia exists in adjustment across markets.

While cointegration tests suggest there are long-run relationships between markets, short-run relationships may also exist. In the absence of stationarity in levels, we explore short-run bivariate Granger causality between pairs of innovations in price (first differences were found stationary). The results are presented in table 3. In all cases, the null hypothesis of no Granger causality is rejected at a test size of .10 though linkages between feeder cattle, live cattle, and wholesale prices can not be rejected at a significance level of .05. These results do not necessarily suggest noncompetitive behavior. Results are consistent with the interpretation of direct linkages between central market prices (feeder and live cattle) and retail level prices, and between wholesale and retail level prices.

Granger causality tests provide limited insight into market efficiency. Following the argument presented above, if markets are intertemporally efficient then the change in

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non-normal residuals

price will be an iid random variable. If each product market involves distinct fundamentals, i.e. their information sets (e.g. $\Omega^{c}{}_{t,i}$, $\Omega^{c}{}_{t,j}$ for two commodities *i* and *j*) are independent, then the changes in price will be independent. Granger causality tests provide evidence concerning intertemporal dependence. In general, we find evidence that prices are interrelated even in the short-run. We find evidence that the links closest to the production side are weakest.

To consider evidence of transmission of volatility, we first estimate the intertemporal variation in volatility based on a GARCH(1,1) model on price differences for each commodity. Estimated GARCH models are reported in Table 4. The results indicate each series exhibits GARCH type errors and none of the series appear to be IGARCH. This result implies that shocks to the unexplained portion of prices do not persist in any of the beef markets suggesting the markets are intertemporally arbitraged. To consider the transmission of volatility across markets, GARCH based conditional variances were generated for each commodity price series and a VAR model was estimated for the conditional variances. Loy and Weaver motivate this possibility for food markets. The results from the VAR model of conditional variances are presented in table 5. Optimal lag length was derived from the SIC criteria. The table reveals relationships exist among the conditional variances with the most significant being the own conditional variance lag. However, in general, optimal lag length is very short, indicating adjustment to changing market conditions is rapid. Cross-commodity transmission of volatility is also rapid. Feeder cattle and live cattle price volatility impact on wholesale price volatility appears nearly contemporaneous, similar results are found for the impacts of feeder cattle and live cattle price volatility on retail price volatility. Finally, a significant relationship exists between retail price volatility and wholesale price volatility (downward transmission). That is, it appears volatility in the retail market partially explains volatility in the wholesale market suggesting that the wholesale market is responsive to changes in consumer preferences.

Figure 1 Beef Prices Analyzed (Levels: Cents/Pound)

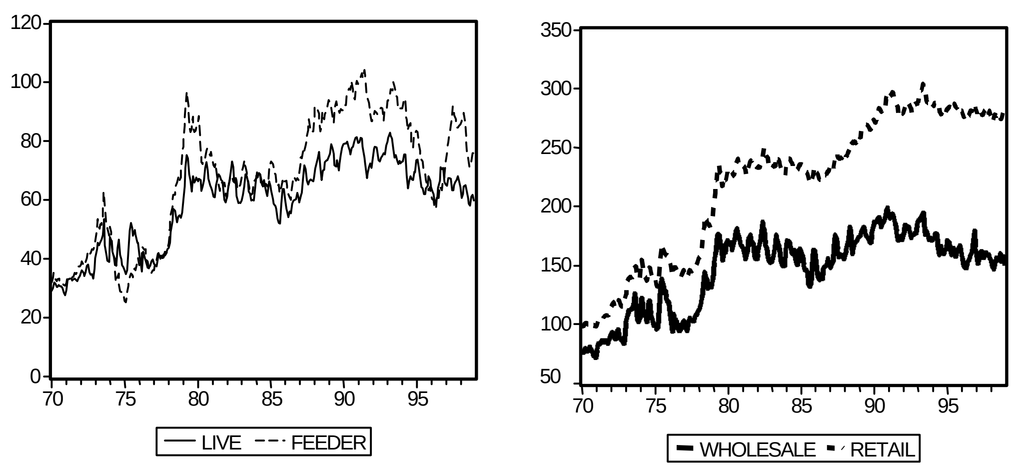

Table 1: Descriptive Statistics for Prices

	Feeder Cattle	Live Cattle	Wholesale	Retail
Mean	67.388	59.226	146.687	220.300
Median	67.950	63.735	158.300	234.550
Skewness	-.307	-.578	-.719	-.608
Kurtosis	1.925	2.151	2.295	1.989
Jarque-Bera	21.684	29.473	37.103	36.054
P-Value	0.000	0.000	0.000	0.000

Table 2: Multivariate Cointegration Test Results (Price Levels)

Test	Null Hypothesis	Test Statistic	Critical Values		
			20%	10%	5%
Lambda-Max Test					
	r=0	53.2	22.9	25.6	28.2
	r=1	21.3	17.5	19.8	21.9
	r=2	19.7	11.6	13.8	15.8
	r=3	4.8	5.9	7.6	9.1
Trace Test					
	r£3	4.8	5.9	7.6	9.1
	r£2	24.5	15.4	18.0	20.2
	r£1	45.7	28.8	32.1	35.1
	r=0	99.0	45.6	49.9	53.4

Table 3: Granger Causality Test Results Based on Price Innovations

Null Hypothesis	**F-Statistic**	**P-Value**
Feeder Cattle does not Granger Cause Live Cattle	1.439	.059
Feeder Cattle does not Granger Cause Wholesale Prices	1.421	.066
Feeder Cattle does not Granger Cause Retail Prices	2.564	1.3E-05
Live Cattle does not Granger Cause Wholesale Prices	1.415	.068
Live Cattle does not Granger Cause Retail Prices	4.169	1.2E-11
Wholesale Prices does not Granger Cause Retail Prices	4.118	1.9E-11

Table 4: GARCH(1,1) Results (Price Innovations)

	Feeder Cattle		**Live Cattle**		**Wholesale Price**		**Retail Price**	
	Parameter	T-Value	Parameter	T-Value	Parameter	T-Value	Parameter	T-Value
ARCH(0)	.301	1.956	.594	2.286	3.999	2.034	3.334	2.483
ARCH(1)	.157	4.113	.091	2.520	.150	2.664	.212	2.950
GARCH(1)	.809	22.640	.800	12.568	.720	7.901	.489	3.145

Table 5: Conditional Variance Vector Autoregression Estimates

	FEEDER	LIVE	WHOLESALE	RETAIL
FEEDER(-1)	0.956314	0.127675	0.005886	0.201824
	(0.05881)	(0.03322)	(0.10811)	(0.09036)
	(16.2622)	(3.84335)	(0.05445)	(2.23353)
FEEDER(-2)	-0.077636	-0.058208	0.176922	-0.089866
	(0.06018)	(0.03400)	(0.11064)	(0.09247)
	(-1.29004)	(-1.71216)	(1.59915)	(-0.97179)
LIVE(-1)	-0.126580	0.628923	0.158669	-0.405793
	(0.15013)	(0.08481)	(0.27599)	(0.23068)
	(-0.84316)	(7.41596)	(0.57491)	(-1.75909)
LIVE(-2)	0.026140	0.149449	-0.199365	0.381424
	(0.14822)	(0.08373)	(0.27248)	(0.22775)
	(0.17636)	(1.78491)	(-0.73166)	(1.67473)
WHOLESALE(-1)	0.036306	0.038363	0.519035	0.069123
	(0.03071)	(0.01735)	(0.05646)	(0.04719)
	(1.18219)	(2.21128)	(9.19333)	(1.46479)
WHOLESALE(-2)	0.013683	-0.012110	0.072820	0.008779
	(0.03082)	(0.01741)	(0.05666)	(0.04736)
	(0.44399)	(-0.69559)	(1.28529)	(0.18538)
RETAIL(-1)	0.013247	0.056428	0.299854	0.978906
	(0.05450)	(0.03079)	(0.10020)	(0.08375)
	(0.24304)	(1.83269)	(2.99260)	(11.6884)
RETAIL(-2)	0.014846	-0.072200	-0.325167	-0.207904
	(0.05435)	(0.03070)	(0.09992)	(0.08352)
	(0.27314)	(-2.35158)	(-3.25438)	(-2.48942)
C	0.213494	0.340232	1.131637	0.764806
	(0.11691)	(0.06604)	(0.21492)	(0.17964)
	(1.82620)	(5.15184)	(5.26544)	(4.25749)
R-squared	0.800674	0.770896	0.491946	0.748788
Adj. R-squared	0.795886	0.765392	0.479741	0.742753
Sum sq. resids	25.34836	8.089109	85.66838	59.85098
S.E. equation	0.275901	0.155858	0.507210	0.423949
Log likelihood	-40.31841	154.9970	-248.5571	-187.2320
Akaike AIC	-2.549465	-3.691661	-1.331695	-1.690321
Schwarz SC	-2.448549	-3.590745	-1.230779	-1.589405
Mean dependent	2.449935	2.309494	3.301341	5.410771
S.D. dependent	0.610683	0.321778	0.703199	0.835869
Determinant Residual Covariance		2.59E-05		
Log Likelihood		-135.1979		
Akaike Information Criteria		-10.35035		
Schwarz Criteria		-9.946687		

Standard errors and t-statistics in parentheses

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