Regional Competitiveness in Fresh Produce Markets: Exploring Seasonal Dynamics and the Role of Energy Costs in Apple Markets

Wenjing Hu, Dawn Thilmany McFadden, and Dustin L. Pendell

The fresh produce sector is subject to season-specific market conditions so understanding differential impacts of various factors across marketing periods is important. We analyze the market structure, key factors influencing shipments, and seasonal price relationships in regional apple markets at the shipping-point and terminal-market levels using a symmetric variable threshold autoregressive model that allows threshold bands (which define price ranges considered in shipping decisions) to vary seasonally. We find that transportation costs and seasonality have a significant impact on threshold bands of market pairs and that the impact varies seasonally. This varying band across seasons may represent suppliers who perceive more or less opportunities to adjust their supply between regional markets and gain advantage by being responsive to market conditions.

Key Words: apple markets, market structure, price relationship, threshold autoregressive model

The U.S. apple industry has been consolidating in most states (beginning in the late 1990s) under the pressure of international and domestic competition and industry financial losses. Growers, packers, shippers, and processors that were not technically competitive or of efficient scale were driven from the industry between 1995 and 2007. U.S. production during that period was stable due to improvements in horticultural technology and production efficiency (International Trade Commission 2010). As a result of markets focusing more on healthy diet options, per capita domestic consumption of apples is expected to increase in future years, and U.S. producers may face fewer challenges in domestic markets than in foreign ones, where they increasingly must compete with China and Chile. However, the dynamics of the national apple market are also changing and will present new challenges to supply chain planners, especially during the harvest season.

Several factors contribute to limits on regional trade in apples in the United States. According to reports from *The Packer* (Ohlemeier 2010), an industry-based publication, lack of availability of trucks and rising transportation

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costs are two of the main constraints, especially in the fall. In addition, fuel price dynamics continue to affect shipping activities. According to the U.S. Energy Information Administration (EIA), the on-highway diesel fuel price increased 38.7 percent between February 2011 and February 2012 (EIA 2012). Because apples are harvested seasonally but supplied year-round, the market relationships at different points in the apple supply chain present an interesting case by which to explore how transportation costs and seasonality affect regional trade in apples at various market levels and what seasonal dynamics are present at different levels of the supply chain. We explore these market-driven characteristics of the domestic apple supply chain and contribute to the literature on market integration by comparing constant and dynamic market relationships and examining the influence of seasonality and transportation costs at different market levels.

The transmission of market shocks across spatially distinct markets is a good context in which to study the structure, conduct, and performance of a market (Goodwin 2006). A considerable body of literature has examined market relationships through price transmission for various commodities, including meat, livestock products, vegetables, and fruits (e.g., Goodwin and Piggott 2001, Mancuso, Goodwin, and Grennes 2003, Van Campenhout 2007). However, few studies have focused on the role of seasonality and energy costs (e.g., Bekkerman, Goodwin, and Piggott 2013), and, more importantly, even fewer have compared price relationships, seasonal dynamics, and transportation cost effects at various points in the supply chain. In addition to providing a general market-structure analysis, this study fills this gap by examining how spatial market structures vary seasonally with changes in energy costs using a symmetric variable threshold autoregressive (TAR) model specifically focused on the supply level, shipping points, and terminal markets for apples. This study advances Bekkerman, Goodwin, and Piggott's (2013) TAR model by incorporating a more exact definition of seasonality that is based on records of shipments from each U.S. shipping point and shipping-point price records. In addition, this study benefits from more accurate data on energy costs in the form of seasonal truck rates.

The U.S. Apple Industry and Supply Chain

According to the U.S. International Trade Commission (USITC) (2010), the United States was the third largest apple-producing country in the world in 2008 (China and the European Union were ranked first and second, respectively) with a commercial value of $2.206 billion in revenue. Washington ranked first among the states in supplying fresh apples, accounting for 72.25 percent of the 2008 domestic supply, followed by New York (9.53 percent), Michigan (3.34 percent), and Pennsylvania (3.02 percent). In terms of consumption, apples were ranked third in the United States for fruit in general and first for fresh fruit at 16.2 pounds per capita (Economic Research Service (ERS) 2012). Preferences among consumers nationally and internationally have been shifting from primarily Red Delicious apples to newer varieties such as Fuji and Gala, with U.S. producers and exporters following suit, and the market share of Red Delicious has dropped in recent years (USITC 2010). Red Delicious is still the most-consumed apple variety in the United States and represented 26.07 percent of total U.S. apple production in 2008 (ERS 2012). Washington State produces more Red Delicious apples than any other state; 30 percent of the total U.S. crop is grown there and its Red Delicious apples account for about 43 percent of U.S. apple exports (Washington Secretary of State's Office 2011).

As for most fresh produce categories, the supply chain for U.S. fresh apples includes growers, packers, shippers, processors, brokers, and retailers. There currently are seven shipping points for apples in the United States: the Appalachian district (Virginia, West Virginia, Maryland, and Pennsylvania), New York (NY), Michigan, the San Joaquin Valley in California, western North Carolina, the Yakima Valley and Wenatchee district (YVWD) in Washington, and the port-of-entry Philadelphia area (PEPA). The PEPA supplies imported apples from Chile, including Fujis, Granny Smiths, Galas, and Braeburns but not including fresh Red Delicious apples.

Apples vary somewhat from other fresh produce because apples are not as perishable as many other crops and thus can be marketed over a longer season using controlled-atmosphere storage. Consider the supply of fresh Red Delicious apples at shipping points as an example. Most shipping points supply apples over eight months, far longer than the harvest period. The YVWD supplies fresh Red Delicious apples year-round. The Appalachian district, NY, and Michigan supply fresh Red Delicious apples most of the year, the exception being May to September prior to the harvest. North Carolina supplies fresh Red Delicious apples only in months when new crops are available—September to October.

Shipping Point Prices, Terminal Market Prices, and Truck Rates

We use data for Red Delicious apples because of their predominant share of the fresh apple market and the consistent availability of price data. Included in our data set are weekly shipping-point prices and terminal-market prices for fresh Red Delicious apples plus domestic truck rates for apples from the U.S. Department of Agriculture's (USDA's) Agricultural Marketing Service (AMS) Census of Agriculture (2008, 2011). Weekly on-highway diesel fuel prices for the Midwest, East Coast, and West Coast from EIA account for direct transportation costs between terminal markets. The shipping-point prices, terminal-market prices, and on-highway diesel fuel prices cover January 10, 1998, through December 31, 2011. The domestic truck rates span January 7, 2006, through December 31, 2011. Apple price series for carton tray packs are converted to dollars per pound, truck rates are converted to dollars per pound of apples per mile, and on-highway diesel fuel prices are converted to dollars per mile. All of the price series are deflated by the consumer price index to January 1998 prices.

Because we restrict our study to Red Delicious apples, we examine the Appalachian district, Michigan, NY, and YVWD shipping-point markets. Summary statistics are presented in Table 1.

As expected, the highest average price ($0.44 per pound) is for apples from the Appalachian district and NY, a result of relatively high demand[1] and relatively small local supplies in those regions. Generally, though, the price ranges for the five regions are fairly similar to each other. Shipping-point prices are highest at the end of the season just prior to harvest when supplies in regular storage

[1] If we were to assume that per capita consumption of Red Delicious apples is the same in every state, New York's large population (ranked third in 2008 (U.S. Census Bureau 2010)) would represent a significant demand driver.

Table 1. Summary Statistics of Shipping-point Prices and Terminal-market Prices for Fresh Red Delicious Apples

Market	Observations per Week	Mean	Std. Dev.	Max.	Min.
		Dollars per Pound			
Shipping Point Price					
Appalachian district	394	0.44	0.15	0.87	0.23
Michigan	547	0.42	0.13	0.80	0.21
New York	508	0.44	0.14	0.78	0.23
Yakima Valley and Wenatchee district, Washington	726	0.43	0.15	1.00	0.22
Terminal Market Price					
Atlanta	730	0.60	0.22	1.27	0.31
Chicago	729	0.64	0.21	1.32	0.33
Los Angeles	729	0.51	0.18	1.13	0.15
New York	728	0.60	0.22	1.39	0.20
Seattle	723	0.56	0.20	1.24	0.28

Note: The data on prices cover the period of January 10, 1998, through December 31, 2011. Some observations within the data are missing because markets did not report prices. The date is excluded if the price data for all locations are missing; other missing data are imputed based on the average of the price in the previous week and the price in the following week to maintain a consistent time series. All analysis is done with the logarithmic values of prices.

(RS) are replaced with supplies from controlled-atmosphere storage (CAS). The premium between CAS in later months and RS after harvest may be driven by the additional cost of CAS.

Taking consistency of supply records for destination terminal markets in the truck rate reports into consideration, we selected five of the fifteen potential terminal markets for our analysis of price relationships: Los Angeles (LA) for western markets, Chicago for northcentral markets, NY for northeastern markets, Atlanta for southeastern markets, and Seattle as a local market (to Washington suppliers).

Despite Seattle being the closest of the markets to the Washington production area, the LA terminal market had the lowest average price ($0.51 per pound). This suggests that imports and/or other fruit products influence price behavior in terminal markets that are relatively distant from domestic apple supply regions.

It is important to review several aspects of the market in the years covered in this study. During the late 1990s and early 2000s, retailers, in response to rising labor and energy costs, industrywide financial losses, and excess supplies of apples, reduced what they were willing to pay apple packers and shippers. Beginning in 2002, prices began to rise because growers and packers had consolidated, supplies were tighter, and consumer demand had increased as more out-of-season apples and varieties of apples became available. Consumers' interest in healthy diets may also have played a role.

We focus in our analysis on an important transaction cost, transportation, not only because truck hauling is the most commonly used domestic distribution method but also because truck rates vary seasonally with shipping-point trade activities. With the exception of the YVWD in Washington (which ships to all of the five terminal markets), the shipping points supply fresh apples only seasonally. Given YVWD's longer trade seasons and the wide geographic coverage of its shipments, the Washington district appears to play a significant role in the overall domestic supply chain for fresh apples.

Table 2 presents summary statistics for representative weekly truck rates for fresh apples originating from the YVWD for January 2006 through December 2011. In general, the closer the terminal market is to the YVWD, the lower the domestic transportation costs are. The Miami terminal market reports the highest average transportation cost at $0.20 per pound while the closest terminal market, Seattle, reports the lowest average transportation cost at $0.03 per pound.

The Model

To examine market integration among spatially separate shipping-point/ terminal markets for fresh Red Delicious apples in the United States, we use a vector autoregressive (VAR) model and Granger causality tests. Given the data available, the models are developed for four shipping-point markets and five terminal markets for fresh Red Delicious apples. Stationarity is required for the VAR model and Granger causality tests so we also conduct an augmented Dickey-Fuller (ADF) test. The lag lengths were selected based on the Schwarz information criterion (SIC).

A TAR model is used to estimate transaction cost bands and the market structure. The TAR model is constructed as

$$\delta_t^{ij} = P_t^i - P_t^j \quad (1)$$

where P_t^i and P_t^j are prices for a homogenous product in two separate markets, *i* and *j*, at time *t*; P_t^i is the price for fresh Red Delicious apples in the central

Table 2. Summary Statistics of Weekly Truck Rates for Fresh Apples Originating from the Yakima Valley and Wenatchee District

Terminal Market	Observations per Week	Mean	Std. Dev.	Max.	Min.
		Dollars per Pound			
Shipped from Yakima Valley and Wenatchee District, Washington					
To Atlanta	237	0.18	0.021	0.22	0.07
To Chicago	278	0.12	0.015	0.15	0.02
To Dallas	202	0.14	0.015	0.16	0.08
To Los Angeles	83	0.06	0.008	0.08	0.05
To Miami	178	0.20	0.023	0.24	0.11
To New York	263	0.19	0.022	0.23	0.09
To Seattle	197	0.03	0.003	0.04	0.02

Note: The truck rate data cover the period of January 7, 2006, through December 31, 2011. All prices are deflated by the January 1998 consumer price index. Truck rates are estimated based on 48- to 53-foot refrigerated trailers from the origin shipping area to the destination terminal market.

shipping-point (YVWD)/terminal market (Seattle) based on research on price relationships among market pairs,[2] and P_t^j is the price in another shipping-point/terminal market. We estimate how the price difference between markets at time t responds to the price difference in the preceding period as

$$\Delta\delta_t^{ij} = \alpha\delta_{t-1}^{ij} + \varepsilon_t \tag{2}$$

where $\Delta\delta_t^{ij}$ is the change in the price difference from time t – 1 to t. Thus,

$$\Delta\delta_t^{ij} = \delta_t^{ij} - \delta_{t-1}^{ij}.$$

The residual term ε_t is a white-noise term, $\varepsilon_t \sim N(0, \sigma^2)$, and α is the speed of price adjustment, which indicates the response of the price difference at time t to the price difference at time t – 1.

Based on Balke and Fomby's (1997) definition and the assumption that there is no price adjustment within the transaction band (the price difference is within the equilibrium band and the market players are satisfied) ($\alpha_{in} = 0$), our TAR model is defined as

$$\Delta\delta_t^{ij} = \begin{cases} \alpha_{out}\delta_{t-1} + \varepsilon_t & \delta_{t-1} > c \\ \varepsilon_t & \text{if } -c \le \delta_{t-1} \le c. \\ \alpha_{out}\delta_{t-1} + \varepsilon_t & \delta_{t-1} < -c \end{cases} \tag{3}$$

Two sets of parameters must be estimated: the adjustment outside the transaction band (α_{out}) and the threshold that represents the transaction cost (c) that causes a regime switch (e.g., Goodwin and Piggott 2001, Mancuso, Goodwin, and Grennes 2003, Van Campenhout[3] 2007). The variable TAR model provides a more accurate set of estimates than a constant threshold model (Van Campenhout 2007, Bekkerman, Goodwin, and Piggott 2013). Following Bekkerman, Goodwin, and Piggott (2013), we allow the thresholds to vary according to the truck rates (on-highway diesel prices) and seasonality, which is illustrated in equation 4 for shipping points and equation 5 for terminal markets:

$$c_{St} = \beta_0 + \beta_1 TR_t + \beta_2 S_{1t} \tag{4}$$

$$c_{Tt} = \beta_0 + \beta_1 TR_t + \beta_2 S_{1t} + \beta_3 S_{2t} \tag{5}$$

where TR_t is the truck rate for shipping apples between two shipping points in dollars per pound of apples per mile. We use on-highway diesel prices between terminal markets in dollars per mile to represent transportation costs. We also include a seasonal dummy variable, S_t. Local production affects marketing of Red Delicious apples. Consequently, we define seasonality for shipping-point and terminal markets differently based on the availability of local apples, price dynamics, and records of movement. For shipping points, we divide each year into two seasons: September through December ($S_{1t} = 1$) and January through

[2] Details of the estimation process are available from the authors upon request.

[3] The authors are grateful to Bjorn Van Campenhout for sharing his Stata code for the TAR models.

April (S_{2t} = 1), which was chosen as the base season. Although imported apples likely affect overall dynamics of the market, their incorporation exceeds the scope of this study. It is likely that imports are the sole supply competing against CAS apples from the YVWD shipping point during the off-season.

For terminal markets that receive a supply year-round, each year is divided into three seasons: September through December (S_{1t} = 1), January through April (S_{2t} = 1), and May through August when only stored CAS apples are available. The third season is used as the base season in the analysis. Both a standard TAR model with a constant threshold and a TAR model with a variable symmetric threshold are estimated. The thresholds are identified using a grid search with a criterion of the minimum sum of squared errors for the observations in the outer regime. As starting values for the thresholds, at least 20 percent of the observations were required to be either within or outside of the band.[4]

Results

The ADF test confirmed that all of the price series were nonstationary, and Chow tests confirmed the presence of structural breaks at the first week of the harvest season for each shipping-point/terminal market. When we removed the structural breaks, all of the price series became stationary.

Given the identified time-series properties, we estimated a VAR model in levels after removing the structural breaks and present the results in Tables 3 and 4.

We first analyzed prices for the shipping points (the Appalachian district, NY, Michigan, and YVWD). As expected, the lagged one-period own-prices in the shipping-point-price equations were positive and statistically significant for all of the shipping points except NY. The two-period lagged own-prices were positive and statistically significant for all shipping points except Michigan. A 1 percent increase in the preceding week's price led to an increase in the contemporaneous price of 1.81 percent in the Appalachian district, 0.66 percent in Michigan, and 0.52 percent in the YVWD (see Table 3). With the exception of the YVWD, all of the shipping-point prices were sensitive to all other prices. The Appalachian district and YVWD price series both had a significant influence on prices in the other markets.

For the terminal markets (LA, Chicago, NY, Atlanta, and Seattle), the one-period and two-period lagged own-prices were positive and statistically significant in all of the terminal market equations (see Table 4). All of the terminal markets had a significant influence on Atlanta, and LA had a significant influence on all of the other terminal markets. This result may be explained by Richards and Patterson's (2003) finding that greater buying power in LA drives down prices there and influences prices in other regions. Seattle had a significant influence on Chicago and Atlanta but not on LA and NY, both of which imported a large amount of fresh Red Delicious apples.

The results of the Granger causality tests for shipping points and terminal markets show that all F-statistics for the YVWD's effect on other shipping points were statistically significant. The null hypothesis of no Granger causality was rejected, indicating that prices in the YVWD significantly affected the price-formation process of all of the other shipping points analyzed.[5]

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[4] Further explanation of the estimation process is available from the authors upon request.

[5] The results of the Granger causality tests for shipping points and terminal markets are available as a technical appendix from the authors.

Table 3. Vector Autoregression Estimates for U.S. Shipping-point Prices

Shipping Point	Variable	Dependent Variable: Natural Logarithm of Price			
		Appalachian P_{ADt}	Michigan P_{MNt}	New York P_{NYt}	YVWD P_{YVWDt}
	Intercept	–0.01 (–0.21)	–0.01 (–0.17)	–0.01 (–0.15)	–0.07*** (–2.45)
Appalachian	P_{ADt-1}	1.81*** (4.41)	0.78** (1.70)	0.87** (2.11)	0.58*** (2.33)
	P_{ADt-2}	–1.08*** (–2.69)	–0.98** (–2.18)	–1.02*** (–2.53)	–0.46** (–1.88)
Michigan	P_{MNt-1}	–0.42 (–1.11)	0.66* (1.55)	–0.43 (–1.12)	–0.20 (–0.85)
	P_{MNt-2}	0.55* (1.46)	0.38 (0.90)	0.52** (1.37)	0.18 (0.76)
New York	P_{NYt-1}	–1.02*** (–2.35)	–1.17*** (–2.40)	–0.06 (–0.13)	–0.20 (–0.75)
	P_{NYt-2}	0.62* (1.39)	0.76* (1.51)	0.64* (1.43)	0.30 (1.10)
YVWD	$P_{YVWDt-1}$	0.02 (0.10)	0.03 (0.16)	0.02 (0.11)	0.52*** (5.18)
	$P_{YVWDt-2}$	0.40*** (2.63)	0.41*** (2.44)	0.34** (2.22)	0.20** (2.11)
R-square		0.62	0.56	0.58	0.81

Note: The t-statistics are listed in parentheses. *, **, and *** denote statistical significance at the 10 percent, 5 percent, and 1 percent level respectively. The lag lengths (two) were selected based on the Akaike information criterion and the Schwarz information criterion.

According to the results of the Granger causality tests, there was bilateral causality between most of the market pairs and consequently no clear market leader in the formation of prices between these markets. There was a unidirectional causality between the Appalachian district and Michigan (Michigan $\rightarrow$ Appalachian district), which suggests that Michigan acts as a market leader in price formation and the Appalachian district as a market follower. That result is not surprising given the relatively large quantity of apples produced in Michigan compared to the Appalachian district. The lack of causality between Michigan and NY as shipping points may represent mostly local supplies and little interstate shipment between Michigan and NY. The results also show bilateral causalities between all of the terminal markets. Since there is greater market information available at the terminal market level, greater market integration is expected.

We chose the YVWD in Washington/Seattle as the reference location (central market) for both the shipping points and the terminal markets. The results of the ADF unit-root test show that the price differences were stationary for all of the market pairs. Ordinary least square estimation of the cointegrating relationships between prices following Engle and Granger (1987) was

Table 4. Vector Autoregression Estimates for U.S. Terminal-market Prices

		Dependent Variable: Natural Logarithm of Price				
Terminal Market	**Variable**	**Atlanta** P_{ATt}	**Chicago** P_{CHIt}	**Los Angeles** P_{LAt}	**New York** P_{NYt}	**Seattle** P_{SEAt}
	Intercept	0.01 (0.70)	0.04*** (2.40)	0.00 (−0.38)	−0.01 (−0.79)	0.00 (0.01)
Atlanta	P_{ATt-1}	0.14*** (3.65)	−0.44** (−2.26)	−0.01 (−0.08)	−0.02 (−0.11)	0.15 (0.99)
	P_{ATt-2}	0.09*** (2.42)	0.30* (1.50)	0.36*** (2.41)	0.07 (0.36)	0.16 (1.01)
Chicago	P_{CHIt-1}	−0.18* (−1.38)	0.40*** (10.70)	0.06 (0.58)	−0.13 (−0.93)	0.13 (1.22)
	P_{CHIt-2}	0.15 (1.14)	0.11*** (3.13)	−0.05 (−0.54)	0.15 (1.18)	−0.01 (−0.13)
Los Angeles	P_{LAt-1}	0.53*** (3.18)	0.32** (1.71)	0.16*** (4.51)	0.82*** (4.57)	−0.41*** (−2.80)
	P_{LAt-2}	0.03 (0.18)	−0.13 (−0.68)	0.22*** (6.08)	−0.40** (−2.15)	0.51*** (3.47)
New York	P_{NYt-1}	−0.25** (−1.80)	0.18 (1.27)	0.29*** (2.75)	0.19*** (5.11)	0.06 (0.55)
	P_{NYt-2}	0.28** (2.05)	−0.04 (−0.25)	−0.20** (−1.89)	0.18*** (5.03)	0.04 (0.35)
Seattle	P_{SEAt-1}	0.64*** (3.39)	−0.25 (−1.21)	−0.10 (−0.63)	0.09 (0.45)	0.21*** (5.56)
	P_{SEAt-2}	−0.35** (−1.89)	0.54*** (2.74)	0.17 (1.11)	0.11 (0.56)	0.12*** (3.20)
R-square		0.73	0.71	0.77	0.74	0.78

Note: The t-statistics are listed in parentheses. *, **, and *** denote statistical significance at the 10 percent, 5 percent, and 1 percent level respectively. The lag lengths (two) were selected based on the Akaike information criterion and the Schwarz information criterion.

conducted.[6] The results suggest that the price in the YVWD-shipping/Seattle-terminal market was cointegrated with the prices in all of the other shipping-point/terminal markets.

Estimates of the threshold bands are shown in Table 5 for 147 shipping-point observations and 730 terminal-market observations that were matched by date in the constant threshold model and by seasonal truck rates for shipping points and year-round on-highway diesel prices for terminal markets in the variable threshold model. The neutral band represents the price difference required to trigger equilibrium conditions. Thus, the band indicates links between markets in each market pair. For example, the price difference between the Appalachian district and YVWD shipping points needed to exceed 14 percent of YVWD prices to trigger conditions (e.g., price changes, less or more shipments) that

[6] The results are available as a technical appendix from the authors.

Table 5. Threshold-band Parameter Estimates

	Constant Threshold		Symmetric Variable Threshold					
Market Pair	c	**Sum of Sq'd Errors**	β_0	β_1	β_2	β_3	**Sum of Sq'd Errors**	**Likeli-hood Ratio**
Shipping Point			$c_t = \beta_0 + \beta_1 TR_t + \beta_2 S_{1t}$					
Appalachian-YVWD	0.14	0.31	−0.66***	1.53***	0.98***	—	0.29	180.49*
Michigan-YVWD	0.09	0.56	−0.37***	1.14***	1.04***	—	0.45	73.17*
NY-YVWD	0.09	0.31	−0.59***	1.39***	1.01***	—	0.23	27.02*
Terminal Market			$c_t = \beta_0 + \beta_1 TR_t + \beta_2 S_{1t} + \beta_3 S_{2t}$					
Seattle-Atlanta	0.09	1.93	−0.15***	1.15***	0.92***	0.96***	1.88	25.48*
Seattle-Chicago	0.09	3.45	0.09***	0.64***	1.00***	0.98***	3.42	116.50*
Seattle-LA	0.21	4.03	−0.33***	1.09***	0.97***	0.97***	3.67	184.50*
Seattle-NY	0.04	3.76	−0.14***	1.04***	0.98***	0.96***	3.75	41.46*

Notes: $c = (P_t^i - P_t^j) / P_t^j$. c is the threshold and β_1 represents parameters of variables. *TR* is the estimated transportation cost between shipping points in dollars per pound of apples per mile and between terminal markets in dollars per mile. *S* is a seasonal dummy variable. *, **, and *** denote statistical significance at the 10 percent, 5 percent, and 1 percent level respectively.

will drive the market back to equilibrium while the trigger price difference between YVWD and Michigan or NY was 9 percent.

For the TAR model with a constant threshold, the neutral band between YVWD and Michigan or NY (9 percent) was smaller than the band between YVWD and the Appalachian district (14 percent). Thus, the size of the price difference needed to trigger arbitrage between YVWD and Michigan or NY was larger than the difference needed to trigger arbitrage between YVWD and Appalachia. The smallest neutral band was between Seattle and NY (4 percent) and the largest was between Seattle and LA (21 percent). These results for different market pairs are expected given the relatively large distances between some of the markets—relatively wide neutral bands indicate that a relatively large transaction cost is required to trigger arbitrage activity. The smaller band between NY and YVWD indicates a tight linkage between the two markets, which points to a possible discount against transaction costs because of the large volume of trade between those regions. Overall, the threshold-band estimates were larger for shipping points than for terminal markets. This is expected because market information is more readily available at the terminal markets, potentially making terminal markets more efficient.

For the TAR model with a symmetric variable band, transaction costs were assumed to be equal regardless of the direction of trade between two markets, and the parameters were estimated using a grid search. Thus, while a direct analysis of the parameters estimated is not appropriate, it is useful to understand the effect of each component on the threshold band. As expected, the transportation cost (truck rates / diesel prices) had a significant positive effect on the threshold band of all of the shipping-point and terminal-market pairs (Table 5). These results suggest that higher transportation costs lead to a wider neutral band. Higher transportation costs also represent greater uncertainty about returns from cross-region shipments of a high-volume lower-value good. The seasonality component had a significant positive effect on the threshold, pointing to the threshold band being wider during the harvest season when locally produced apples are available than during months when only CAS and imported apples are available.

Graphically, the symmetric variable thresholds were wider and were concentrated around corresponding constant thresholds. This coincides with results of a study by Bekkerman, Goodwin, and Piggott (2013), which found that a symmetric variable threshold model yielded wider thresholds than a constant threshold model. In our study, the estimated symmetric variable thresholds for the terminal markets varied across seasons. Beginning in 2005, the bands grew wider than previous years during the off-season, likely because of increasing competition from international suppliers.

In most cases, the thresholds were wider during the apple harvest season when local apples would be available in a variety of U.S. regions and less intra-region trading would take place. This concurs with our expectations; at harvest, the supply is large and can meet both local demand and demand from other areas. The variable threshold model generally yielded a wider threshold and a lower sum of squared errors than the constant threshold model. Likelihood-ratio tests of the constant versus the variable threshold model suggested rejection of the hypothesis of a constant threshold, further supporting the variable threshold model as a better representation of market behavior.

Table 6 (shipping points) and Table 7 (terminal markets) show probabilities of observations lying inside and outside of the threshold band between market pairs. Three regimes were defined. If we apply a large shock to one of

Table 6. Shipping Points: Markets That Fall within and outside of the Threshold Bands

Market Pair	**Regime 1** $P_{YVWD} < P_{other}$ trigger for suppliers to increase supply to other shipping points	**Regime 2** Equilibrium	**Regime 3** $P_{YVWD} > P_{other}$ trigger for suppliers to increase supply to YVWD
Constant Band TAR Model			
Appalachian-YVWD	30 (20.55%)	116 (79.45%)	0
Michigan-YVWD	61 (41.78%)	69 (47.26%)	16 (10.96%)
New York-YVWD	89 (60.96%)	57 (39.04%)	0
Variable Band TAR Model			
Appalachian-YVWD	146 (100%)	0	0
Michigan-YVWD	146 (100%)	0	0
New York-YVWD	146 (100%)	0	0

Table 7. Terminal Markets: Markets That Fall within and outside the Threshold Bands

Market Pair	Regime 1 $P_{Seattle} < P_{other}$ trigger to increase supplies to other markets	Regime 2 Equilibrium	Regime 3 $P_{Seattle} > P_{other}$ trigger to increase supplies to Seattle
Constant Band TAR Model			
Seattle-Atlanta	326 (44.72%)	312 (42.80%)	91 (12.48%)
Seattle-Chicago	430 (58.98%)	258 (35.39%)	41 (5.62%)
Seattle-Los Angeles	2 (0.27%)	554 (75.99%)	173 (23.73%)
Seattle-New York	394 (54.05%)	149 (20.44%)	186 (25.51%)
Symmetric Band TAR Model			
Seattle-Atlanta	0	721 (98.90%)	8 (1.10%)
Seattle-Chicago	2 (0.27%)	660 (90.53%)	67 (9.19%)
Seattle-Los Angeles	3 (0.41%)	725 (99.45%)	1 (0.14%)
Seattle-New York	199 (27.30%)	111 (15.23%)	419 (57.48%)

the markets, this will cause the spatial price difference to exceed the limits of the threshold band. As a result, the supply for the market that has the higher price will increase until the price difference falls back within the bounds of the threshold. Under regime 1, the shock increases the supply to the market other than the central market. Under regime 3, the presence of the shock increases the supply to the central market. Under regime 2, a small deviation in the price difference does not trigger price adjustments between markets, signifying market equilibrium.

In the constant threshold model, the probability of an observation aligning with each regime varied across shipping-point/terminal-market pairs. For example, for the Appalachian-YVWD and NY-YVWD shipping points, no observation fell within regime 3 (Table 6). The Appalachian-YVWD pair was in equilibrium most of the time. For the Michigan-YVWD market, there was a 50-50 split between regimes 1 and 2. Overall, under a constant threshold, there was little probability of increasing the supply to the YVWD shipping point. However, with symmetric variable estimation, the frequency of regime 1 indicates the potential for shifts of supply from YVWD to other shipping points at times when localized, albeit more limited, supplies would be available near terminal markets. Still, given the YVWD region's dominance as a supplier, we expect prices to be lower for the YVWD shipping point than for other shipping points even when transportation costs are included in both seasons.

Table 8. Estimated Adjustment Speeds and Half-lives

	TAR with Constant Threshold		TAR with Variable Threshold	
Market Pair	**Half-life**	**Adjustment Speed**	**Half-life**	**Adjustment Speed**
Shipping Point				
Appalachian-YVWD	4.39	–0.15***	7.48	–0.09***
Michigan-YVWD	4.88	–0.13***	5.58	–0.12***
New York-YVWD	9.65	–0.07***	12.40	–0.05***
Terminal Market				
Seattle-Atlanta	9.19	–0.07***	2.19	–0.27***
Seattle-Chicago	13.29	–0.05***	8.13	–0.08***
Seattle-Los Angeles	4.73	–0.14***	1.01	–0.50***
Seattle-New York	7.08	–0.09***	7.11	–0.09***

Notes: *** denotes statistical significance at the 1 percent level.

The results for terminal markets showed a different pattern (Table 7). Under the constant threshold, there were a significant number of observations for each regime. With the exception of Seattle-LA (due to low prices in LA), the probabilities of alignment were much greater for regimes 1 and 2 than for regime 3. In the symmetric variable model, on the other hand, most of the observations fell in regime 2. For Seattle-NY, the trade direction reversed when the threshold varied according to the transportation costs and seasonality, a result that fits our expectations given the shortage of trucks at western shipping points, the rising cost of fuel, and the bargaining power of large buyers in NY.

Our comparison of the results of the constant and symmetric threshold autoregressive models indicates that one can detect more numerous supply adjustments toward other shipping points for Red Delicious apple markets when the threshold band is allowed to vary with transportation costs and seasons. However, there will be fewer adjustments toward other terminal markets when the threshold is variable. These results fit with our Granger causality tests, which indicated that there is no clear market leader among the terminal markets (unlike Washington's dominance among shipping points). The size of the season-specific band suggests that differences in prices and the size of the threshold bands are largest during the harvest season. This may suggest that the Washington supply points are vulnerable to increasing energy costs, a tenet of relocalization campaigns in some markets.

Table 8 presents the estimated speed and half-life for each market pair's adjustment toward equilibrium after a shock.[7] The estimates were different for the constant threshold model and the variable threshold model. Under the constant threshold model, adjustment was fastest for the Appalachian-YVWD pair (0.15). Under the variable threshold model, adjustment was fastest for the Michigan-YVWD pair (0.13). In both models, adjustment was slowest for

[7] The half-life is the time required to eliminate half of the deviation from price parity due to a shock. For an estimated adjustment coefficient of $\tilde{\alpha}$, the half-life is $\ln(0.5) / \ln(1 + \tilde{\alpha})$.

NY-YVWD—0.07 under the constant threshold and 0.05 under the variable threshold. These results indicate that shorter transportation distances allow for faster market adjustments.

Under the constant-threshold model, the Appalachian-YVWD shipping point pair had the shortest half-life—deviations in this market pair were 50 percent smaller after about four weeks. Under the variable-threshold model, the Michigan-YVWD shipping-point pair had the shortest half-life. This is expected because wider neutral bands indicate less market interaction and longer transportation distances suggest slower adjustments. The longest half-life in both models was for NY-YVWD (9.65 weeks in the constant-threshold model and 12.40 weeks in the variable-threshold model).

For the terminal markets, Seattle-Chicago had the longest half-life and Seattle-LA had the shortest under both threshold models. This result suggests that adjustment speeds decrease as the transportation distance increases.

In contrast to the half-life results for the terminal markets and results of Bekkerman, Goodwin, and Piggott (2013), the half-life for every shipping-point pair was larger under the variable threshold model than under the constant threshold model, a finding worthy of further exploration with industry stakeholders.

Conclusions and Marketing Implications

This study employed several methods to analyze the market structure and price relationships at various spatial shipping points and terminal markets for apples as one example by which to illustrate how market dynamics for fresh produce may be different from dynamics for more storable commodities. We constructed a symmetric variable TAR model to examine how market structure is affected by various market forces such as truck rates and spot (cash) markets across seasons. We found that the symmetric variable TAR model generally better represented market price behavior than the more commonly used constant model.

Truck rates and seasonality had significant impacts on threshold bands of prices for several pairs of key markets. A closer examination of market links showed that the YVWD in Washington State (the largest apple-production region in the nation) significantly affected price-formation for all of the other shipping points analyzed and that there was no clear market leader among terminal markets studied.

We then estimated constant-threshold and variable-threshold TAR models to determine whether greater flexibility in models of how market structures work at different times of the year could add value to the price analysis. Our results showed that higher transportation costs (truck rates) led to a wider neutral band between markets (as expected), which led to an increase in transaction costs and prices. However, a more subtle implication was that evidence of greater uncertainty about the returns from cross-region shipments of high-volume, low-value goods could explain why U.S. fresh produce markets may be more segmented at times.

Overall, the estimated threshold bands for shipping points were larger than estimated bands for terminal markets. When we allowed for more types of adjustments in supply between markets (by allowing the threshold band to vary in response to transportation costs and seasonality), we found evidence of wider bands between shipping-point and terminal markets than when the thresholds were constant, particularly during the apple harvest season. This result is consistent with the idea that a larger number of potential trade partners affect the market dynamics when locally oriented markets and supplies are active. Consequently, the range of shipping-point and terminal-market pairs, the prices received, and the transaction costs will vary when local supplies of apples remain as an option (small supplies generally translate into particularly short market seasons in most regions of the United States), and understanding that dynamic becomes even more important if locally focused markets continue to emerge and grow.

Since transaction costs, including the cost of energy and labor, likely drive spatial price differences, deflation of prices by regional producer price indices may be important in future studies even if it is consequently more difficult to tease out whether energy/transport costs are related to differential competition between regions once such an adjustment is made. Additionally, the comparison of results of the TAR model with results derived from other switching-regime models may provide important insights into the market structure and contribute to development of methodologies.

Price differences are also influenced by the quality, branding, volume of shipments, and consistency of the supply of apples throughout the year and by relationships between sellers and buyers. Thus, additional information regarding those factors could increase the effectiveness of the model and improve our understanding of market relationships. In addition, an analysis of vertical market relationships across supply chain levels is important to efforts to thoroughly understand the market structure. In pursuing these two lines of inquiry, it may be useful to develop case studies of specific shipper-buyer-retailer supply chains and to explore whether market planning and branding strategies play roles in managing risk associated with procurement in markets that demonstrate some complex seasonal variability.

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