Spectral Analysis of Asymmetric Price Transmission in the U.S. Pork Market

by

Douglas J. Miller and Marvin L. Hayenga

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Economists have proposed a number of plausible explanations for observed price transmission asymmetries in commodity markets. The reasons may be broadly classified as theories of cooperative oligopoly, search costs in locally imperfect markets, or asymmetric costs of inventory adjustment. Unfortunately, the econometric methods commonly used in such studies do not allow us to distinguish pricing behavior under the competing theories. In this paper, we argue that the alternatives may be distinguished by firm responses to high and low frequency (rapid or slow) price cycles. We use Engle's band spectrum regression to examine the symmetry of price transmission for price cycles of different frequencies. The spectral analysis results indicate that changes in wholesale pork prices are asymmetrically transmitted to retail prices in relatively low frequency cycles, which is not consistent with the search cost theory. Conversely, wholesale pork prices asymmetrically respond to changes in farm prices at all frequencies, which is not consistent with the search cost or inventory management theories.

Introduction

Over the past several decades, producers, consumers, food industry interest groups, legislators, and others have expressed concerns about the efficiency and equity of price transmission in the marketing channel for agricultural and food products. A common concern is that prices are "sticky" or slowly responsive to price changes in other levels of the marketing channel. Further, the response to rising and falling prices may not be symmetric. In particular, consumer groups have expressed concern that retail (downstream) prices rise more quickly than they fall given associated changes in the wholesale (upstream) sector. Concerns about rate and symmetry of price response are commonly raised if one or more sectors in the marketing channel are highly concentrated and dominated by a few firms.

In response to such concerns, economists have conducted several studies of price transmission across market levels. In general, the studies are based on time series models of price linkages between upstream and downstream firms. The rate of price response is measured through the lag relationship between upstream and downstream prices. The symmetry of price response is determined by measuring the relative response in downstream prices as upstream prices rise or fall. Recent studies of price transmission in markets for meat products have been conducted by Bailey and Brorsen, Boyd and Brorsen, Hahn, Schroeder, and Schroeder and Hayenga, and a summary of research on other agricultural commodities is provided by Schwartz and Willett. Other recent contributions have focused on symmetry of price response in the U.S. petroleum market (Borenstein *et al.* and Balke *et al.*).

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As noted by most authors, there may be several reasons for observed asymmetries in commodity prices. Unfortunately, the econometric methods commonly used in the price asymmetry studies do not allow us to refine the set of plausible explanations. The purpose of this paper is to consider an alternate approach to the asymmetry issue based on frequency domain time series methods. Although the frequency-based methods cannot conclusively determine the cause of all observed price asymmetries, we may be able to use this approach to further refine our research agenda.

Theories of Asymmetric Price Transmission

Borenstein *et al.* and Balke *et al.* discuss the competing theories of asymmetric price transmission. In general, the explanations offered in the literature may be roughly grouped in three categories: theories of local market power and search costs, inventory management costs, and tacit or explicit collusion among firms in an oligopoly.

Local market power and costly search

Grocery stores, meat processors, gasoline stations, and other wholesale and retail firms may enjoy local market power due to the lack of similar firms in a given neighborhood or region. Although customers of these firms face a finite number of choices, they may not be able to gather full information about prices offered by other firms due to the costs of search. In particular, a consumer may be unsure if a recent price increase at their local retail outlet was matched by the other retail firms. At the time, the consumer may simply pay the higher price to avoid making a costly search for a better price. Thus, retail firms can temporarily widen their profit margins by taking advantage of search costs.

Asymmetric costs of inventory management

Reagan and Weitzman and others have shown that firms may asymmetrically adjust prices due to the unequal costs of maintaining relatively high or low inventory levels. In general, the costs of experiencing a stockout are greater than the cost of carrying excess stocks. If upstream prices fall several periods in a row, the increase in quantity demanded may prevent firms from maintaining or replenishing inventories. To protect against a stockout, the firms may lower their prices at a slower rate than the decline in upstream prices. Consequently, asymmetric price transmission may reflect the difference in inventory costs.

Cooperative Oligopolies

Suppose a few dominant firms explicitly or tacitly cooperate to maintain an effective cartel in an industry. The traditional kinked-demand oligopoly predicts sticky prices, and other features of the market may provide plausible reasons for asymmetric price adjustment. For example, even if market conditions are ideal for collusive behavior (highly inelastic demand and concentrated supply), cartels are difficult to maintain due to the incentive for one firm to cheat on the group. To maintain market power, the collusive firms can use trigger prices, defined market areas or shares, industry associations, or other means to identify cheating behavior. Suppose the firms set a trigger price that serves as a minimum for the cartel. If a firm attracts excess market share by setting its price too low, the other firms will punish the cheating firm in some way. As upstream prices rise, firms can quickly raise their prices to maintain profit margins without fear of punishment. However, as upstream prices fall, firms may hesitate to lower prices too quickly in order to avoid punishment.

At this point, we emphasize that other plausible explanations have been offered in the literature. In most cases, one or more of the possibilities may be eliminated by referring to our knowledge of the relevant markets or institutions. For example, the inventory theory is not applicable to livestock or other non-storable commodities. However, we are often left with two or more competing theories that cannot be empirically distinguished with the methods commonly used in practice. In the following section, we argue that some of the alternatives may be distinguished if we consider firm responses to quickly or slowly evolving cycles in upstream prices. The proposed method of analysis focuses on the frequency of price cycles and is commonly known as spectral analysis.

Price Cycles and Firm Behavior

In time series analysis, prices or other observed outcomes of a stochastic process may be viewed in terms of their frequency of occurrence as well as their order of occurrence. Although the time series methods commonly used in economic research focus on events in the time domain, a large literature on frequency domain methods has evolved in statistics and econometrics. Before discussing the competing theories asymmetric price adjustment from a frequency domain perspective, we first review the concepts of periodic behavior and the frequency of the stochastic cycles.

Under Cramer's spectral representation theorem, a mean-zero covariance stationary random process Y_t may be composed as the sum of periodic or cyclic components of different frequencies, $\omega \in [-\pi, \pi]$. In the context of prices, high frequency (ω near π or $-\pi$) price cycles occur rapidly and are associated with transitory shocks to the market or economic system. In contrast, low frequency (ω near zero) price cycles represent slow moving changes in the system. Some prominent economic phenomena have been analyzed in terms of the frequency of related events. For example, Engle (1974) noted that the permanent income hypothesis implies that the marginal propensity to consume is different for permanent (low frequency) and transitory (high frequency) changes in income. To examine empirical support for the claim, Engle estimated the marginal propensity to consume for high and low frequency income data. Interestingly, the estimated marginal propensity parameter was not significantly different across the frequency regimes, which contradicts the permanent income hypothesis.

Other contributions to the economics literature suggest that the competing theories of asymmetric price transmission may be distinguished in the frequency domain. First, consider firm behavior in locally imperfect markets with search costs. For high frequency price cycles, firms can quickly raise prices as upstream prices rise but slowly reduce prices as the upstream price declines. Given the transitory nature of the change, consumers cannot afford to search for a better price and are caught paying higher prices in the short-run. Alternatively, firms cannot widen their margins if prices fall slowly and consumers have time to search for a better price. Thus, the presence of search costs in locally imperfect markets implies that asymmetric price transmission may occur for high (but not low) frequency price changes.

Regarding the inventory management theory, Blinder finds that firms allow inventories to build or decline for short periods of time as prices change in transitory fashion. However, firms alter their behavior in response to sustained price movements that cause inventories to increase or decline over subsequent periods. Thus, firms adjust their inventory management practices in response to low (but not high) frequency price cycles. The principle reason firms do not respond to transitory price changes are menu costs, or the costs of adopting new price or quantity strategies. A large number of studies in the macroeconomics literature find that small menu costs can result in wages or other prices that are "sticky" in the short-run. Further, Reagan and Weitzman find that the low frequency responses are asymmetric due to the higher cost assigned to low inventory situations. Consequently, asymmetric price transmission occurs for low (but not high) frequency price cycles under the inventory theory, and the expected pattern of asymmetric adjustment is exactly opposite the search cost case.

Price Transmission in the U. S. Pork Market

The U.S. markets for pork, beef, and other meat products have received considerable attention from researchers over the past three decades. The efficiency of price transmission in the markets is a common theme, perhaps due to the concentration of the meat processing and retail food marketing sectors. Recent reports indicate that the domestic pork-packing industry has a four-firm concentration ratio of 53%, and Ward finds that local four-firm concentration ratios can exceed 70%. As well, livestock are non-storable commodities subject to biological production lags, and the short-run supply curves for meat are highly inelastic. Consequently, livestock producers are unable to adjust production in response to transitory price changes, and some have expressed concern that they are at the mercy of downstream firms in the short-run.

Data for this study are weekly observations of pork prices at the farm, wholesale, and retail levels for 1981-95.[1] The farm-level data are interior Iowa-southern Minnesota live hog prices. The wholesale and retail series are composite prices formed as weighted averages from the major meat cuts. To conduct the time domain and spectral analyses, we must first

[1] The data were generously provided by Professor Ted Schroeder, Kansas State University.

remove significant trend and seasonal components from the data. Graphically, the pork price series exhibit slight linear trends, and a linear trend variable was statistically significant in least squares regressions for each price series. To remove the linear trend, we use the first-differences of the pork prices. We also conducted time domain tests for the presence of seasonal effects by regressing the prices on quarterly, monthly, and weekly dummy variables, which were not statistically significant.

Next, we test the stationarity of each price series using the augmented Dickey-Fuller (ADF) and the Enders-Granger tests. The latter hypothesis test is designed to overcome power problems with ADF and other stationarity tests in the presence of asymmetric responses. The adjusted critical values for the ADF tests appear in Table A of Enders, and the T-Max* and F critical values are provided in Tables 2a and 2b by Enders and Granger. The test results are presented in Table 1 and provide strong evidence that the price series are stationary.

We use a vector autoregressive (VAR) process to model the farm, wholesale, and retail pork prices. In general, a VAR model for an m-vector of observations may be stated as

$$\text{(1)} \qquad \mathbf{y}_t = \Phi_0 + \Phi_1 \mathbf{y}_{t-1} + \ldots + \Phi_k \mathbf{y}_{t-k} + \varepsilon_t$$

For the present study, the vector $\mathbf{y}_t$ is $[\Delta R_t, \Delta W_t, \Delta F_t]'$, where R_t, W_t, and F_t are the retail, wholesale, and farm pork prices, respectively. Equation (1) may be viewed as a reduced-form model in which all lagged dependent variables on the righthand side are predetermined, which simplifies the estimation task. The model may be derived from a structural representation of the VAR in which the contemporaneous observations may appear on the righthand side of (1).[2] To determine the order (number of lags) for the pork VAR model, we choose the common number of lags k to minimize the Akaike Information Criterion (AIC) for the system of VAR equations. We identified $k = 4$ as the optimal order for the VAR model. Although other authors have reported longer lags, especially in the wholesale-retail relationship, the following results were not significantly affected if we include higher order lag terms.

To determine the causal structure of the model, we conduct Granger causality and block exogeneity tests. The results of the tests are presented in Table 2. We find that farm prices strongly cause wholesale and retail prices, wholesale prices weakly cause retail prices, and there is no significant feedback from the downstream prices to the upstream markets. Although ordinary least squares is typically used to estimate VAR models, the estimator is inefficient if we impose the causality restrictions (i.e., the set of explanatory variables in each equation are not identical). We use the seemingly unrelated regressions (SUR) estimator to

[2] If the price series are non-stationary and cointegrated, the long-run restriction on the VAR model may be imposed with an error-correction mechanism.

compute the SUR estimates of the VAR model parameters. The estimated model parameters are reported in Table A. The model exhibits reasonably good fit to the pork price series. Although the results are not presented to save space, the diagnostic statistics and hypothesis test results provide further evidence in support of the stated VAR model.

Time Domain Tests for Asymmetry

To evaluate empirical support for the symmetry of price response among levels in the pork marketing channel, we restate the VAR model (1) as

$$(2) \qquad \mathbf{y}_t = \Phi_0 + \Phi_1^+ \mathbf{y}_{t-1}^+ + \Phi_1^- \mathbf{y}_{t-1}^- + \ldots + \Phi_k^+ \mathbf{y}_{t-k}^+ + \Phi_k^- \mathbf{y}_{t-k}^- + \varepsilon_t$$

Equation (2) is a special case of a threshold autoregressive process that allows for asymmetric response to increases or decreases in $\mathbf{y}_t$ for preceding periods. The lagged dependent variables are defined as $\mathbf{y}_{t-j}^+ = \max(\mathbf{y}_{t-j}, \mathbf{0})$ and as $\mathbf{y}_{t-j}^- = \min(\mathbf{y}_{t-j}, \mathbf{0})$, and Φ_j^+ and Φ_j^- are conformable (m x m) parameter matrices with the causality restrictions imposed. The pork VAR model is based on first-differences of prices, and the $\mathbf{y}_{t-j}^+$ and $\mathbf{y}_{t-j}^-$ variables represent positive and negative changes (respectively) in retail, wholesale, and farm pork prices.

Classical hypothesis tests of price transmission symmetry are conducted by comparing the response parameters for price increases and decreases. In terms of the VAR model stated in Equation (2), we consider joint null hypotheses of the form

$$(3) \qquad H_0\text{: } \Phi_k^+(m, m+1) = \Phi_k^-(m, m+1) \text{ for m of interest and for each k}$$

The hypotheses may be imposed on the asymmetric VAR model as a set of k = 4 linear restrictions $\mathbf{c}\Phi = \mathbf{0}$, and the associated Wald test statistic

$$(4) \qquad \text{Wald} = \hat{\Phi}'\mathbf{c}'\left[\mathbf{c}\text{Var}(\hat{\beta})\mathbf{c}\right]^{-1}\mathbf{c}\hat{\Phi}$$

is asymptotically $\chi^2(k)$ under the null assumption (3).

We report the Wald test results in Table 3 in the row labeled "Full sample". In the retail equation, the response of retail pork prices to changes in the wholesale price is not significantly asymmetric (the observed p-value is 0.53). Conversely, we reject the symmetry hypothesis in the farm-wholesale margin for tests conducted at levels greater than 0.055. In summary, we find no evidence of asymmetries in the wholesale-retail margin and marginally significant asymmetries in the farm-wholesale margin.

Band Spectrum Regression

To examine the symmetry of price transmission for high and low frequency price cycles, we use an estimation method known as band spectrum regression. The method was formally introduced and developed by Engle (1974, 1980), and a comprehensive discussion of the method is provided by Hylleberg (Section 4.3). Although spectral regression methods are not widely used, the required steps are relatively straightforward: 1) convert the price data to the frequency domain by a Fourier transformation, 2) select the band of high or low frequency observations of interest, and 3) use the observations for this band to estimate the model parameters. By analogy to time domain regression, note that a simple way to model time-varying behavior is to estimate separate regression models for subsets of the sample period. In band spectrum regression, the same idea is applied by estimating the model parameters for subsets (bands) of the frequency domain rather than subsets of the time domain.

For present purposes, we rewrite the VAR model (2) as a linear regression model of the form $\mathbf{y} = \mathbf{X}\Phi + \varepsilon$. The time domain observations **y** and **X** may be converted to frequency domain observations (indexed by $\omega_j = j\pi / n$ for $j = 1,\ldots,n$) with a discrete Fourier transform, **Wy** and **WX**. The transformation matrix **W** (known as the Fourier matrix) is orthogonal, and the transpose (inverse) of the matrix $\mathbf{W}'$ can be used to convert frequency domain observations back to the time domain. To identify the frequency band of interest, let **A** be an (n x n) diagonal matrix with elements $a_{ii} = 1$ for $i = [\omega/2\pi]$ (i.e, integer portion of the ratio) defined with respect to the frequencies of interest, $\omega_1 \leq \omega \leq \omega_2$. Then, the band spectrum regression estimate is based on the transformed data, $\mathbf{y}^* = \mathbf{AZy}$ and $\mathbf{X}^* = \mathbf{AZX}$.[3]

The band spectrum regression estimator is simply $\tilde{\Phi} = (\mathbf{X}'\mathbf{Z}'\mathbf{AZX})^{-1}\mathbf{X}'\mathbf{Z}'\mathbf{AZy}$, and the estimates are used to compute the Wald test statistics (4). Under appropriate regularity conditions, the estimator satisfies the Gauss-Markov Theorem in small (finite) samples and is consistent and asymptotically normal and efficient in large samples. Due to the orthogonality property of the Fourier matrix $\mathbf{W}'\mathbf{W} = \mathbf{I}_n$, the estimator reduces to the ordinary least squares regressor if we select the full set of frequencies (i.e., $\mathbf{A} = \mathbf{I}_n$).

Band Spectral Tests of Asymmetry

To test the symmetry of response at various frequencies, we first divide the frequency domain in four overlapping subsets, [0, 0.2], [0.1, 0.3], [0.2, 0.4], and [0.3, 0.5]. The frequency bands are associated with weekly cycles lasting at least 5 weeks (lowest frequency), 3.33 to 10 weeks, 2.5 to 5 weeks, and 2 to 3.33 weeks (highest frequency). We identify the bands by the mid-points of the frequency intervals (0.1, 0.2, 0.3, and 0.4), which correspond to 2.5, 3.33,

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[3] The frequency-based data may be complex-valued under some Fourier transformations. Engle (1974) and Harvey (1980) discuss alternate means of forming real-valued data that may be used in most regression packages. We use the transformation recommended by Harvey.

5, and 10 week cycles. The hypothesis test results are presented in Table 3. For the retail pork price equation, we find that the response to changes in the wholesale price is significantly asymmetric for frequency bands with midpoints $\omega = 0.1$ and $\omega = 0.2$. Recall that the time domain Wald test could not reject the symmetry hypothesis for the wholesale-retail margin. Thus, the asymmetric response at low frequencies is masked by the symmetric response at high frequencies in the time domain test.

Given our discussion of the competing theories of asymmetric behavior, the observed pattern is not consistent with the presence of search costs in locally imperfect markets but may be explained by the other theories. As previously noted, the inventory management theory is not directly applicable to livestock and other non-storable commodities, but much of the pork sold at the retail level is processed (e.g., bacon, sausage, cured hams) and may be stored for several weeks. Second, the observed symmetry in price transmission for high frequency changes may be consistent with a cooperative retail oligopoly in the presence of significant menu costs. For typical retail foodstores with electronic inventory (scanner) systems, the costs of changing prices are not small and only about 16% of the food prices change in the average week (Levy, *et al.*). Consequently, retailers may not respond to high frequency (transitory) changes in wholesale prices, but they may exhibit asymmetric response to longer-lived price cycles. Although the spectral methods do not allow us to further distinguish between the inventory or cooperative oligopoly theories, we can firmly reject the search cost theory.

Regarding the farm-wholesale margin, the band spectral tests confirm the asymmetries observed in the time domain test. From Table 3, we find that the p-values for each of the Wald test statistics are much lower than the Type I error rates commonly used in practice. Consequently, the farm-wholesale margin is asymmetric at all frequencies, which conflicts with the search cost and inventory management theories of asymmetric price response. Although we emphasize that our rejection of two theories does not automatically imply that we should "accept" the remaining theory, we note that other studies (e.g., Koontz, Garcia, and Hudson) present evidence of cooperative behavior among beef packers. The test results suggest that a similar study of the wholesale pork sector is warranted.

Concluding Remarks

In this paper, we use band spectrum regression to estimate the symmetry of farm-wholesale-retail price transmission for high and low frequency changes in pork prices. The band spectral test results indicate that traditional time domain methods can mask underlying asymmetries that can occur in subsets of the frequency domain. In particular, we are unable to reject the null hypothesis of symmetric price transmission in the wholesale-retail price margin based on the time domain (full sample) results. The band spectral tests also indicate that retail price changes are significantly asymmetric for low frequency cycles in wholesale prices.

Further, the spectral evidence presented in this paper indicates that the observed asymmetries in the wholesale-retail margin are not consistent with search costs or other theories that imply asymmetries at high frequencies. Conversely, the farm-wholesale margin is asymmetric at all frequencies, which is not consistent with search costs, inventory management, or other theories that imply asymmetries at high or low frequencies (but not both). Again, we strongly emphasize that our rejection of two of the three competing theories does not imply that we should automatically accept the remaining alternative. The advantage provided by the spectral methods is the ability to eliminate explanations that may be plausible but are not empirically supported in the frequency domain. As such, the search for reasons underlying asymmetric price transmission may continue with a refined set of objectives.

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Table 1. Stationarity Test Results

	Retail	Wholesale	Farm
Augmented Dickey-Fuller	-3.65	-3.85	-4.88

(Reject unit root with drift or trend at 5% level if t-ratio < -2.68)

	Retail	Wholesale	Farm
Enders-Granger T-Max$_T$*	-21.252	-20.159	-19.595

(Reject unit root with drift or trend if the largest t-ratio in absolute value falls outside the interval (-3.60, -0.76) for a 5% level test)

Table 2. Causality Test Results (asymptotic p-values in parentheses)

Granger Causality (row variable Granger-causes the column variable)

	Retail	Wholesale	Farm
Retail		2.527	0.385
		(0.0386)	(0.819)
Wholesale	2.695		0.411
	(0.0299)		(0.801)
Farm	3.412	36.886	
	(0.0089)	(0.0000)	

Block exogeneity (significance of the variable in the other equations)

Retail	Wholesale	Farm
13.564	12.812	192.516
(0.938)	(0.1185)	(0.0000)

Table 3. Wald test statistics for symmetry of the band spectrum regression models

Midpoint of the Frequency Band	Symmetry of the Retail-Wholesale Equation	Symmetry of the Wholesale-Farm Equation
10 weeks (ω=0.10)	10.153	28.884
	(0.0379)	(0.0000)
5 weeks (ω=0.20)	12.591	11.739
	(0.0135)	(0.0194)
3.33 weeks (ω=0.30)	1.290	16.212
	(0.8631)	(0.0027)
2.50 weeks (ω=0.40)	1.576	34.416
	(0.8131)	(0.0000)
Full sample	2.727	9.341
	(0.605)	(0.0531)

(Asymptotic p-values are in parentheses below the observed Wald test statistics)

Table A. Estimated VAR, symmetry and causality imposed (t-ratios in parentheses)

	ΔR_t	ΔW_t	ΔF_t
Constant	0.0331	-0.0027	0.0022
	(0.129)	(0.058)	(0.053)
ΔR_{t-1}	-0.720		
	(20.18)		
ΔR_{t-2}	-0.513		
	(12.00)		
ΔR_{t-3}	-0.340		
	(7.92)		
ΔR_{t-4}	-0.147		
	(4.11)		
ΔW_{t-1}	0.176	-0.278	
	(0.757)	(7.73)	
ΔW_{t-2}	0.716	-0.176	
	(2.98)	(4.71)	
ΔW_{t-3}	0.103	-0.098	
	(0.43)	(2.68)	
ΔW_{t-4}	0.371	-0.0031	
	(1.62)	(0.087)	
ΔF_{t-1}	0.393	0.420	0.418
	(1.49)	(9.10)	(11.61)
ΔF_{t-2}	-0.960	0.318	0.116
	(3.39)	(6.44)	(2.98)
ΔF_{t-3}	0.393	0.0320	-0.050
	(1.35)	(0.63)	(1.28)
ΔF_{t-4}	0.185	-0.007	-0.055
	(0.67)	(0.15)	(1.53)
System R^2		0.554	
Equation R^2	0.368	0.167	0.216