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Vertical Price Transmission of Perishable Products: The Case of Fresh Fruits in the Western United States

Byeong-il Ahn and Hyunok Lee

This paper investigates the asymmetry of price transmission in the marketing chain of shipping points and terminal markets for fresh fruits in the western United States. To preserve the distinct price patterns related to product perishability, we use data constructed at a fine time scale and representing the vertical markets linked with shipments. Using a decade of weekly data, we estimate the autoregressive distributed lag price transmission model and derive the dynamic multiplier effects of price responses. Our results indicate that the price adjustments and asymmetry patterns are closely related to product characteristics, especially the intensity of product perishability.

Key words: asymmetry, dynamic multiplier responses, marketing chain, price transmission, shipping point, terminal market

Introduction

Price transmission is an important element of linked markets that produce value-added goods. The pattern of price transmission among interrelated markets is governed by factors such as product characteristics, product transformation, and market structure. Earlier studies of price transmission in food markets assumed the symmetry of price response; that is, the extent of price transmission is not related to the direction of the initial price shock. A number of recent studies have empirically tested the asymmetry of price transmission within an analytical framework that allows price transmission to be asymmetric with respect to the direction of the initial shocks.

Previous work on asymmetric price transmission includes studies on gasoline prices (Borenstein, Cameron, and Gilbert, 1997; Kaufmann and Laskowski, 2005; Kilian and Vigfusson, 2011), pork prices in several marketing tiers (Punyawadee, Boyd, and Faminow, 1991; von Cramon-Taubadel, 1998; Luoma, Luoto, and Taipale, 2004; Čechura and Šobrová, 2008), beef prices in the marketing channel (Luoma, Luoto, and Taipale, 2004; Hassouneh, Serra, and Gil, 2010), the prices of packaged products in a supermarket chain (Peltzman, 2000), producer and consumer prices of fresh produce (Ward, 1982; Ahn and Kim, 2008; Götz and Kachel, 2008; Kim and Ward, 2013), international wheat prices (Ghoshray, 2002), and fish prices in the supply chain (Nakajima, Matsui, and Sakai, 2011; Simioni et al., 2013).

This study adds to the asymmetric price transmission literature by exploring the importance of product characteristics and market linkages. Our particular interest, product perishability, has distinct marketing consequences, including the short marketing horizon, high product turnover, and

Byeong-il Ahn is an associate professor in the Department of Food and Resource Economics at Korea University. Hyunok Lee is an agricultural economist in the Department of Agricultural and Resource Economics at University of California, Davis.
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the risk associated with sales delays. To empirically investigate how these aspects affect the pattern of price transmission in a vertical marketing setting, data representing a fine time scale and precisely defining the market channels through which products move are critical. Focusing on three fresh fruits—fresh apples, table grapes, and fresh peaches—we use data constructed at a weekly interval to reflect the short marketing horizon. Further, to ensure that vertical markets are linked with shipments, our data represent the shipping points and terminal markets within Washington state and California, the major producing regions of these products.

Within a framework based on distributed lags in both independent and dependent variables, we empirically examine the asymmetry in price transmission and derive dynamic-multiplier responses in downstream prices to changes in upstream prices. In most prior studies, the test of asymmetric price transmission is based on an F-test or a Wald test that identifies whether the coefficients (or sometimes aggregates of coefficients) capturing the influences of positive or negative shocks on the dependent variable are statistically different from one another. In addition to the usual parametric tests, the present study extends the tests of asymmetry to dynamic multiplier effects by performing Monte Carlo simulations.

Previous research has provided hypotheses about empirical evidence of asymmetric price transmission. The existence of asymmetry has sometimes been interpreted as an indication of market imperfections (Meyer and von Cramon-Taubadel, 2004; Carman and Sexton, 2005; Koutroumanidis, Zafeiriou, and Arabatzis, 2009). One widely held view is that market imperfection stems from market power. Under that interpretation, market power induces asymmetric patterns of price transmission as firms attempt to maximize rents (McCorriston, Morgan, and Rayner, 1998; Azzam and Schroeter, 1995; Chen and Lent, 1992; Bunte and Peerlings, 2003; Carman and Sexton, 2005; Guillen and Franquesa, 2010). Other hypotheses explaining asymmetry include menu (or re-pricing) costs (Carlton, 1989), disparate cost shares (Bettendorf and Verboven, 2000), inventory-holding behavior (Reagan and Weitzman, 1982), asymmetric market information (Bailey and Brorsen, 1989), risk dealing with perishable products (Ward, 1982), and supply and demand curvature (Xia, 2009).

Empirical contexts for these hypotheses include a wide range of industries, products, and segments of the marketing chain. Product characteristics and market environments are likely important elements affecting asymmetry and may affect the interpretation of results.[1] Our study focuses on fresh fruits, as did prior work by Ward (1982) and Kim and Ward (2013).[2] Both of these studies considered markets trading highly perishable products, in which product transformation is relatively minimal. In cases of relatively inelastic short-run supply of these products, price linkages in related markets are expected to be strong.

Empirical Model

Our empirical approach to test asymmetric price transmission was pioneered by Wolffram (1971) and Houck (1977), who advanced a framework that explicitly segmented adjustments by the direction of the initial price shock. This framework allows price responses to follow separate paths depending on whether the shock is positive or negative. Recognizing that price adjustments may take several periods to be fully realized, Ward (1982) and Boyd and Brorsen (1988) elaborated on Houck's model by introducing into the model lagged variables of asymmetric price transmission based on the direction of initial price shock and analyzed the process of price adjustments in their application to the vertical marketing chains of the U.S. vegetable and pork industries.

While such a multiperiod model is relatively simple to implement, the empirical approach may not be consistent with the time series properties of the data, especially the path of time series data

[1] The relevance of these factors depends on the industry and the segment of marketing chain considered. For example, menu cost would be most relevant at retail, while disparate cost shares would be relevant for value-added products. Inventory-holding behavior may be most applicable to storable items, and product perishability affects marketing risk.

[2] The study by Kim and Ward (2013) considers more than 100 individual food items; fruits and vegetables represent one of five aggregated food categories.

toward the long-run equilibrium. To remedy this concern researchers have employed a cointegration method in their tests for price-transmission asymmetry of petroleum product markets (Borenstein, Cameron, and Gilbert, 1997), German pork markets (von Cramon-Taubadel, 1998), world and producing-country coffee markets (Krivonos, 2004), and wood product markets (Ahn and Lee, 2013). Threshold error-correction models have also been used to investigate regime-dependent price transmission. Recognizing the potential role of transaction costs as a threshold in price transmission in spatially separated markets, this approach incorporated threshold-type price adjustments into the tests of market integration (Goodwin and Piggott, 2001; Abdulai, 2002; Ghoshray, 2002; Myers and Jayne, 2012; Greb et al., 2013). However, the threshold approach is more usefully applied to spatially separated markets than to the vertical markets in which product always flows in one direction regardless of transaction costs. Thus, the present study—which focuses on producer and wholesale market—adopts the framework of directional asymmetric transmission where asymmetry is based on the direction of the price shock. Further, we do not adopt the error-correction model because, as presented later, our data do not support the cointegration relationship between the prices.

In the context of this literature, and as a first step to develop our empirical model, we define the relationship between current and previous prices in a vertical marketing chain. Let P_t^d and P_t^u be the downstream and upstream prices at time t, where P_t^d depends on its own lagged prices and the current and lagged upstream prices. Thus, a typical autoregressive distributed lag (ADL) model with a lag length of n can be represented as

$$P_t^d = a_0 + \sum_{i=1}^{n} a_i P_{t-i}^d + \sum_{i=0}^{n} b_i P_{t-i}^u + \varepsilon_t. \tag{1}$$

Converting equation (1) into difference form, we have $\Delta P_t^d = \sum_{i=1}^{n} a_i \Delta P_{t-i}^d + \sum_{i=0}^{n} b_i \Delta P_{t-i}^u + \Delta\varepsilon_t$, where Δ denotes a change from the value in the previous period. The symmetric relationship in this equation can be relaxed to allow asymmetry by separating the explanatory variables according to the sign of the change, which can be achieved by appending binary variables, A_i^+, A_i^-, B_i^+, and B_i^-:

$$\begin{aligned} \Delta P_t^d &= \gamma + \sum_{i=1}^{n} a_i^+ A_i^+ \Delta P_{t-i}^d + \sum_{i=1}^{n} a_i^- A_i^- \Delta P_{t-i}^d + \\ &\sum_{i=0}^{n} b_i^+ B_i^+ \Delta P_{t-i}^u + \sum_{i=0}^{n} b_i^- B_i^- \Delta P_{t-i}^u + e_t; \\ A_i^+ &= \begin{cases} 1 & \text{if } \Delta P_{t-i}^d > 0 \\ 0 & \text{otherwise} \end{cases}, \quad A_i^- = \begin{cases} 1 & \text{if } \Delta P_{t-i}^d < 0 \\ 0 & \text{otherwise} \end{cases}, \\ B_i^+ &= \begin{cases} 1 & \text{if } \Delta P_{t-i}^u > 0 \\ 0 & \text{otherwise} \end{cases}, \quad B_i^- = \begin{cases} 1 & \text{if } \Delta P_{t-i}^u < 0 \\ 0 & \text{otherwise} \end{cases}. \end{aligned} \tag{2}$$

The tests for asymmetric price transmission are based on the parameter estimates, a_i^+, a_i^-, b_i^+, and b_i^- in equation (2). For example, the hypothesis $H_0: b_0^+ = b_0^-$ provides an immediate test of asymmetry between the contemporaneous prices, ΔP_t^u and ΔP_t^d. If these two coefficients are significantly different from one another, contemporaneous asymmetry exists. Tracing the effects of ΔP_t^u and ΔP_t^d is simple at the current period because none of the explanatory variables contains the effects of ΔP_t^u except the term ΔP_t^u itself. However, as the period moves into the future, tracking the effects of ΔP_t^u becomes less obvious because the term ΔP_t^u entered as a lagged term in equation (2) at the future period influences the future downstream prices directly as a lagged upstream price as well as indirectly through lagged dependent prices. Thus, comprehensive analysis of price transmission requires tracing all of these effects. For this task, we adopt the dynamic-multiplier approach, which captures both the direct effects of ΔP_t^u and indirect effects that are realized via lagged downstream prices over the multiple periods.[3] When there is a linear relationship between the variables, the dynamic multiplier can be derived analytically as discussed in Dhrymes (1973), Fomby, Hill, and Johnson (1984), Brorsen, Chavas, and Grant (1985), and Stein and Song (2002).

To express these effects algebraically, let $\Delta\tilde{P}^d_{t+i}$ $(i=0,\ldots,n)$ represent the portion of ΔP^d_{t+i} attributable only to ΔP^u_t. Then, in the event of positive shock of ΔP^u_t, $\Delta\tilde{P}^d_{t+i}$ $(i=0,\ldots,n)$ under the lag structure of nth order can be expressed as

$$\text{(3a)} \qquad \Delta\tilde{P}^d_t = (b^+_0\Delta P^u_t),$$

$$\text{(3b)} \qquad \Delta\tilde{P}^d_{t+1} = (b^+_1\Delta P^u_t) + (a_1\Delta\tilde{P}^d_t),$$

$$\text{(3c)} \qquad \Delta\tilde{P}^d_{t+2} = (b^+_2\Delta P^u_t) + (a_2\Delta\tilde{P}^d_t + a_1\Delta\tilde{P}^d_{t+1}),$$

$$\text{(3d)} \qquad \Delta\tilde{P}^d_{t+3} = (b^+_3\Delta P^u_t) + (a_3\Delta\tilde{P}^d_t + a_2\Delta\tilde{P}^d_{t+1} + a_1\Delta\tilde{P}^d_{t+2}), \ \ldots,$$

$$\text{(3e)} \qquad \Delta\tilde{P}^d_{t+n} = (b^+_n\Delta P^u_t) + (a_n\Delta\tilde{P}^d_t + a_{n-1}\Delta\tilde{P}^d_{t+1} + \ldots + a_1\Delta\tilde{P}^d_{t+n-1}).$$

For each equation in equations (3a)–(3e), the first bracketed term represents the direct effect of ΔP^u_t and the terms in the second brackets represent the effects of ΔP^u_t that are exulted through the lagged dependent variables. Note that parameters, a_i, in the second bracket are not assigned with signs. To examine the sign of a_i $(i=1,\ldots,n)$, let us take the example of equation (3c), the expression of $\Delta\tilde{P}^d_{t+2}$. For the term $a_2\Delta\tilde{P}^d_t$, the sign of a_2 corresponds with the sign of ΔP^d_t (not with the sign of $\Delta\tilde{P}^d_t$) Likewise, a_1 in the next term, $a_1\Delta\tilde{P}^d_{t+1}$, would be positive if $\Delta P^d_{t+1} > 0$ and negative if $\Delta P^d_{t+1} < 0$. The sign of a_i is not known *a priori* because there is no guarantee that the signs of ΔP^d_{t+1} and $\Delta\tilde{P}^d_{t+1}$ are the same.

The pattern of dynamic multiplier effects for each successive period provides insight about how the downstream price adjusts in response to the initial price shock in the upstream market. Summing up the dynamic multiplier effect at each period provides the comprehensive effect of the initial shock and the issue of symmetry on price transmission will be most appropriately investigated in the context of this cumulative dynamic multiplier effect. However, the fact that the expressions in equations (3a)–(3e) involve parameters that are determined conditionally indicates that the hypothesis test on the symmetry of cumulative dynamic multiplier effect cannot be expressed in parametric form. Therefore, an alternative test method is needed, and we adopt a numerical computational method of Monte Carlo simulations to draw inferences.

A brief remark on the possible expansion of model specification is in order. Under the cointegration property of the time series variables (Enders, 1995), the model specification expressed in equation (2) can be reformulated into an error-correction model that incorporates long-run adjustments (von Cramon-Taubadel and Loy, 1996). Due to the specification of the error-correction model depending on the results of the cointegration test, we defer any discussion of the error-correction model to a later section.

Data

One distinct characteristic of fresh fruits is perishability—a product characteristic that contributes to the short-term fluctuation of market price. This suggests that the price data that can be employed for the analysis of price transmission must be able to reflect such short-term fluctuations. In order to explore the linkage between markets at the appropriate time scale, we obtained weekly time series price data from the Agricultural Marketing Service (AMS) of the U.S. Department of

[3] The impulse-response approach—which is more commonly used for VAR frameworks—can be adopted instead of the dynamic-multiplier approach. In a VAR model, the symmetric relationship between dependent and lagged dependent variables is presumed. However, our analytical model includes asymmetric (i.e., positive and negative) lagged dependent variables, which makes it harder to track dynamic effects within the impulse-response approach.

Table 1. Weekly Price Data Statistics ($/lb)

	Location	Mean	Median	Max.	Min.	Std. Dev.	Variance
Apples (n=713)							
Shipping point	Washington State	0.367	0.363	0.775	0.213	0.099	0.010
Terminal	Seattle, WA	0.477	0.463	0.963	0.288	0.126	0.016
Table grapes (n=572)							
Shipping point	Central Valley, CA	0.825	0.761	2.389	0.464	0.280	0.079
Terminal	Los Angeles	1.038	0.944	3.056	0.568	0.332	0.110
Peaches (n=473)							
Shipping point	Central Valley, CA	0.527	0.500	1.455	0.227	0.202	0.041
Terminal	Los Angeles	0.702	0.636	1.727	0.296	0.266	0.071

Source: U.S. Department of Agriculture, Agricultural Marketing Service.

Agriculture.[4] We also focus on clearly defined products, which requires selecting specific varieties. We consider data from 1998 to 2011for fresh Red Delicious apples, Thompson seedless table grapes, and peaches designated as "various yellow flesh."

The next important consideration is to choose specific markets through which the product flows. Each market represented by our data is associated with a clear geographical boundary. The shipping points considered are Washington state for Red Delicious apples and the Central Valley of California for table grapes and peaches. The terminal market for apples is Seattle. For table grapes and peaches the terminal market is Los Angeles. Each shipping point represents a major production region in the country, and the designated downstream market is the major destination of the shipments from the respective upstream market (more detailed data information is provided in appendix table A1).

Figure 1 plots the data for each fruit, and table 1 provides summary statistics. Where markets do not span the whole year, there are missing values for peaches and grapes in weeks in which no prices are recorded. Discontinuity of the time series for fresh peaches and table grapes coincides with their off-seasons, whereas relatively continuous time series for apples indicate that they are supplied throughout almost the whole year.[5] For all fruit, the two price series tend to move together, exhibiting the similar cycle of peak and non-peak times during a season. Consistent with intuition, apples, which tend to be less perishable than the other fruits, show less price variation than table grapes and peaches. This is also confirmed by the summary statistics in table 1, which indicate average variations around the mean (coefficients of variation) are 26–27% for apples, 32–34% for table grapes, and 38% for peaches.

Preliminary Tests

To check for potential non-stationarity of the time series, we perform unit root tests on the non-differenced as well as differenced variables. Unit root tests on the non-differenced variables are performed based on vector autoregressive (VAR) models, which are used to identify lag orders and causality, and the tests on differenced data are based on price transmission equation (2). Optimal lag orders are selected based on statistical criteria, and the causality tests are conducted to identify the relationship between shipping point and terminal prices. We conduct unit root tests with differenced variables to determine whether to include error-correction terms. With cointegration between the terminal and FOB prices, the price-transmission equation can be further developed to represent a long-run relationship of these price series by including error-correction terms.

[4] Another alternative data source—the Bureau of Labor Statistics (BLS)—extends to the retail level, but is only available monthly.

[5] For table grapes and peaches, terminal prices tend to extend for longer periods than shipping point prices. This is likely due to the fact that a terminal market generally handles a larger volume of products than a typical shipping point. Data discontinuity implies that our empirical estimation loses a few observations in the beginning of each season because not all lagged variables are available for those periods.

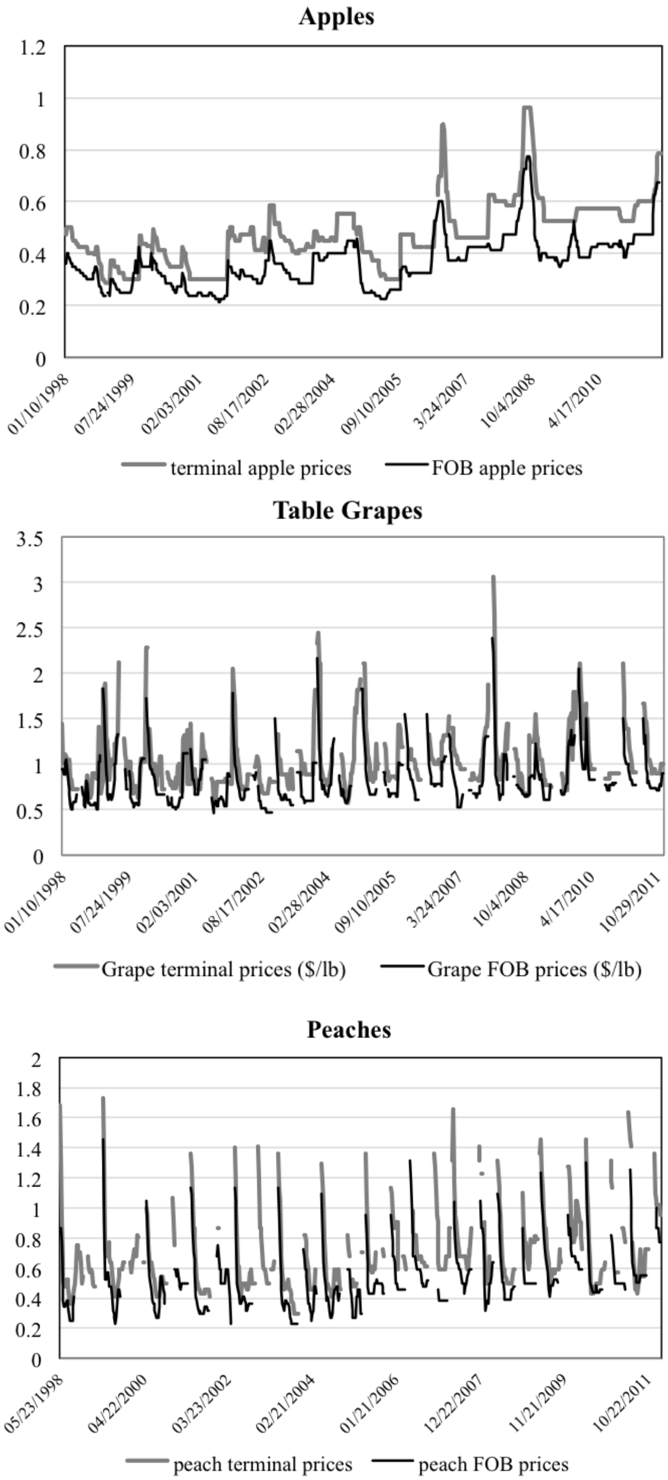

Figure 1. Weekly Prices ($/lb) of Fresh Apples, Table Grapes and Fresh Peaches at Terminal Market and Shipping Point (FOB)

Source: AMS.

Table 2. Lag Order Choice: Schwartz Bayesian Information Criterion

	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5
Apples	−10.2861	−10.2833	−10.2571	−10.2426	−10.2424
Table grapes	−3.2993	−3.5159	−3.5507	−3.6190	−3.4588
Peaches	−6.1230	−6.3708	−6.6944	−6.7072	−6.6920

Table 3. Granger Causality Test Results

Causality	Chi^2 Test Statistics	Pr.(| chi^2 | > Critical Value)	d.f.
Apples			
H_1: Shipping Point Price (P^S) → Terminal Price(P^T) (H_0: $b_0^T = b_1^T = \ldots = b_K^T = 0$)	30.8340	0.0000	1
H_1: Terminal Price (P^T) → Shipping Point Price (P^S) (H_0: $b_0^S = b_1^S = \ldots = b_K^S = 0$)	0.0026	0.9591	1
Table grapes			
H_1: Shipping Point Price (P^S) → Terminal Price (P^T) (H_0: $b_0^T = b_1^T = \ldots = b_K^T = 0$)	41.3703	0.0000	4
H_1: Terminal Price (P^T) → Shipping Point Price (P^S) (H_0: $b_0^S = b_1^S = \ldots = b_K^S = 0$)	0.7550	0.9444	4
Peaches			
H_1: Shipping Point Price (P^S) → Terminal Price (P^T) (H_0: $b_0^T = b_1^T = \ldots = b_K^T = 0$)	102.2311	0.0000	1
H_1: Terminal Price (P^T) → Shipping Point Price (P^S) (H_0: $b_0^S = b_1^S = \ldots = b_K^S = 0$)	1.1427	0.8874	1

Lag Order Choice and Causality Tests

The following VAR model is used to determine the optimal lag orders:

$$(4)\quad \begin{bmatrix} P_t^T \\ P_t^S \end{bmatrix} = \begin{bmatrix} \gamma^T \\ \gamma^S \end{bmatrix} + \begin{bmatrix} a_1^T \ b_1^T \\ a_1^S \ b_1^S \end{bmatrix} \begin{bmatrix} P_{t-1}^T \\ P_{t-1}^S \end{bmatrix} + \begin{bmatrix} a_2^T \ b_2^T \\ a_2^S \ b_2^S \end{bmatrix} \begin{bmatrix} P_{t-2}^T \\ P_{t-2}^S \end{bmatrix} + \ldots + \begin{bmatrix} a_k^T \ b_k^T \\ a_k^S \ b_k^S \end{bmatrix} \begin{bmatrix} P_{t-k}^T \\ P_{t-k}^S \end{bmatrix} + \begin{bmatrix} \varepsilon_t^T \\ \varepsilon_t^S \end{bmatrix},$$

where superscripts T and S denote terminal and shipping point (which correspond to downstream and upstream, respectively) and the possibility of the maximum lag order is set to be five ($k = 5$). We first conduct the stationarity tests for the variables in equation (4) by applying Augmented Dickey-Fuller (ADF) tests. Our tests on the variables in equation (4) indicate that all price variables were stationary for all fruits. The optimum lag order is selected based on the Schwartz Bayesian Information Criterion (SBIC), and table 2 presents the SBIC values at each order of lags., We select the lag orders based on the minimum value criteria, one for apples, four for table grapes, and four for peaches (Enders, 1995).

Our price transmission equation (2) is based on the assumption that the current terminal price is influenced by the shipping point price, which implies that causality runs from upstream to downstream.[6] This assumption, however, has to be verified empirically. Granger causality tests are performed based on equation (1), where the lags are specified using the findings on optimal lags. From the equation $P_t^T = \gamma^T + \sum_{i=1}^{k} a_i^T P_{t-i}^T + \sum_{i=0}^{K} b_i^T P_{t-i}^s + \varepsilon_t^T$, we can say that P^s causes P^T if we reject the null hypothesis, $H_0 : b_0^T = b_1^T = \cdots = b_k^T = 0$. Likewise, we can also test the hypothesis that P^T causes P^S based on the equation $P_t^s = \gamma^s + \sum_{i=1}^{k} a_i^s P_{t-i}^S + \sum_{i=0}^{k} b_i^s P_{t-i}^T$. We can say that P^T

[6] Koutroumanidis, Zafeiriou, and Arabatzis (2009) investigated the marketing chain for wood products where consumer price influences producer price.

Table 4. Unit Root Tests for Variables of Price Transmission Equation

Variables	Apples	Table Grapes	Peaches
		ADF Test Statistics	
$B^{+}\Delta P_t^s$	−23.583	-21.042	-17.065
$B^{-}\Delta P_t^s$	−8.251	-13.749	-11.097
$B^{+}\Delta P_{t-1}^s$	−23.584	-21.042	-17.065
$B^{-}\Delta P_{t-1}^s$	−8.251	-13.749	-11.097
$A^{+}\Delta P_{t-1}^s$	−23.239	-20.501	-20.050
$A^{-}\Delta P_{t-1}^s$	−15.248	-21.082	-14.606
		Critical Value at 5% Significance	
	−3.416	-3.418	-3.420

causes P^s if we reject the null hypothesis, $H_0 : b_0^s = b_1^s = \cdots = b_k^s = 0$. As shown in table 3, the null hypotheses of $H_0 : b_0^T = b_1^T = \cdots = b_k^T = 0$ are strongly rejected for all fruits, which is consistent with our underlying model assumption.

Unit-Root Tests for Differenced Variables

Estimation results are only meaningful when the variables in the regression are stationary. We conduct unit root tests for the variables (differenced variables) included in equation (2) using ADF tests. If the absolute value of the ADF test statistic is greater than the absolute critical value, the null hypothesis of unit root (or nonstationarity) is rejected. Our test results in table 4 indicate that the hypothesis of unit root is rejected for every variable tested, which implies little possibility of spurious relationships for regression. Our results on unit root tests are consistent with the results found by Gray (1963), who showed that price movements with seasonal patterns tend to maintain the constant mean and variance over time.[7] Further, our test results supporting the stationary processes of the time series data also preclude any model expansion to an error-correction specification (von Cramon-Taubadel, 1998).

Estimation Results of Asymmetric Price Transmission

Using the optimal lags found in the previous section, we estimate equation (2) for each fruit using the OLS technique and present the results in table 5. Overall estimation results indicate that results on shipping point prices (ΔP^s) are more robust in terms of statistical significance than those on the lagged terminal prices (ΔP^T). Moreover, for all three fruits, all shipping point prices (current and lagged) have positive effects on the current terminal price as expected. This indicates that changes in shipping point prices, either current or lagged, cause changes in the current terminal price in the same direction. However, opposite results are obtained for lagged terminal prices. Except for the apple equation, all coefficients on lagged terminal prices are negative, indicating that changes in lagged terminal prices induce changes in the current terminal price in the opposite direction. That is, an increase (decrease) in the past terminal price causes a decline (increase) in the current terminal price. This finding, combined with the finding on positive direct effects of shipping point prices, indicates that lagged own prices work as a dampening factor in the process of price transmission even though positive shipping point price effects may dominate. In general, the parameter estimates for the shipping point prices tend to be more robust than those for own lagged prices.

[7] The lack of price cointegration was also observed in other market contexts. Michael, Nobay, and Peel (1994) and Mainardi (2001) found no price cointegration in the context of spatially separated markets, and McNew and Fackler (1997) pointed out that non-stationarity of transport and processing costs could contribute to no findings of cointegration between price vectors in spatially separated markets, even in the presence of arbitrage.

Table 5. Estimation Results for Asymmetric Price Transmission Equation

		Apples		Table Grapes		Peaches	
Coefficient	**Regressor**	**Coeff. Est.**	**Std. Error**	**Coeff. Est.**	**Std. Error**	**Coeff. Est.**	**Std. Error**
γ		0.0002	0.0009	0.0084	0.0080	0.0053	0.0054
b_0^+	$B^+\Delta P_t^s$	0.6677***	0.0600	0.8324***	0.0702	0.2030	0.1291
b_1^+	$B^+\Delta P_{t-1}^s$	0.2015***	0.0689	0.2646***	0.0855	0.5035***	0.1395
b_2^+	$B^+\Delta P_{t-2}^s$			0.2896***	0.0908	0.0651	0.1808
b_3^+	$B^+\Delta P_{t-3}^s$			0.3751***	0.1001	0.0792	0.1856
b_4^+	$B^+\Delta P_{t-4}^s$			0.0174	0.0904	0.1947	0.1880
b_0^-	$B^-\Delta P_t^s$	0.0796	0.0879	0.7168***	0.1841	0.2647**	0.1301
b_1^-	$B^-\Delta P_{t-1}^s$	0.3446***	0.0907	0.6088***	0.1488	0.7430***	0.1223
b_2^-	$B^-\Delta P_{t-2}^s$			0.0032	0.1442	0.1068	0.1148
b_3^-	$B^-\Delta P_{t-3}^s$			0.1344	0.1231	0.3420***	0.0973
b_4^-	$B^-\Delta P_{t-4}^s$			0.1490	0.1074	0.1925**	0.0788
a_1^+	$A^+\Delta P_{t-1}^s$	0.0229	0.0433	−0.1128*	0.0650	−0.0433	0.1058
a_2^+	$A^+\Delta P_{t-2}^s$			−0.2388***	0.0724	−0.1345	0.1218
a_3^+	$A^+\Delta P_{t-3}^s$			−0.3485***	0.0826	−0.1446	0.1255
a_4^+	$A^+\Delta P_{t-4}^s$			−0.0199	0.1207	−0.1948	0.1690
a_1^-	$A^-\Delta P_{t-1}^s$	0.4064***	0.0758	−0.2913***	0.0769	−0.0371	0.0988
a_2^-	$A^-\Delta P_{t-2}^s$			−0.1027	0.0720	−0.1696**	0.0840
a_3^-	$A^-\Delta P_{t-3}^s$			−0.0003	0.0611	−0.1666**	0.0756
a_4^-	$A^-\Delta P_{t-4}^s$			−0.0279	0.0517	−0.1946***	0.0556
D	Dummy	−0.0224***	0.0066	−0.1160***	0.0233	−0.0259*	0.0149
	R^2	0.2551		0.4291		0.3939	

F-test results

Null Hypothesis	**Test stat(d.f.)**	**Pr(|F|>c)**	**Test stat(d.f.)**	**Pr(|F|>c)**	**Test stat(d.f.)**	**Pr(|F|>c)**
$b_0^+ = b_0^+$	29.1559	0.0000	0.3226	0.5704	0.0974 (1,240)	0.7552
$\sum_{i=0}^k b_i^+ = \sum_{i=0}^k b_i^-$	9.7003 (1,693)	0.0019	0.2929 (1,348)	0.5887	2.9198 (1,240)	0.0888

Notes: Single, double, and triple asterisks (*, **, ***) indicate statistical significance at the 10%, 5%, and 1% level. There were some weeks (less than 1% of observations) when the terminal price was lower than the shipping point price. We used a dummy variable to represent these periods in the regression.

Table 6. Cumulative Dynamic Multiplier Effect

		Cumulative Positive Response		Cumulative Negative Response	
	Initial Shock in Absolute Value $	$	% of Initial Shock	$	% of Initial Shock
Apples	0.0167	0.015	89%	-0.012	71%
Table grapes	0.1491	0.121	81%	-0.156	105%
Peaches	0.0933	0.088	94%	-0.131	140%

For both directions, the largest effects of shipping point price shocks on the current terminal price are the change in either the current or one lagged shipping point price. Thus most of each price shock is transmitted immediately or within a week. However, while we expect lagged price effects to moderate as the order of lag increases, for peaches, especially, relatively strong effects are observed with the third lag shipping point price in the case of positive shock and with the fourth lag shipping point price in the case of negative shock.

To investigate the symmetry of price transmission, we first conduct the likelihood ratio tests based on equation (2). The alternative model (unconstrained model) as expressed as equation (2) with no restrictions allows price transmission to be asymmetric, while the more parsimonious, null model (constrained model) restricts price transmission to be symmetric by imposing $b_i^+ = b_i^-$ (for all *i*) and $a_i^+ = a_i^-$ (for all *i*). Our test results indicate that we reject the null model for all three fruits at the 5% significance level, supporting that price shocks are transmitted asymmetrically for all three fruits.[8] To examine the pattern of price transmission in more detail, we investigate the symmetry of immediate impact. We test the null hypothesis ($H_0 : b_0^+ = b_0^-$) that a shock in the current shipping point price is symmetrically transmitted to the current terminal price. The hypothesis of symmetric concurrent impact is strongly rejected for apples (with P-value < 0.01) but cannot be rejected for table grapes and peaches. The direction of asymmetry for apples implies that the magnitude of change in terminal price induced by a change in current shipping point price is larger in the case of an increase in shipping point price than in the case of a decrease in shipping point price.

The effects of a given price shock extend over multiple periods through lagged price effects. The usual test of aggregate asymmetry effects is based on the sum of estimated coefficients of all prices.[9] However, in our case, such a test would not provide accurate information about asymmetry since a shock in one period influences the dependent variable at contemporary as well as future periods through lagged dependent variables. Therefore, a complete analysis of an initial price shock involves tracing all of these effects. We use dynamic multipliers to do so.

Asymmetric Dynamic Multiplier Effects

Based on the dynamic multiplier effects expressed in equations (3a)–(3e) and the parameter estimates presented in table 5, we derive the responses of the terminal price to positive and negative impulses of the same magnitude. We use the absolute value of one standard deviation of shipping point price (per pound) to represent a typical change in weekly shipping point price and set the magnitude to the initial shock. These assumed shocks are \$0.0168 for apples, \$0.1491 for table grapes, and \$0.0933 for peaches, which amount to 4.5%, 18%, and 18% of the respective mean shipping point prices. Positive and negative effects are prescribed simply by taking positive and negative values of these terms.

[8] We conducted the likelihood ratio test, which tests the likelihood of symmetry. The χ^2 test statistics obtained from our likelihood ratio test are 2,056 for apples, 385.4 for grapes, and 440 for peaches. With the respective degrees of freedom of 3, 9, and 9, the associated critical values are 3.84, 16.92, and 16.92 at the 5% significance level. Given that each test statistic is greater than the respective critical value, the null hypothesis of symmetry for each price series is rejected.

[9] We conducted the hypothesis test for symmetry, $\sum_{i=0}^{k} b_i^+ = \sum_{i=0}^{k} b_i^-$, for each fruit. Our test results indicate that the null hypothesis was rejected for apples at the 1% significance level, cannot be rejected for table grapes at the 10% significance level, and was rejected for peaches at the 10% significance level (with the respective Pr(|F|>c) at 0.002, 0.58, and 0.09).

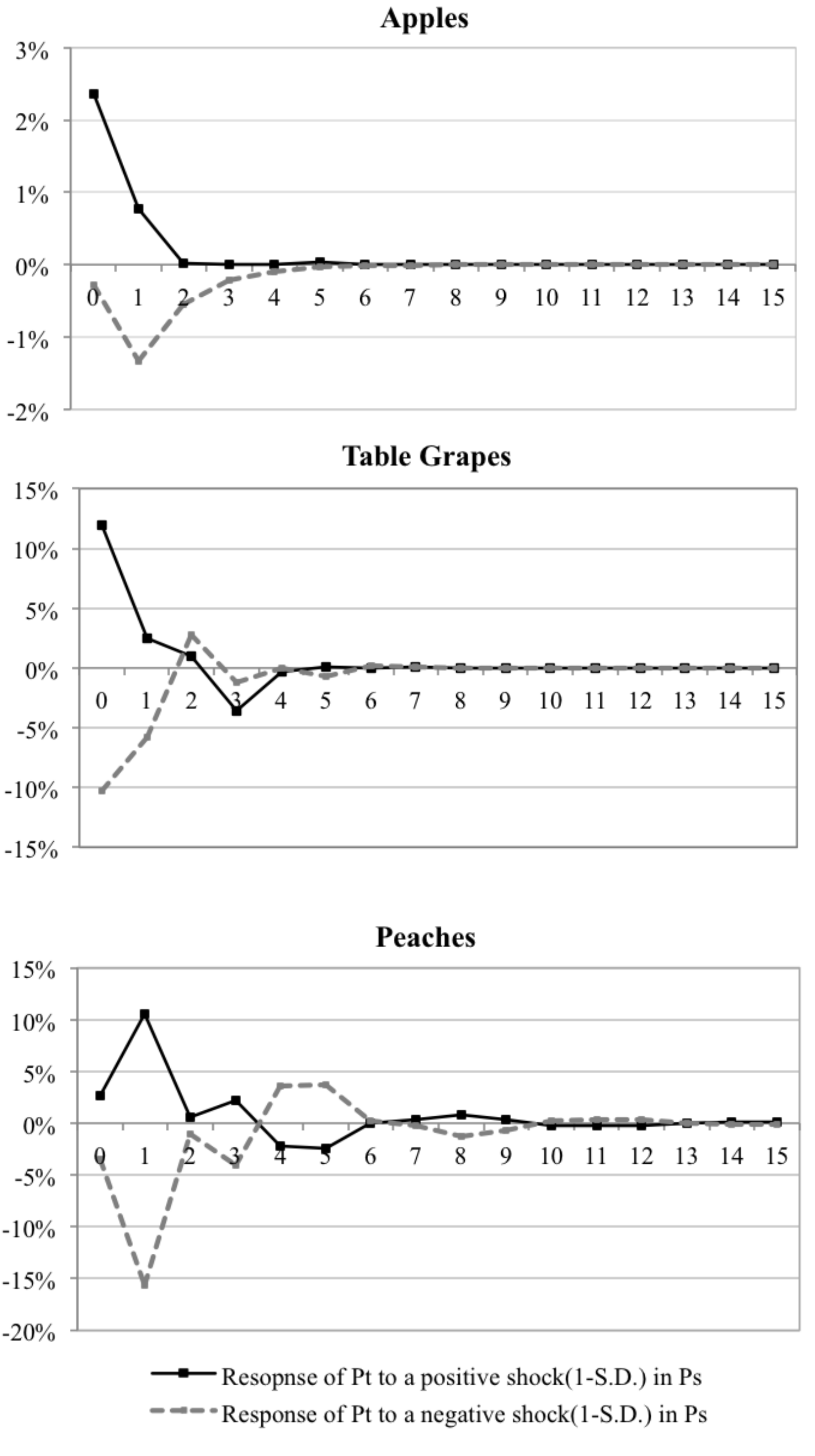

Figure 2. Responses of Terminal Price Measured as Percentage of Mean Terminal Price to Positive and Negative Changes in Shipping Point Price by One Standard Deviation

Notes: Standard deviations of the shipping point prices for apples, table grapes, and peaches are 0.0168, 0.1491, and 0.0933 $/lb, respectively. These price shocks represent 4.5%, 18%, and 18% of mean shipping point prices for apples, table grapes, and peaches.

Figure 2 presents the resulting dynamic multiplier effects of terminal price measured as a share of the mean terminal price, with the solid and dotted lines corresponding to the terminal price responses to the positive and negative shocks, respectively. Responses for each fruit are distinct in terms of magnitude and duration in price transmission. Several observations are immediate from comparison across crops. First, the dynamic multiplier effect and the duration of the full adjustment are also short for apples relative to the other two fruits. Second, the immediate response (i.e., $t = 0$) for apples and grapes tends to be most intense, and price transmission effects, in general, tend to taper with time. Third, peaches exhibit a unique pattern of responses—the adjustment process extends over many periods and shows pronounced fluctuations.

The relatively small responses and speedy adjustment for apples are consistent with the fact that the initial shock for apples was only one fourth of those for other fruits. Apples are also less perishable and have a longer season than peaches and table grapes, which dampens the effects on downstream price. Recent supermarket data also indicate that spoilage at supermarkets was higher for fresh peaches than table grapes.[10] More spoilage suggests higher perishability of fresh peaches, which tends to impair smooth market adjustment.

The impacts of lagged dependent variable determine whether and how quickly dynamic multiplier effects converge to zero. For example, for table grapes and peaches, the dynamic multiplier effects change signs during the adjustment process. Given that both current and lagged shipping point price effects are positive for both fruits (table 5), sign changes in multiplier effects are due to negative effects of own lagged prices that are strong enough to outweigh the positive shipping price effects.

Table 6 presents the cumulative dynamic multiplier effects when responses are fully realized. These cumulative values allow us to investigate what portion of the shock in the upstream market is transmitted to the downstream market. As shown in table 6, in the case of positive dynamic multiplier effects, price transmission for all three fruits is less than full, implying that the wholesaler's selling price increases, on average, less than the increase in his purchasing price. Therefore, the wholesaler's margin per unit of product must shrink when the upstream market has a positive price shock. In the case of negative dynamic multiplier effect, results are mixed; price transmission is not full for apples but is more than full for table grapes and peaches (Kim and Ward, 2013). This implies that the wholesaler's margin, on average, increases for apples but decreases for table grapes and peaches during the period of price downturn.[11]

We now turn to tests of the symmetry of dynamic multiplier effects. Formal parametric tests are not possible, but insights on this issue can be gained by applying an alternative statistical method based on Monte Carlo simulations. Simulations of dynamic multiplier effects are performed under the assumption that each estimated coefficient has a normal distribution with its mean and standard deviation set at the estimated value and standard error. We derive associated dynamic multiplier effect curves from 1,000 random combinations of coefficients. For example, tests for symmetry at each period, $H_0 : \Delta\tilde{P}^{d+}_{t+i} = -\Delta\tilde{P}^{d-}_{t+i}$, which can be performed on the combined sum, $\Delta\tilde{P}^{d+}_{t+i} + \Delta\tilde{P}^{d-}_{t+i} = 0$, were conducted by first creating a distribution from 1,000 random draws of this sum under the distributional assumption of the coefficients as stated above and then deriving the mean and standard error of this simulated sum.

If the constructed t-value is greater than the critical value 1.96, we reject the null hypothesis at the 95% of significance and conclude that responses at the ith period after the initial shock are asymmetric. Likewise, tests on cumulative responses are conducted on the derived mean and

[10] The supermarket loss estimates are 15% for fresh peaches and 8% for table grapes (Buzby et al., 2009). Storage life in a refrigerator is one month for apples, five days for table grapes, and less than five days for peaches (Hillers, 2005). Ashby (1995) noted that table grapes are easily affected by gray mold and peaches are very sensitive to temperature.

[11] Our results for table grapes and peaches are shared by Kim and Ward (2013), who showed that price transmission in the context of the farm and wholesale segment for fruits and vegetables is less than full during rising market prices but more than full during falling market prices.

standard error of the combined sum of cumulative responses, $\sum \Delta \tilde{P}^{d+}_{t+i} + \sum \Delta \tilde{P}^{d-}_{t+1}$.[12] The maximum value of i in this sum is the duration of time for full adjustment, which we set to be ten weeks based on our previous results. Our discussion below highlights only the asymmetry tests of cumulative dynamic multiplier effects (detailed Monte Carlo test results are reported in appendix table A2).[13]

Figure 3 shows the simulated means of the combined cumulative response terms and associated 95% confidence intervals. When the derived confidence interval is located above zero at a specific period, say i, it implies that the combined term is statistically different from zero at period i and thus positive asymmetry exists for the cumulative dynamic multiplier effect defined up to period i. Likewise, the derived confidence interval located below zero implies negative asymmetry.

For apples, the means of the combined simulated terms are all positive and the associated 95% confidence intervals are located above zero for all periods. This supports positive asymmetry for apples with statistical confidence. For table grapes, the direction of asymmetry changes the sign up to week two, but beyond week two cumulative responses show negative asymmetry. For peaches, our simulation results support negative asymmetry for all periods with statistical confidence. Further, at each period, confidence intervals for all three fruits locate in either the positive or negative region, meaning that our findings of asymmetry for each period are all supported statistically.

The mean values of combined cumulative responses at period 15 (when effects are fully realized) are \$0.0028/lb, −\$0.0347/lb, and −\$0.0411/lb for apples, table grapes, and peaches, respectively. These mean values also represent 0.6%, −3.3%, and −6% of the average terminal price and 17%, 23%, and 44% of the original shock for apples, table grapes, and peaches (in absolute value), respectively. These measures suggest that fully realized price transmission shows positive asymmetry for apples and negative asymmetry for both table grapes and peaches. Asymmetry tends to be mildest for apples and most robust for peaches.

Discussion and Summary

This paper investigates the asymmetry of price transmission in the marketing chain of shipping points and terminal markets for fresh fruit. Applying an autoregressive distributed lag model to weekly time series data, we traced multiperiod adjustments of terminal price responses to a change in shipping point price that is differentiated by the direction of the change. Specifically, we derived the dynamic multiplier effects of the terminal price. Based on derived responses to negative and positive shocks, we investigate the pattern of price adjustments and the asymmetry of dynamic multiplier effects. We also provide statistical inferences on asymmetry based on Monte Carlo simulations.

Our empirical findings are delineated between apples and two other fruits, table grapes and peaches, in the speed and scope of adjustments as well as asymmetry of responses to the initial shock. Price adjustments for apples were smaller in scope and faster than those for table grapes and peaches. Apples fully adjust in four weeks, while table grapes and peaches took almost ten weeks to fully adjust. Moreover, responses for apples gradually tapered with time, but responses for table grapes and peaches showed considerable fluctuation with no steady pattern.

Direction of price asymmetry was also distinct among these fruits. Cumulative dynamic multiplier effects showed positive asymmetry at all adjustment periods for apples but negative asymmetry at most periods for table grapes and at all periods for peaches. Positive asymmetry for apples was moderate. For example, the mean asymmetry, when responses were fully realized, was less than 1% of the mean terminal price of apples. Typical hypotheses used to explain positive asymmetry do not account for these results. Plausibility of organized market power or the menu

[12] When $i = 0$, the cumulative response becomes the same as the impulse response at the current period.

[13] Our investigation shows that the phases of asymmetric response differ by fruit and period. In most cases, derived t-values are significant, meaning that our tests support asymmetry. At the initial period ($t = 0$), apples and table grapes show positive asymmetry but peaches show negative asymmetry. After the initial period, negative asymmetry dominates for apples and table grapes, while results for peaches are mixed.

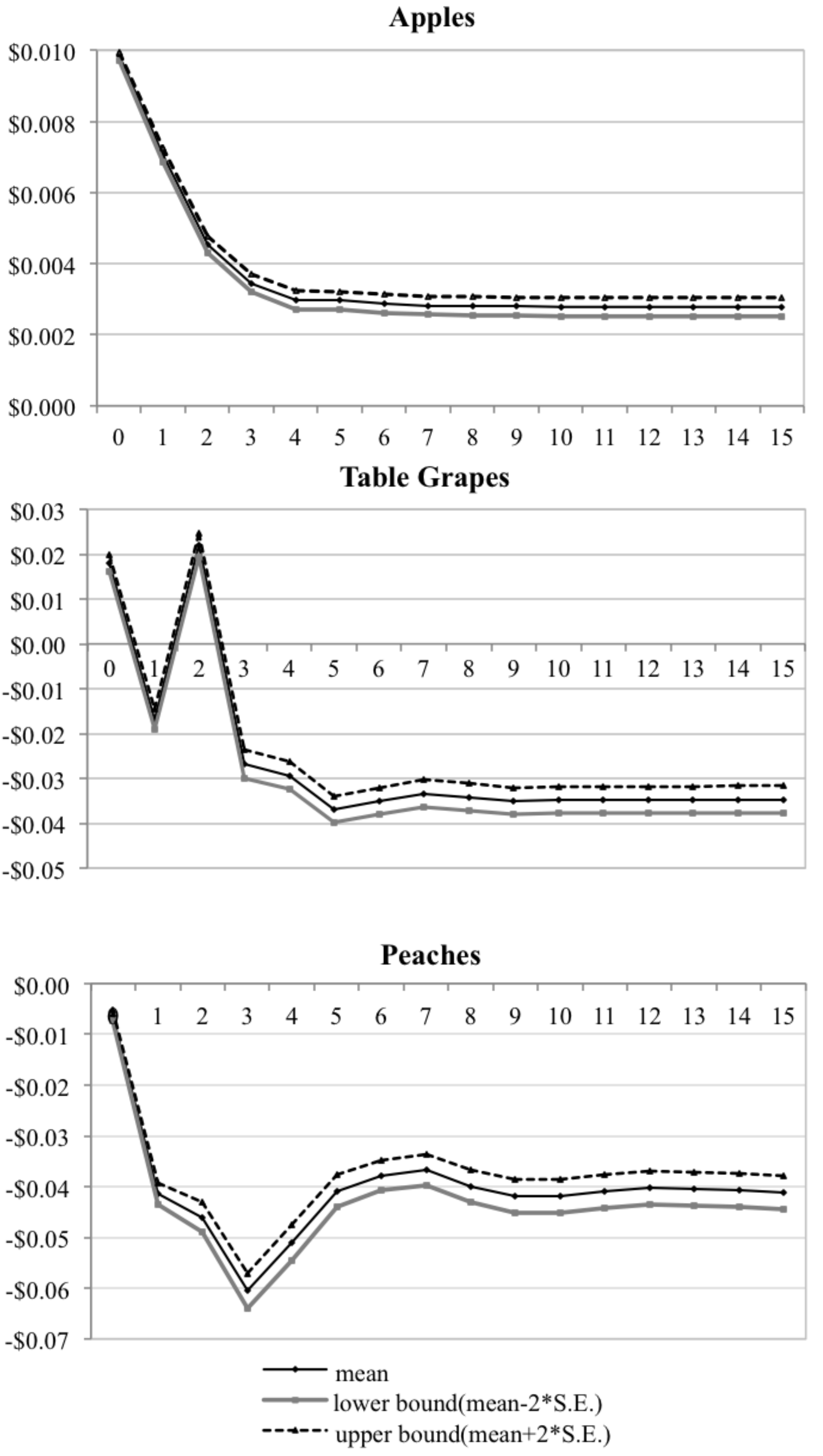

Figure 3. Means ($/lb) and 95% Confidence Intervals of the Sum of Two Cumulative Response Terms Generated Using Monte Carlo Simulations

cost at the terminal level is weak.[14] More plausible is the inventory-holding hypothesis, which suggests that marketers increase inventory holdings in times of low demand rather than cut output prices, resulting in positive asymmetry (Reagan and Weitzman, 1982). Given the storability of apples relative to the other fruits, the inventory-holding hypothesis is not inconsistent with our results for fruit markets.

Our findings of negative asymmetry were stronger. For peaches, mean asymmetry was 6% of the mean terminal price. This result and similar findings for table grapes differ from the typical empirical outcome, which mainly focuses on positive asymmetry. The exceptions were Ward (1982) and Kim and Ward (2013). Ward (1982) found negative asymmetry in the way a wholesale price shock was transmitted in the retail price. Ward argued that retailers' resistance to raising prices stems from the short marketing horizon associated with perishable products that require high turnover. That is, downward price pressure increases the risk associated with downstream marketers holding perishable products, which induces marketers to dispose of the inventory at a price lowered by more than the initial price shock. Our results on peaches concur closely with those by Kim and Ward (2013) on the marketing chain between shipping points and wholesale for the vegetable and fruit category.

Using weekly data enables us to find that the price response initiates almost immediately or at most one week later after the shock and that the full price adjustments tend to last a considerable time, more than one month for very perishable fruits such as peaches or table grapes. Further, we find that for those very perishable fruits, upstream price increases are not fully reflected at the downstream market, whereas downstream prices adjust more than fully to upstream price decreases.

This research suggests that product characteristics affect patterns of price transmission, a point reinforced by the different transmission patterns found for apples, table grapes, and peaches. Even among individual fresh fruits, which are often aggregated into a produce category, we found that specific product characteristics (such as the degree of perishability or the length of season) are important enough to change the direction of price transmission asymmetry. Our study has implications for understanding vertical market price transmission more broadly. For example, marketing margin research should incorporate product characteristics into its analysis in addition to other relevant market factors such as market structure.

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[14] For negative asymmetry, the market power hypothesis presumes market power sided with the upstream marketers. However, the market power hypothesis for negative asymmetry seems to be even more implausible than positive asymmetry when there are shipping points serving fewer terminal markets.

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Appendix A

Table A1. Data Description

	Apples	Table Grapes	Peaches
Data period	1/10/1998–10/1/2011	1/10/1998–12/242011	5/23/1998–2/1/2012
Fruit variety	Red Delicious	Thompson Seedless	Various yellow flesh
Grade	Washington Extra Fancy	n/a	n/a
Size	88s	Large	40–42s
Container	Carton tray pack	All containers	Carton 2 layer tray pack
Price unit	$/lb	$/lb	$/lb
Terminal market location	Seattle	Los Angeles	Los Angeles
Shipping point location	Washington State	Central Valley, California	Central Valley (Central and Southern part of San Joaquin Valley), California

Table A2. Test Results of Asymmetric Responses of Terminal Price (P_t) to a Positive/Negative Impulse in Shipping Point Price (P_s), Based on Monte Carlo Simulation

	Apples			Table Grapes			Peaches		
Impulse Responses at the End of	Mean of Simulated Summation ($\Delta P_{t+i}^{d+} + \Delta P_{t+i}^{d-}$)	Standard Error of Simulated Mean	Simulated t-value	Mean of Simulated Summation ($\Delta P_{t+i}^{d+} + \Delta P_{t+i}^{d-}$)	Standard Error of Simulated Mean	Simulated t-value	Mean of Simulated Summation ($\Delta P_{t+i}^{d+} + \Delta P_{t+i}^{d-}$)	Standard Error of Simulated Mean	Simulated t-value
0 periods ($i = 0$)	9.958E−03	5.658E−05	176.0066	1.743E−02	9.511E−04	18.3219	−6.396E−03	5.298E−04	−12.0733
1 period ($i = 1$)	−2.803E−03	6.366E−05	−44.0337	−3.604E−02	9.017E−04	−39.9745	−3.447E−02	9.170E−04	−37.5878
2 periods ($i = 2$)	−2.472E−03	2.776E−05	−89.0501	4.058E−02	9.022E−04	44.9761	−3.694E−03	1.153E−03	−3.2027
3 periods ($i = 3$)	−1.072E−03	1.614E−05	−66.4255	−4.894E−02	8.600E−04	−56.9061	−1.173E−02	1.125E−03	−10.4236
4 periods ($i = 4$)	−4.666E−04	9.436E−06	−49.4492	−3.094E−03	6.246E−04	−4.9539	1.069E−02	4.953E−04	21.5848
5 periods ($i = 5$)				−7.773E−03	3.290E−04	−23.6297	8.935E−03	5.571E−04	16.0374
6 periods ($i = 6$)				2.172E−03	2.153E−04	10.0872	2.342E−03	3.304E−04	7.0889
7 periods ($i = 7$)				1.678E−03	1.119E−04	15.0000	8.881E−04	2.877E−04	3.0867
8 periods ($i = 8$)				−7.145E−04	9.495E−05	−7.5251	−2.760E−03	1.538E−04	−17.9420
9 periods ($i = 9$)				−1.039E−03	8.789E−05	−11.8247	−1.755E−03	1.574E−04	−11.1544
10 periods ($i = 10$)				2.803E−04	6.406E−05	4.3752			

Notes: The tests were conducted based on the responses of terminal prices not percentage responses.