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Agricultural Economics and Rural Policy Group

Drivers of Asymmetric Vertical Price Transmission

The case of fresh vegetables in California

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Abstract

This thesis aims to examine the leading hypotheses for the drivers behind vertical price transmission asymmetry, and assess their applicability to California romaine lettuce, celery, and broccoli at the shipping point and wholesale market levels. Four potential drivers were identified, and through a literature review and interviews with six vegetable wholesalers and an academic expert, inventory management was determined to be the only relevant driver. Wholesalers emphasized that both maintaining stock and avoiding spoilage were important considerations in their pricing decisions. Econometric analysis of weekly price data from 2007-2017 identified two types of asymmetry. From period to period, positive shipping point price changes are more fully transmitted to FOB prices for lettuce and broccoli. Over the long run, cumulative shipping point price changes are more fully transmitted to FOB prices for romaine lettuce, celery, and broccoli. This suggests that maintaining stock (and thus decreasing prices more gradually than increasing prices) is the most influential driver of asymmetry present in the market for these vegetables.

Preface

This thesis was written in partial fulfillment of graduation requirements for the MSc program International Development Studies at Wageningen University and Research. This thesis was written within the Agricultural Economics and Rural Policy group.

I would like to thank a few key people who supported me in writing this thesis. Thank you to my thesis supervisors – to Dr. Liesbeth Dries for her feedback and helpful suggestions throughout the process and to Dr. Rico Ihle for his detailed comments. I would also like to acknowledge the industry and academic experts that made this possible – Dr. Roberta Cook and the California vegetable wholesalers whom I interviewed, Michael Janis at the San Francisco Produce Market, and Taryn Pfalzgraf and the Blue Book team for granting database access. Thanks also go out to my sister for teaching me how to write web scraping scripts for extracting the price data, and to my boyfriend for his support and thoughtful commentary.

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I. Introduction

1.1. Background

In the spring of 2017, even while heavy rains ended California's record-setting five-year drought, vegetable production dropped, according to an article published in the *Sacramento Bee*. The Central Valley in California, which is often referred to as "America's salad bowl" because it grows the vast majority of the nation's fresh fruits and vegetables, faced a decrease in vegetable output. As a result, prices rose throughout the supply chain – among farmers, shippers, wholesalers, retailers, and consumers (Kasler, 2017). However, prices didn't increase evenly between vegetable types or between different supply chain actors – for example, from March to mid-April, broccoli shipping point prices jumped by 87%, while the broccoli wholesale price increased by 106% (USDA Agricultural Marketing Service, 2017).

The study of the extent to which changes in price are transferred along the supply chain is called vertical price transmission. If prices are perfectly transmitted, downstream prices adjust fully and immediately to changes in upstream prices. However, in agricultural markets, this is often not the case and upstream price increases are generally transmitted more quickly and fully than are upstream price decreases (Vavra & Goodwin, 2005); in other words, these markets are frequently characterized by asymmetric vertical price transmission. In the agro-food supply chain, this mechanism plays an important role in determining food prices and has welfare implications for farmers, consumers, and everyone in between (Schwartz & Willett, 1994). Understanding the factors that influence this price transmission, meanwhile, can provide insight into the (in)efficiencies of resource allocation at different places in the supply chain (Bakucs, Falkowski, & Fertő, 2014). As such, the extent and drivers of vertical price transmission asymmetry are highly relevant for policymakers aiming to maximize societal welfare and efficient resource allocation.

A wealth of empirical literature exists that examines asymmetric price transmission in various products and contexts, including Finnish beef and pork (Luoma, Luoto, & Taipale, 2004), French salmon and cod (Simioni, Gonzales, Guillotreau, & Le Grel, 2013), various U.S. food commodities (Kim & Ward, 2013), and Israeli grapefruit exports (Goetz, von Cramon-Taubadel, & Kachel, 2008). Although the majority of empirical studies do find evidence of price transmission asymmetry, the significance and direction of the effect varies, and the magnitude of price asymmetries is highly inconsistent between countries, sectors, and measurement techniques (von Cramon-Taubadel, Loy, & Meyer, 2006).

There is also a wide range of recent literature developing theoretical hypotheses for the drivers behind asymmetric price transmission. One leading hypothesis concerns itself with non-competitive markets as a driver of asymmetric price transmission. There are many more farms than there are wholesalers or retailers, and this unequal buying power may lead to asymmetries – and inefficient resource allocation – as the relatively powerful downstream actors adjust prices with the goal of capturing greater profits (Vavra & Goodwin, 2005). This hypothesis predicts that price reductions at the farm-level are passed on to the consumer only slowly and incompletely, whereas farm-level price increases are passed on more quickly (Vavra & Goodwin, 2005).

Asymmetry is not necessarily evidence of inefficiency, however. Reagan & Weitzman (1982) suggest downstream actors may reduce their prices relatively slowly as an inventory management strategy that helps them to maintain stock because a more rapid price reduction could mean that their inventory runs out. Ward (1982) argues that downstream actors may *increase* prices relatively slowly in the case of perishable goods in order to minimize spoilage risk from unsold products. Besides non-competitive markets and inventory management, other leading hypotheses for the drivers of price asymmetry in the agri-food supply chain include government intervention and sticky prices (Vavra & Goodwin, 2005).

Despite the prolific empirical literature examining vertical price transmission and the theoretical literature that develops models for drivers of asymmetry, there are relatively few empirical studies that connect both aspects. This is due in part to the challenge in integrating competing theoretical predictions into econometric analyses (Bakucs et al., 2014). The heterogeneity of vertical price transmission for various products and markets also presents a challenge in developing a model that connects the existence of asymmetry with its causes. Identifying the mechanisms behind price asymmetry, however, has important implications for policy; for example, under the non-competitive markets hypothesis, asymmetric price transmission represents a loss in welfare that policymakers would want to correct, but this is not the case under the inventory management hypothesis.

1.2 Research Focus

This research will therefore use quantitative and qualitative data to link asymmetric price transmission across distinct supply chain stages with its possible drivers. Specifically, it will examine price transmission from shipping point to wholesale terminal market for fresh vegetables in California. California was selected because it provides the majority of national supply amidst a climate of growing consumer demand for fresh produce. Fresh vegetables were selected because they are an ideal subject for price transmission studies due to (1) their minimal processing from farm to consumer and (2) their high perishability which can result in volatile prices.

The research will focus on and compare three major crops in the California fresh vegetable industry: romaine lettuce, celery, and broccoli. The United States production of these vegetables is concentrated in California, with more than $\frac{3}{4}$ of national production occurring in the state for all three vegetables. They were all among the ten most valuable vegetable crops for the state in the 2015 crop year, with a total value above \$400 million (California Department of Food and Agriculture, 2017). Their perishability, however, varies; romaine lettuce is considered highly perishable (with an average shrinkage of 20.2% in US supermarkets between 2011 and 2012), while supermarket losses of celery and broccoli are much lower at 8.5% and 6.7%, respectively (Buzby, Bentley, Padera, Ammon, & Campuzano, 2015). More perishable products are expected to have more volatile shipping point prices, which may affect the way that their downstream prices are adjusted.

1.3 Objective and Research Questions

This research will investigate the presence of price transmission asymmetry for the selected fresh vegetables, and identify and check relevant theoretical explanations. The main research objective is to critically examine the leading hypotheses for the drivers behind vertical price transmission asymmetry, and assess their applicability to California fresh vegetable supply chains. Four research questions have been formulated:

1. What is the state of the art of theoretical and empirical vertical price transmission research in fresh produce markets?
2. What is the structure of the selected fresh vegetable value chains in California?
3. What do wholesalers active in the selected fresh vegetable value chains perceive as the primary drivers behind their pricing decisions?
4. What is the empirical evidence on asymmetric price transmission in fresh vegetable markets of California?

1.4 Thesis Structure

The first research question will be addressed through a literature review. First, asymmetric price transmission will be defined, and then a historical overview of common empirical approaches will be given. This section will also specify the types of asymmetry examined during this thesis. Next, empirical evidence of price transmission asymmetry in fresh produce markets will be examined, and finally, the leading hypotheses explaining price transmission asymmetry will be described.

The second research question will provide a basic description of fresh produce marketing channels in the US, and indicate the ways in which the structure of the supply chains deviates for lettuce, celery, and broccoli in California. It will also provide an overview of characteristics of lettuce, celery, and broccoli with specific reference to the key factors for each hypothesis identified for price asymmetry. Data sources for this research question will include USDA statistics, a literature review, and an interview with Dr. Roberta Cook, an expert in fresh produce marketing at the UC Davis Vegetable Research & Information Center.

The third research question will use a survey of California wholesalers to identify self-reported motivations for their pricing decisions and categorize them according to theoretical predictions. It aims to describe how and why these actors change their sales price in response to upstream price changes, with the purpose of identifying the primary drivers considered relevant in these supply chains for vertical price transmission.

The fourth research question will empirically test the relationship between downstream and upstream prices under price shocks, in order to investigate the presence or absence of various types of asymmetry. The specific tests used will depend on the results of the other research questions.

The final section will discuss results and conclude, first by addressing conclusions for each research question individually, and then by considering the thesis and research objective as a whole. Finally, limitations of the research will be discussed and recommendations for further research will be suggested.

II. Literature Review of Vertical Price Transmission Research

Research Question 1: What is the state of the art of theoretical and empirical vertical price transmission research in fresh produce markets?

This section will address Research Question 1 by introducing the concepts of vertical price transmission and asymmetry. Then, an overview of common empirical methods used to test for asymmetry will provide the basis for defining and explaining price transmission asymmetry in greater detail. Next, the contextual focus will be narrowed to fresh produce markets. An overview will be given of the recent empirical studies for vertical price transmission asymmetry in this sector, and finally, potential drivers of this asymmetry will be introduced.

2.1 Introduction to Vertical Price Transmission and Asymmetry

The study of the extent to which changes in price are transferred along the supply chain is called vertical price transmission. If prices are perfectly transmitted, downstream prices adjust fully and immediately to changes in upstream prices, or vice versa. In such a case, upstream and downstream prices will exist in a long-run equilibrium and each price can be estimated from the other.¹ For example, following Kinnucan and Forker (1987), price relationships can be represented as $W = b_1F + b_2Z$, where W and F represent wholesale and farm prices respectively, Z represents prices of marketing inputs, and b_1 and b_2 represent the price coefficients and are fixed based on past prices. Therefore, given the values of b_1 , b_2 , F , and Z , one could estimate the value of W (and vice versa for estimating Z).

In agricultural markets, however, price shocks are often transmitted slowly or incompletely between farm, wholesale, and retail levels (Vavra & Goodwin, 2005). Furthermore, many supply chain relationships are subject to price transmission asymmetry. At its most basic, the term asymmetry indicates that “the reaction of the price at one level of the marketing chain to a price change at another level depends on whether the initial change is positive or negative” (von Cramon-Taubadel, 1998, p. 3). For example, as Peltzman finds in his exhaustive study of 120 agricultural goods as well as 162 other goods, “in two out of three markets, output prices rise faster than they fall” (Peltzman, 2000, p. 480).

2.2 Common Empirical Approaches for Measuring Vertical Price Transmission Asymmetry

Over the last few decades, methods for measuring vertical price transmission asymmetry have been refined (Meyer & von Cramon-Taubadel, 2004). This section will provide a brief overview of the development of empirical methods in this field, thus highlighting the variations in approaches and indicating their benefits and disadvantages. This will also provide the basis for defining the types of asymmetry that are used in this paper.

Empirical models in this field can be difficult to compare due to variations in notation; therefore, this paper will describe most models using the notation provided in Meyer and von Cramon-Taubadel (2004). This notation assumes that an input price in period t (p_t^{in}) affects the output price in period t (p_t^{out}).

¹ Assuming competitive market conditions, constant returns to scale, and production technology in fixed proportions.

Table 1: Early Models of Asymmetric Price Transmission for Stationary Price Series

Model history	Formula
Most early models of asymmetric price transmission were based on an equation proposed by Tweeten and Quance (1969). In this equation, β^+ and β^- represent the positive and negative influences of p_t^{in} on p_t^{out} .	Equation 1 $p_t^{out} = \alpha + \beta^+ D_t^+ p_t^{in} + \beta^- D_t^- p_t^{in} + \varepsilon_t$ where $D_t^+ = 1 \text{ if } p_t^{in} \geq p_{t-1}^{in} \text{ and } D_t^+ = 0 \text{ if } p_t^{in} < p_{t-1}^{in};$ $D_t^- = 1 \text{ if } p_t^{in} < p_{t-1}^{in} \text{ and } D_t^- = 0 \text{ if } p_t^{in} \geq p_{t-1}^{in};$ which splits p^{in} into two variables depending on whether it is increasing or decreasing.
<u>Wolffram's First Differencing Model:</u> Wolffram (1971) proved that Tweeten & Quance's method can result in biased estimates of β^+ and β^- (if p_t^{out} and p_t^{in} are not cointegrated), and thus suggested an alternative model based on cumulative price variations.	Equation 2 $p_t^{out} = \alpha + \beta^+ (p_0^{in} + \sum_{j=1}^t D^+ \Delta p_{t-j}^{in}) + \beta^- (p_0^{in} - \sum_{j=1}^t D^- \Delta p_{t-j}^{in}) + \varepsilon_t$ where Δ is the first difference operator, and additional explanatory variables are included in the form of the sums of positive and negative price variations in p^{in}.
<u>Houck's Cumulative Lag Model:</u> After noting that p_0^{in} and p_0^{out} do not have independent explanatory power in the case of differential effects, Houck (1977) proposed a variation on Wolffram's model, using the cumulated prices from the first to the current period.	Equation 3 $p_t^{out} - p_0^{out} = \alpha_0 + \beta^+ \sum_{j=0}^t \Delta p_{t-j}^{in+} + \beta^- \sum_{j=0}^t \Delta p_{t-j}^{in-} + \varepsilon_t$ where $\Delta p_{t-j}^{in+} = \Delta p_{t-j}^{in} \text{ if } \Delta p_{t-j}^{in} > 0, \text{ and } \Delta p_{t-j}^{in+} = 0 \text{ otherwise; and}$ $\Delta p_{t-j}^{in-} = \Delta p_{t-j}^{in} \text{ if } \Delta p_{t-j}^{in} < 0, \text{ and } \Delta p_{t-j}^{in-} = 0$
<u>Karrenbrock's Period-to-Period Lag Model:</u> Karrenbrock (1991) offered a specification focuses on period-to-period variation rather than all cumulated prices. In Karrenbrock's model, changes in p^{out} from period to period are regressed on the summed positive and negative changes in p^{in} over a specified number of lags.	Equation 4 $\Delta p_t^{out} = \alpha_0 + \beta_i^+ \sum_{i=1}^s \Delta p_{t-i}^{in+} + \beta_j^- \sum_{j=0}^n \Delta p_{t-j}^{in-} + \varepsilon_t$

Salas' Partial Adjustment Model:

In the 1990s, another model type emerged that allowed researchers, in a two-step process, to first estimate a long-run equilibrium level of p^{out} and then measure the rates of adjustment of p^{out} to its long-run equilibrium. As specified by Salas (2002), first an equilibrium level p^{out*} is estimated, and then the change in p_t^{out} is regressed on the positive and negative deviations of p_t^{out*} from p_t^{out} . ϕ^+ and ϕ^- thus represent the positive and negative rates of adjustment towards the long-run equilibrium.

Equation 5

$$\Delta p_t^{out} = \phi^+(p_{t-1}^{out*} - p_{t-1}^{out})^+ + \phi^-(p_{t-1}^{out*} - p_{t-1}^{out})^- + \varepsilon_t$$

where

p_t^{out*} represents the estimated long-run equilibrium of p_t^{out} ;

$$(p_{t-1}^{out*} - p_{t-1}^{out})^+ = \begin{cases} p_{t-1}^{out*} - p_{t-1}^{out} & \text{if } p_{t-1}^{out*} - p_{t-1}^{out} > 0; \\ 0 & \text{otherwise} \end{cases}$$

and

$$(p_{t-1}^{out*} - p_{t-1}^{out})^- = \begin{cases} p_{t-1}^{out*} - p_{t-1}^{out} & \text{if } p_{t-1}^{out*} - p_{t-1}^{out} < 0 \\ 0 & \text{otherwise} \end{cases}$$

Table created by author, based on Frey and Manera (2007) and Meyer and von Cramon-Taubadel (2004).

All models in Table 1 assume stationarity² of variables, but Granger and Newbold (1974) demonstrate that OLS regressions involving non-stationary variables (which is common for price series) exhibit a tendency for spuriously significant results – and thus over-reject the null hypothesis of symmetry. This instigated a shift to more care in interpreting time-series price data, including the introduction of stationarity tests and the development of cointegration models as a method to avoid spurious regression (Meyer & von Cramon-Taubadel, 2004).

Cointegration occurs when non-stationary variables share a stationary long-run equilibrium relationship. In other words, if p^{in} and p^{out} are both non-stationary, but a stationary linear combination of these series exists, then the series are cointegrated. For example, if p^{in} and p^{out} are integrated of order one, but p^{in} minus p^{out} is integrated of order zero, that indicates cointegration of the two series (Stigler & Tortora, 2011). This relationship is the basis for some widely used tests in asymmetric price transmission research.

² Stationary time series have a mean and variance that remain constant over time; in other words, they do not exhibit an increasing or decreasing trend or undergo periodic fluctuations. Stationary time series are said to be integrated of order zero, while non-stationary time series are integrated of order one or higher (Meyer & von Cramon-Taubadel, 2004).

Table 2: Granger and Lee's Two-Step Error Correction Model for Cointegrated Price Series

Model History	Formula
Engle and Granger (1987) show that if p_t^{in} and p_t^{out} are cointegrated, their relationship can be analyzed using an error correction model. Granger and Lee (1989) adapted this model to test for asymmetric price transmission in a two-step procedure. They introduce an error correction model that incorporates asymmetric adjustment terms (also called error correction terms, or ECT) as a method for testing asymmetric price transmission in cointegrated series. This model makes p_t^{out} responsive to changes in p_t^{in} (or vice versa) and, through the ECT, corrects for any deviations from the long-run equilibrium that remain from previous periods.	Equation 6a Estimate $p_t^{\text{out}} = \alpha_0 + \beta_1 p_t^{\text{in}} + \mu_t$ and test for cointegration of p_t^{in} and p_t^{out}. If they are cointegrated, then this equation estimates their long-run equilibrium. The residuals of Equation 6a represent the positive and negative deviations from the long-run equilibrium between p_t^{in} and p_t^{out}. These residuals μ_t are estimated, and their lags serve as the ECT used in Equation 6b.
	Equation 6b If p_t^{in} and p_t^{out} are cointegrated, the following error correction model is estimated: $\Delta p_t^{\text{out}} = \alpha_0 + \sum_{i=1}^m \alpha_i^+ \Delta p_{t-i}^{\text{out}+} + \sum_{i=1}^n \alpha_i^- \Delta p_{t-i}^{\text{out}-} + \sum_{j=0}^p \beta_j^+ \Delta p_{t-j}^{\text{in}+} + \sum_{j=0}^q \beta_j^- \Delta p_{t-j}^{\text{in}-} + \theta^+ \mu_{t-1}^+ + \theta^- \mu_{t-1}^- + \varepsilon_t$

Table created by author, based on Chou, Chang, and Hu (2013), Frey and Manera (2007), Meyer and von Cramon-Taubadel (2004), and Hassouneh, von Cramon-Taubadel, Serra, and Gil (2012).

In 2004, Meyer and von Cramon-Taubadel (2004) noted that each of the models described above continued to appear in price transmission research and that no methodological consensus had been reached; however, error correction models have now become standard in analyzing asymmetric price transmission, as this model type enables analyzing various types of asymmetry in cointegrated price series (Hassouneh et al., 2012).³

Therefore, the error correction model used in Equation 6b will be used to clarify the term “asymmetry” as it is used in this paper. As noted by Frey and Manera (2007), this term does not have a single fixed meaning, and its use can vary from study to study.⁴ A simple and widely used convention is to distinguish between short-run and long-run asymmetries. (Frey & Manera, 2007) Price transmission asymmetry can involve the magnitude as well as the speed of the price reaction, and this distinction can be used to clarify the difference between short-run and long-run asymmetries, as discussed in Figures 1a-c. However, the short-run/long-run dichotomy still leaves ambiguity, so this thesis will also use the definitions established by Frey and Manera (2007) and distinguish between distributed lag

³ However, given the variation between types of asymmetries and datasets, econometric models of price transmission should be chosen for the data at hand, the relevant supply chain structure, and the type of asymmetry under investigation (Frey & Manera, 2007; Meyer & von Cramon-Taubadel, 2004; Vavra & Goodwin, 2005). Useful empirical analysis depends not only on the specification but also on the characteristics of the dataset and the interpretation of results. As argued by Goodwin and Vavra (2009), “any conclusions about price transmission made in a vacuum regarding an understanding of the basic characteristics of the market being evaluated are questionable” (2009, p. 10); rather, it is critical to design and interpret each analysis in light of its institutional setting.

⁴ See the review paper by Frey and Manera (2007), Econometric Models of Asymmetric Price Transmission, for an exhaustive discussion of the various understandings of the term “asymmetry” in price transmission research.

effect asymmetry, cumulated impact asymmetry in period-to-period and cumulative models, and equilibrium adjustment path asymmetry. These types of asymmetry will be explained below.

A negative price shock may elicit a different magnitude of price response relative to an equivalent positive price shock. This is shown in Figure 1a: a positive price shock to upstream/input price p^{in} results in a reaction of equivalent magnitude in the downstream/output price p^{out} , whereas for a negative price shock to p^{in} , p^{out} shows a much less than equivalent decrease. Short-run asymmetry analysis considers asymmetry at one point in time, and is therefore generally used to compare how strongly p^{out} responds to positive as compared to negative changes in p^{in} . If at any given time, the impact of p_{in}^+ differs from the impact of p_{in}^- , this is short-run asymmetry in the form of distributed lag effect asymmetry. This is represented in Equation 6b by the null hypothesis $\beta_j^+ = \beta_j^-$.

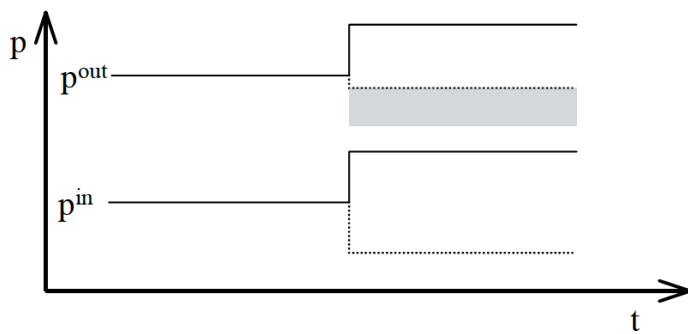


Figure 1a: Price Asymmetry in Magnitude (Meyer & von Cramon-Taubadel, 2004)

Positive and negative price shocks could also elicit different lags in adjusting prices, as shown in Figure 1b: a positive price shock to p^{in} results in an immediate price adjustment in p^{out} , while an equivalent negative price shock to p^{in} results in a price adjustment in p^{out} only after a lag of n periods. Long-run analysis enables examination of lag length. Impulse response functions can be used to test if p_{in} takes a different number of lags to readjust to an equilibrium level depending on whether it has undergone a positive or negative shock; however, impulse response functions are beyond the scope of this thesis.

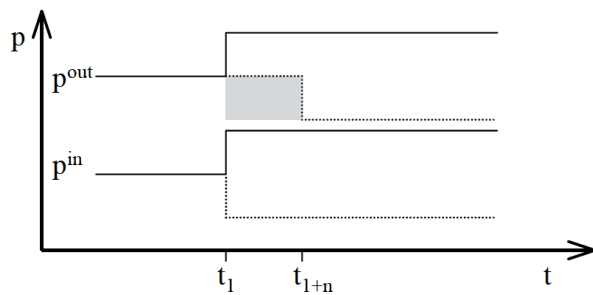


Figure 1b: Price Asymmetry in Lag Length (Meyer & von Cramon-Taubadel, 2004)

Asymmetry may also refer to a combination of magnitude and speed. An example is shown in Figure 1c: a positive price shock to p^{in} at time t_1 results in an immediate partial price adjustment in p^{out} and a full price adjustment in p^{out} at t_2 , while an equivalent negative price shock to p^{in} results in a partial p^{out} price adjustment at t_1 , a more complete price adjustment at t_2 , and a more complete (but still not full) price adjustment at t_3 (Meyer & von Cramon-Taubadel, 2004). For example, long-run asymmetry would exist if the cumulated effects of p_{in}^+ and p_{in}^- differ. This can take the form of period-to-period

cumulative asymmetry (tested in Equation 6b via the null hypothesis $\sum_{j=1}^p \beta_j^+ = \sum_{j=1}^q \beta_j^-$) or cumulative asymmetry based on the sum of all changes since the initial period (tested in Equation 6b via the null hypothesis $\sum_{j=0}^T \beta_j^+ = \sum_{j=0}^T \beta_j^-$). Long-run asymmetry also includes equilibrium path adjustment asymmetry, which occurs if the rate of adjustment towards the long-term equilibrium differs if prices are above or below the equilibrium level (tested in Equation 6b via the null hypothesis $\theta^+ = \theta^-$).

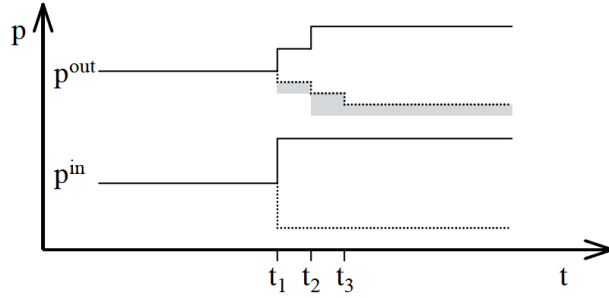


Figure 1c: Price Asymmetry in Magnitude & Lag Length (Meyer & von Cramon-Taubadel, 2004)

The types of asymmetry investigated in this paper are summarized in Table 3 (below), along with their abbreviations and the corresponding null hypotheses of symmetry based on Equation 6b ($\Delta p_t^{out} = \alpha_0 + \sum_{i=1}^m \alpha_i^+ \Delta p_{t-i}^{out+} + \sum_{i=1}^n \alpha_i^- \Delta p_{t-i}^{out-} + \sum_{j=0}^p \beta_j^+ \Delta p_{t-j}^{in+} + \sum_{j=0}^q \beta_j^- \Delta p_{t-j}^{in-} + \theta^+ \mu_{t-1}^+ + \theta^- \mu_{t-1}^- + \varepsilon_t$).

Table 3: Types of Asymmetry Investigated

Type of (a)symmetry	Asymmetry	Symmetry	H ₀ from Eq. 6b
Distributed lag effect	DLEA	DLES	$\beta_j^+ = \beta_j^-$
Cumulated impact using period-to-period models	CIPPA	CIPPS	$\sum_{j=1}^p \beta_j^+ = \sum_{j=1}^q \beta_j^-$
Cumulated impact using cumulative models	CICA	CICS	$\sum_{j=0}^t \beta_j^+ = \sum_{j=0}^t \beta_j^-$
Equilibrium adjustment path	EAPA	EAPS	$\theta^+ = \theta^-$

2.3 Empirical Evidence of Vertical Price Transmission Asymmetry in Fresh Produce Markets

The lack of a standardized classification of types of asymmetry, combined with the variation between models, data frequency, marketing levels, and regions of study, present a challenge in the study of price transmission asymmetry, and evidence for asymmetry tends to be highly heterogeneous, as highlighted in Table 4 (below).

Table 4: Empirical Evidence of Vertical Price Transmission Asymmetry in Fresh Produce Markets (Adapted from Frey and Manera (2007)).

Study	(A)symmetry tested & identified	Model	Levels	Country	Product type	Sample	Frequency
Parrott, Eastwood, and Brooker (2001)	DLES, CICS	Cumulative Lag	FOB-retail	USA	Fresh tomatoes	1988-1993	Weekly
Hassan and Simioni (2001)	EAPS	Error Correction	FOB-retail	France	Tomatoes	1997-2001	Weekly
Hassan and Simioni (2001)	EAPA	Error Correction	FOB-retail	France	Chicory	1997-2001	Weekly
von Cramon-Taubadel, Loy, and Meyer (2003)	EAPA (individual store prices)	Error Correction	Wholesale-retail	Germany	Lettuce	1995-2000	Weekly
von Cramon-Taubadel et al. (2003)	EAPS (average retail prices)	Error Correction	Wholesale-retail	Germany	Lettuce	1995-2000	Weekly
Girapunthong, VanSickle, and Renwick (2003)	DLES, CICS	Cumulative Lag	Farm-retail	USA	Fresh tomatoes	1975-1998	Monthly
Girapunthong et al. (2003)	DLEA, CICA	Cumulative Lag	Farm-wholesale	USA	Fresh tomatoes	1975-1998	Monthly
Girapunthong et al. (2003)	DLEA, CICS	Cumulative Lag	Wholesale-retail	USA	Fresh tomatoes	1975-1998	Monthly
Aguero (2004)	EAPS or EAPA depending on specification	Error Correction	Wholesale-retail	Peru	Potatoes	1995-2001	Daily
Aguero (2004)	EAPA or EAPS depending on specification	Error Correction	Wholesale-retail	Peru	Fresh tomatoes	1995-2001	Daily
Ahn and Lee (2015)	DLEA, CIPPA	Period-to-Period Lag	FOB-wholesale	USA	Apples, peaches, grapes	1998-2011	Weekly

2.4 Potential Drivers of Price Transmission Asymmetry in Fresh Produce Markets

Theoretical literature suggests a variety of possible drivers of asymmetry in vertical price transmission (Ball & Mankiw, 1992; Blinder, 1994; Brown & Yucel, 2000; Kinnucan & Forker, 1987; Kovenock & Widdows, 1998; Reagan & Weitzman, 1982; Ward, 1982). These potential causes are categorized in four main groups by Vavra and Goodwin (2005): non-competitive markets, inventory management, sticky prices, and government intervention.

2.4.1 Non-competitive markets

Several studies point to increasing vertical coordination and downstream consolidation in agri-food chains worldwide (Hobbs & Young, 2000; Lovreta, Koncar, & Stankovic, 2015; McLaughlin, Park, & Hawkes, 2015; OECD, 2013; Swinnen & Maertens, 2007; Wood, 2013), and therefore one leading hypothesis concerns itself with market power as a driver of asymmetric price transmission. Market power, as commonly defined in Industrial Organization, means that firms are able to set prices that exceed marginal costs (Vavra & Goodwin, 2005). There are many more farms than there are wholesalers or retailers, and this unequal buying power may lead to asymmetries – and inefficient resource allocation – as the relatively powerful downstream actors adjust prices with the goal of capturing greater profits (Vavra & Goodwin, 2005). For example, wholesale firms may form an oligopoly characterized by tacit collusion that enables them to maximize profits. If this holds true, positive farm price shocks would cause each wholesaler to quickly and fully raise their selling prices (thereby signaling to their competitors that will uphold the unspoken agreement), whereas in the case of negative farm price shocks, each wholesaler would only lower their selling prices slowly and incompletely, to avoid signaling that they are reducing their margins and thus undermining their arrangement (Brown & Yucel, 2000). This hypothesis predicts that price reductions at the farm-level are passed on to the consumer only slowly and incompletely, whereas farm-level price increases are passed on more quickly (Vavra & Goodwin, 2005) – thus resulting in both short-run and long-run price transmission asymmetry. This could mean that relative to a decrease in p^{in} , an increase in p^{in} could result in a larger adjustment of p^{out} (distributed lag effect asymmetry) or a more rapid and full adjustment of p^{out} (cumulative impact asymmetry in period-to-period or cumulated models).

2.4.2 Inventory management

Reagan and Weitzman (1982) suggest downstream actors may reduce their prices relatively slowly as an inventory management strategy that helps them to maintain stock because a more rapid price reduction could mean that their inventory would run out. In contrast to Reagan and Weitzman (1982), Ward (1982) argues downstream actors may *increase* prices relatively slowly in the case of perishable goods in order to minimize spoilage risk from unsold products. This is expected to affect the rate of adjustment but not the magnitude. If Reagan and Weitzman's argument holds true, then a decrease in p^{in} would result in a delayed and gradual price adjustment of p^{out} (relative to an increase in p^{in}). However, if Ward's argument applies, then a decrease in p^{in} would be more immediately and rapidly transmitted to p^{out} than would an increase in p^{in} . This could be evident via distributed lag asymmetry and cumulated impact asymmetry. Equilibrium adjustment path asymmetry could also exist; if p^{out} were above the long-run equilibrium, following from Reagan and Weitzman, it would move towards the equilibrium more slowly than if p^{out} were below the equilibrium; the inverse is true following Ward's argument.

2.4.3 Sticky prices

The costs of adjusting prices might lead firms to react differently to positive price shocks than to negative price shocks, especially if the price changes are perceived to be temporary. The costs of inflation, relabeling prices, and disseminating news about the price changes may dis-incentivize changing selling prices in response to short-term farm-level price decreases (Ball & Mankiw, 1992; Kovenock & Widdows, 1998). Firms might also want to avoid signaling market changes to their customers, because it may instigate search behavior (Blinder, 1994). This would be manifested in a

p^{out} that is more responsive to small increases in p^{in} than small decreases in p^{in} – which over the long term could result in cumulative impact asymmetry, i.e. a higher total magnitude of positive changes to p^{out} (in response to positive shocks to p^{in}) than of negative changes to p^{out} (in response to negative shocks to p^{in}). However, while sticky prices may be an important factor in some levels of the produce marketing chain (e.g. at the retail level), it is not a key factor for wholesalers. Wholesale merchants use spot markets, so prices are designed to be sensitive to supply-demand fluctuations and adjust on a daily basis. Thus, the sticky prices driver is not relevant for price transmission between the shipping point and wholesale levels in US fresh produce markets.

2.4.4 Government intervention

Kinnucan and Forker (1987) point out that asymmetry could arise if firms believe that adjusting prices in one direction has a higher chance of stimulating government intervention than price adjustments in the opposite direction. For example, wholesalers may anticipate long-term increases in farm price support levels and thus incorporate these increased prices into their selling price quickly and fully, whereas price supports are only rarely (and often temporarily) lowered, thus resulting in a delayed and incomplete wholesale price adjustment. This could be represented by all the types of asymmetries introduced in Figures 1a-c. p^{out} might respond more strongly, more immediately, or more rapidly and fully to an increase in p^{in} than a decrease in p^{out} , and the rate of adjustment may differ depending on the relationship between p^{out} and its long-run equilibrium. However, although the US government does influence produce markets via research and information (such as the USDA Market News Service, which tracks shipping point and terminal market prices for various commodities), price support is limited to grains and oilseeds (Roberta L. Cook, 2017). Thus, in fresh produce markets in the US, government intervention is not relevant for price transmission.

2.4.5 Empirical research

The body of empirical research examining the linkage between asymmetric price transmission and its potential drivers is sparse and focused around non-competitive markets and sticky prices. Peltzman (2000) investigated the relationship between market power and asymmetric price transmission using two different indicators: market concentration⁵ and the number of competing firms in the industry. He found that these indicators yield contrasting results: cumulative impact asymmetry was higher as the number of firms decreased, but lower as concentration levels increased. He also found that “neither inventory holdings nor menu costs [sticky prices] seem a key ingredient in producing price asymmetries” (pp. 493-4). Ray, Chen, Bergen, and Levy (2006), however, investigated short-term grocery wholesale price changes, and found that for price adjustments below 8%, there were significantly more price increases than price decreases, but no systematic difference was found for larger price adjustments – thus supporting the theoretical hypotheses. Chen, Levy, Ray, and Bergen (2008) investigated the same topic using retail scanner data, and found that inflation was indeed relevant to price transmission asymmetry. To the best of my knowledge, there is no published empirical research currently that tests the role of inventory management or government intervention in price transmission asymmetry for US fruits and vegetables.

⁵ Peltzman (2000) uses the Herfindahl-Hirschman Index to measure market concentration. In this index, the market shares of each competing firm are squared and then summed. The most common indicator of market concentration, however, is the four-firm concentration ratio, which is the sales share of the largest four firms in the industry. Generally, empirical evidence is similar for both of these indicators (Carlton & Perloff, 1999).

2.5 Chapter Conclusion

This chapter introduced price transmission asymmetry and identified four types to be investigated in this thesis: distributed lag effect asymmetry, cumulative impact asymmetry (using period-to-period and cumulated models), and equilibrium adjustment path asymmetry. This section also explored key models for empirically testing asymmetry, the mixed evidence on price transmission asymmetry, and the potential drivers of asymmetric price transmission in this market. It was determined that price transmission between the shipping point and terminal market levels of fresh produce trade could be affected by non-competitive markets and inventory management strategies. Thus, factors relevant to these two drivers will be explored in Section 3.

III. Fresh Produce Value Chain Structure

Research Question Two: What is the structure of the selected fresh vegetable value chains in California?

This section will address Research Question Two by describing the typical structure of the value chain for US fresh fruits and vegetables, and then specifically addressing the characteristics of romaine lettuce, celery, and broccoli. It will then further explore the selected vegetables by providing information on their seasonality and market environments, in order to provide context for the non-competitive markets and inventory management drivers of asymmetry.

3.1 Fresh Produce Marketing Channels in the US

According to Calvin et al. (2001, p. 1), a century ago the “typical produce transaction [in the United States] was characterized by many shippers selling to many buyers in terminal wholesale markets” and from there to grocery retailers. However, marketing channels for fresh produce have changed markedly since that time. A simplified schematic of fresh fruit and vegetable marketing channels is shown in Figure 2, along with 1999 estimates of the value of the fresh produce passing through these channels.

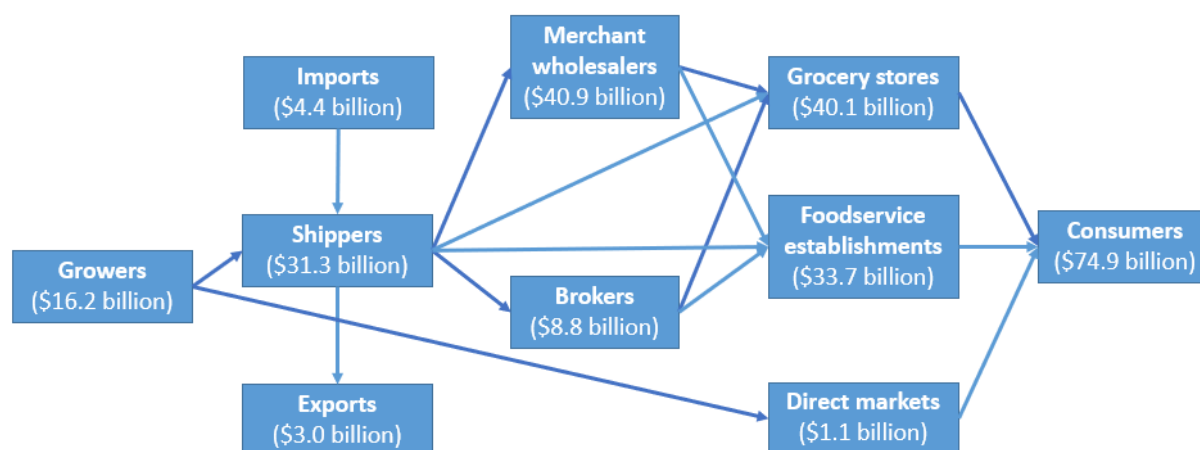


Figure 2: U.S. Fresh Fruit & Vegetable Marketing Channels (1999). Figure adapted from McLaughlin, Green, and Park (1999).

On the upstream side of the value chain, growers represent all farm production. The linkage between growers and shippers is called the shipping point or the FOB (free-on-board) point. This point, where the grower is no longer responsible for transport costs, is the USDA’s data collection point closest to the farm-gate level. This is often used as an estimate of fresh produce production values, because growing, harvesting, and packing can be closely integrated with one another. For example, lettuce is usually washed and packaged immediately by the grower (Kaufman, Handy, McLaughlin, Park, & Green, 2000).

Most produce moves from growers to shippers, although some is directly marketed to consumers by the growers themselves – as is the case with farmer’s markets and community-supported agriculture. Direct marketing has grown since 1999, but still represents a small proportion of total fruit and vegetable sales. Exports and imports of fresh fruits and vegetables occur mostly at the shipping stage.

The vast majority of the shippers are forward-integrated grower-shippers. They sell produce from their own operations as well as from other growers (Roberta L Cook, 2016). From the shipper, a large proportion of sales goes to merchant wholesalers (wholesalers who handle physical product, purchasing in large volumes from shippers and selling produce in smaller quantities; this stage is also referred to as the terminal market) or via brokers (middlemen who negotiate sales between buyers and sellers in the food chain but do not own or physically handle the product).

However, for the past several decades, retailers and foodservice establishments have been purchasing a growing proportion of fresh produce directly from grower-shippers. Manchester (1964) reported that this channel accounted for only 20% of fresh produce sales in 1958 – but as indicated in Figure 3, McLaughlin et al. (1999) reported that grower-shippers sold 50% of their fresh produce directly to retailers and foodservice establishments, 17% via brokers, and only 21% through wholesale merchants. McLaughlin et al. (2015) indicate that as of 2015, about 65% of fresh produce purchased by retailers passes through this channel, while about 15% continues to pass through wholesale markets, and another 15% of sales are arranged by brokers.

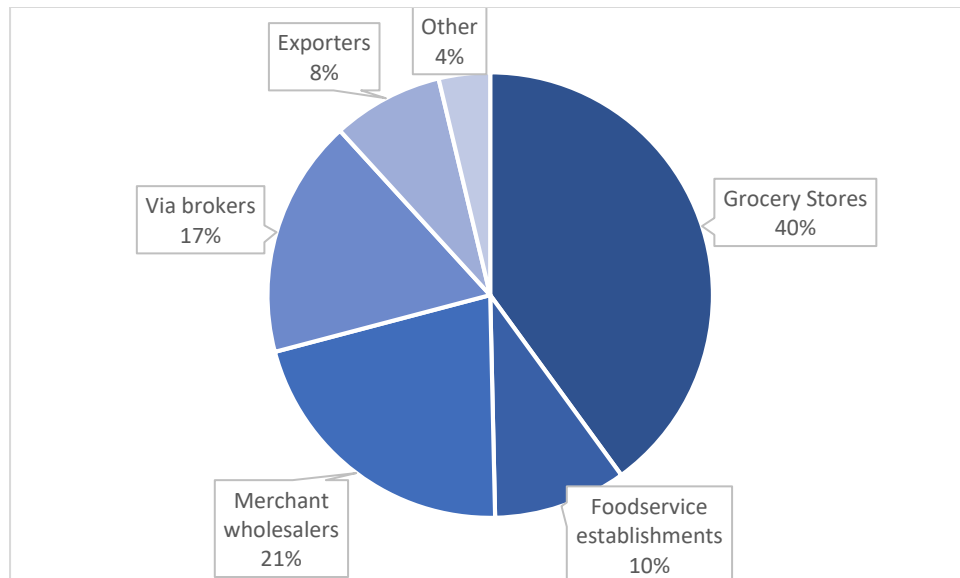


Figure 3: Grower/Shipper Sales by Customer Type (1999). Figure adapted from McLaughlin et al. (1999).

For celery, lettuce, and broccoli, however, brokers play a smaller role. It is estimated that about 75% of volume for these vegetables is sold directly to retailers and food service, while the rest passes through merchant wholesale markets (Roberta L. Cook, 2017).

3.2 Characteristics of California Romaine Lettuce, Celery, and Broccoli

This thesis will focus specifically on California romaine lettuce, celery, and broccoli. California produces most of the nation's supply of these vegetables, and they are among California's most valuable crops. They do vary significantly, however, with regards to perishability; while romaine lettuce and broccoli are highly perishable, celery is hardier.

Table 5: Production and Market Characteristics for Selected Vegetables in California

	Romaine Lettuce	Celery	Broccoli
CA share of US sales ⁶	76.2%	95.9%	94.3%
Area harvested ⁶	63,500 acres	28,500 acres	115,000 acres
Total value ⁶	\$696.9 million	\$437.4 million	\$866.5 million
Vegetable rank in CA, by total production value ⁶	3	6	2
Time from planting to market maturity ⁷	50-80 days	90-125 days	50-80 days
Approximate storage life ⁸	14-21 days	60-90 days	10-14 days

⁶ California Department of Food and Agriculture (2017)

⁷ KZN Department of Agriculture and Rural Development (2016). Estimates refer to average time under optimum growing conditions.

⁸ Smith (2010)

3.3 Seasonal Production of California Celery, Lettuce, and Broccoli

These vegetables are all produced in California year-round, with the highest volume of production taking place along the coast. However, to ensure year-round supply of the vegetables, production takes advantage of the diverse climate zones in California and moves seasonally between four key regions: the Central Coast, the Southern Coast, the Central Valley, and the Southern Deserts.⁹ To protect themselves against shortfalls in supplies, shippers and wholesalers generally source from more than one region at once. (Roberta L. Cook, 2017).

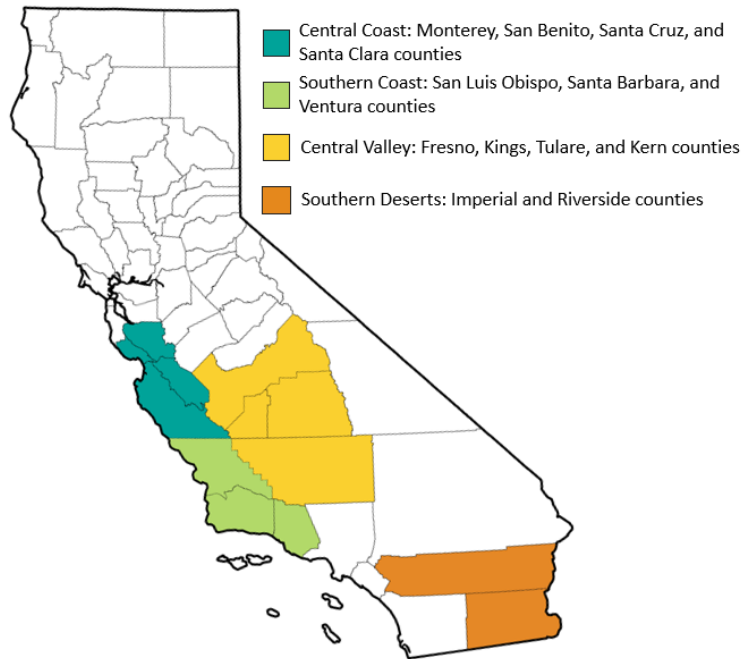


Figure 4: Major Production Regions for California Romaine Lettuce, Broccoli, and Celery. Figure created by author based on Jackson et al. (1996), Le Strange, Cahn, Koike, and Smith (1996), and Koike, Schulbach, and Chaney (1996).

3.4 Market Concentration Among Lettuce, Celery, and Broccoli Growers, Shippers, and Wholesalers

As of 2012, there were 750 romaine lettuce growers, 196 celery growers, and 1200 broccoli growers in California (United States Department of Agriculture, 2012). Bluebook 2011 estimates that there are 1,259 fresh produce shippers in California (Roberta L. Cook, 2017). Growers receive the market price for crops sold, less fees for marketing, packing, and other handling. The shippers, who usually supply year-round in order to maintain relationships with buyers and employees, earn the shipping and marketing fees (Roberta L Cook, 2016).

There are about 1,000 fresh produce wholesalers in North America (Roberta L Cook, 2016), and the number of romaine lettuce, celery, and broccoli merchant wholesalers in California is lower still. As vegetables with similar production regions, all three of these vegetables are generally traded by the same wholesalers. While exact numbers of wholesalers are difficult to identify, Blue Book Produce, the leading produce marketing information agency in the US, was used to find wholesale jobbers and receivers¹⁰ operating through one or more of the five terminal markets in California: the Los Angeles Wholesale Market, the Seventh Street City Market, the Oakland Produce Market, the Golden Gate Produce Terminal, and the San Francisco Wholesale Produce Market. 68 firms were listed as supplying vegetables to one or more of these markets (Blue Book Services, 2017). Blue Book listings, company websites, and phone calls to the company determined that 25 of these firms did not sell lettuce, celery,

⁹ See Appendix 1 for graphs (from 2015-2017) and further details on the annually varying production volumes from each region.

¹⁰ Blue Book defines a receiver as a firm that “purchases and takes physical possession of trucklots or carlots and locally resells same intact or in jobbing lots,” while firms classified as jobbers are those that “sell locally in small lots and purchases from receivers on their local market” (Blue Book Services, 2017).

or broccoli; thus, it is estimated that 43 wholesalers in the California terminal markets trade in the selected vegetables.

In the short run, supply for fresh vegetables is inelastic. Production acreage is fixed during planting (months before the vegetables are ready for trade) and perishability restricts storage of these vegetables (Sexton & Zhang, 1996). According to the literature, this means that growers and shippers tend to have limited bargaining power. However, varying weather patterns result in yields that fluctuate widely from week to week, and this can shift the relative bargaining power between sellers (growers and shippers) and buyers (wholesalers, foodservice, and retailers) (Roberta L Cook, 2011; Sexton & Zhang, 1996). The wholesaler perspective on price dynamics will be discussed further in the next chapter.

3.5 Chapter Conclusion

This chapter explored the structure of fresh produce value chains, with particular attention to celery, romaine lettuce, and broccoli. It was found that merchant wholesalers act as middlemen for about a quarter of the volume for these vegetables as they pass from grower-shippers to retailers and foodservice establishments. Then, after a brief introduction of the characteristics of the selected vegetables, their seasonality and market concentration were described. This served to provide context for the role of non-competitive markets and inventory management strategies. It was determined that these vegetables are all domestically supplied year-round to wholesalers due to their production in various regions of California and Arizona, and that celery has a much longer storage life than lettuce and broccoli. Furthermore, there are more than a thousand total lettuce, celery, and broccoli growers and shippers in California, but less than 50 merchant wholesalers at the state's terminal markets. The information gathered on romaine lettuce, celery, and broccoli value chain structures is used to develop the interviews described in Section 4.

IV. Wholesaler Perspectives on Pricing

Research Question 3: What do wholesalers active in the selected fresh vegetable supply chains perceive as the primary drivers behind their pricing decisions?

The third research question will be addressed through interviews with Los Angeles wholesalers, with the goals of identifying self-reported motivations for pricing decisions and gaining further insight into the structure of California fresh produce value chains. Special attention will be paid to the way terminal market prices adjust to shipping point price increases and decreases, in order to categorize these adjustments according to theoretical predictions. First, the rationale of the survey design will be explained, and then the selection, sampling, and approach will be outlined. Then the results will be presented.

4.1 Rationale of Survey Design

The survey questions (listed in full in Appendix 2) were designed based on the drivers identified in Chapter 2.4. One hypothesis is used to represent the non-competitive markets driver and two hypotheses are used to represent the inventory management driver.

As described in Chapter 2.4, price asymmetry driven by non-competitive markets could take the form of distributed lag effect asymmetry or cumulated impact asymmetry. This would mean that price reductions at the FOB level would be slowly and incompletely reflected in wholesale price reductions – but price increases at the FOB level would be passed on more quickly and fully. Wholesale price adjustments that follow this pattern would be motivated by a desire to avoid undercutting other wholesalers, rather than by a desire to set competitive prices. If survey results support Hypothesis 1, it would be indicative of asymmetry driven by non-competitive markets.

- Hypothesis 1: Relative to FOB prices, wholesalers increase their prices more quickly and fully to avoid undercutting other wholesalers, and wholesalers decrease their prices relatively gradually and incompletely to avoid undercutting other wholesalers.

Price transmission asymmetry driven by inventory management strategies could take the form of distributed lag effect asymmetry, cumulated impact asymmetry (using period-to-period or cumulative models), or equilibrium adjustment path asymmetry. Hypothesis 2 represents the inventory management theory proposed by Reagan and Weitzman (1982) – that in order to avoid spoilage of unsold inventory, a decrease in FOB prices would result in a delayed and gradual (“relatively slow”) price adjustment at the wholesale level, compared to the faster and more immediate (“relatively rapid”) wholesale price adjustments in response to FOB price increases. Hypothesis 3 represents the opposite interpretation of inventory management, as proposed by Ward (1982) – in order to avoid running out of inventory, an increase in FOB prices would result in a delayed and gradual price adjustment at the wholesale level, compared to the faster and more immediate wholesale price adjustments in response to FOB price increases.

- Hypothesis 2: To minimize the risk of spoiled unsold inventory, wholesalers increase their prices relatively rapidly in response to FOB price increases and they decrease their prices relatively slowly in response to FOB price decreases.
- Hypothesis 3: To avoid running out of inventory, wholesalers decrease their prices relatively slowly in response to FOB price decreases and they increase their prices relatively rapidly in response to FOB price increases.

To avoid the double-barreled or leading questions that would be implied by directly using these hypotheses (e.g. “Do you increase your prices relatively slowly to minimize the risk of spoiled unsold inventory?”), these hypotheses are separated into paired multiple-choice questions that include a

binary choice question followed by a Likert scale question (Johns, 2010). This is also expected to discourage respondents from simply entering the same rating for each question, as some answer pairs (e.g. “I increase my prices relatively rapidly...because I want to minimize risk of spoiled unsold inventory”) do not make sense and thus are expected to be rated very low.

The same set of questions is asked for celery, broccoli, and romaine lettuce. This will enable comparison of responses for each commodity and allow the wholesaler-identified drivers to be related to the econometric analyses for each commodity. In other words, the survey serves to distinguish how drivers of price response differ between these three commodities – which can be used to link the econometric results (which will be described in Chapter 5) to potential drivers.

In order to develop a more holistic image of FOB and terminal market pricing, there are also several other questions in the survey, including open-response questions. These questions investigate the price-setting process for FOB prices, the factors relevant for terminal market price determination, sources for learning about supply and demand fluctuations, and the market share of the largest wholesalers.

4.2 Selection, Sampling, and Approach

A Google Forms link to this survey was emailed to the 43 identified California-based wholesalers of fresh celery, broccoli, and lettuce for whom contact details were publicly available. Shortly after the survey was emailed out, the wholesalers were all contacted by telephone. Of these, the owners of six firms consented to a brief interview. The structured survey design is described in Section 4.1 (and Appendix 2), but due to the low response rate, the telephone interviews were conducted in a semi-structure manner to allow for more flexibility and follow-up on topics of interest. To reduce response bias and eliminate privacy concerns, the interviewees were guaranteed anonymity. All wholesalers interviewed sold all three vegetables.

4.3 Interview Findings

The responses of the six wholesalers interviewed addressed the hypotheses outlined in Section 4.1, and also provided further contextual information related to the way the industry functions and how prices are set. Interviewees described the way that FOB prices are determined, the way that terminal market prices are determined, the way that they and their clients monitor market changes, the lag between FOB price shocks and wholesale price adjustments, the relevance of market structure and inventory management strategies in their pricing decisions, and differentiation between pricing for each of the three vegetables examined.

4.3.1 Determining FOB prices

With regards to FOB price-setting, growers generally indicate their desired price, and then negotiate with their clients to reach an agreed price. In contrast to the findings of Sexton and Zhang (1996), the interviewed wholesalers indicated that grower-shippers had more control over FOB prices than wholesalers did, especially when prices were rising. One interviewee remarked that this was because the growers share pricing information among themselves, and another noted that the growers were able to sell their produce nationwide if the prices offered were too low at a terminal market. One wholesaler remarked that they received inventory through three distinct channels: either the grower sends product after setting a price, or growers have extra product and will offload it in exchange for a low percentage return, or growers with a long-established relationship will simply send product and trust that they will be paid based on market price.

4.3.2 Determining terminal market prices

For terminal market prices, produce wholesalers generally aim to sell for an average of about 20% higher than the FOB price in both rising and falling markets, with one interviewee remarking that “you need 15-25% to survive in this business.” One interviewee mentioned that “on a rising market, you try to make more money,” while another commented that “it’s easier to make a good margin on a lower-priced product,” when supply is abundant. Several wholesalers reported that their pricing is based on their predictions of future prices, which are primarily determined by quantities supplied and demanded of undamaged produce. One interviewee remarked that this means “weather is the number-one influence” on price changes at the FOB and terminal market levels. As one wholesaler noted, “you’re trying to find the right price, to figure out the high and the low and stay ahead of the market.”

4.3.3 Monitoring market changes

All interviewees noted that relationships were highly important in produce wholesaling, and while Market News and trade subscriptions helped to keep track of market changes, calling growers and brokers was their primary source of information on changes in price and quantity. One interviewee mentioned that they had to use a fixed terminal market price for everyone on a given day, because potential buyers compare quoted prices among themselves; however, others indicated that the price was highly negotiable based on comparison among other wholesalers, quality of the product, and weight per carton. One wholesaler indicated that they had several pricing structures depending on the volume of the sale.

4.3.4 Lag between FOB price shocks and wholesale price adjustments

The lag time between purchase and delivery varies depending on the production region, but generally the lag is less than a week. Some wholesalers responded that they received products within a day of purchase, while others mentioned a delay of a few days. This also varies based on season, as products grown in more remote regions of California usually take longer to arrive. The timing of terminal price market adjustments relative to FOB price changes can vary. While some wholesalers did not indicate a difference in timing their price adjustments depending on whether prices were rising and falling, others commented that in a rising market, they increase the prices immediately relative to the purchase price, but in a falling market, they could usually delay. One interviewee noted that this was possible because “customers aren’t usually so savvy within 1-2 days...but if my competitor’s prices are all cheaper then I might have to drop it.”

4.3.5 Relevance of market structure and inventory management strategies

When asked directly about specific factors behind their price adjustment decisions, most interviewees responded that avoiding undercutting other wholesalers was not relevant – although one interviewee did describe this as moderately important. Another wholesaler mentioned that driving market margins down wasn’t a concern because produce wholesaling is too fragmented for a single small wholesaler to strongly impact the market. Keeping prices competitive, maintaining stock, and avoiding spoiled inventory were considered important factors by most interviewees. One interviewee also mentioned that having goods spoil because of overly high prices wasn’t a concern, because they could then simply lower their prices. However, they did mention that running out of stock was a concern, because that would be an indicator that they set their price too low, and then they would have to turn away business. Another interviewee mentioned that they didn’t usually hold inventory for more than a couple days, because the close proximity of the production makes frequent purchases easy. He noted, however, that if prices were increasing drastically then they might buy more and try to stock up – however, then “you can’t be too greedy because then you’ll have spoilage.”

4.3.6 Pricing strategies for each vegetable

Most interviewees did not express any difference in their approaches to pricing between the three vegetables. One interviewee remarked that this is because they are all basic, common products supplied by many wholesalers. While broccoli and celery were described as priced using the same approach for all wholesalers, lettuce was occasionally differentiated. For romaine lettuce, maintaining stock and avoiding spoiled inventory were especially important considerations in pricing decisions. One interviewee mentioned that they tried to keep lettuce in stock for no more than 5 days, broccoli for a week, and celery for 1-2 weeks. This wholesaler indicated that this “created more urgency in moving romaine lettuce” (relative to broccoli and celery) so they would sometimes be willing to accept a lower price for it.

4.3.7 Implications for the three hypotheses

Clearly, responses varied between interviewees – however, most interviewees were in general agreement with regards to the three hypotheses outlined in Section 4.1. Hypothesis 1 was rejected. Some wholesalers noted that they do increase their prices immediately upon learning of FOB price increases, but they try to delay price decreases, but they indicated that this was driven by a desire to increase margins. Almost every wholesaler responded that they were unconcerned about undercutting other wholesalers and driving margins down – in fact, it was noted that the fragmented market meant that individual wholesalers could only have minimal impact on the market, and that they could not make sales unless they kept their prices competitive. Hypotheses 2 and 3 received mixed support. Most wholesalers mentioned that avoiding spoilage and maintaining stock were very important in their pricing decisions. However, wholesalers either indicated that they adjust to FOB price increases rapidly relative to price decreases, or that there is no difference between the timing of their price adjustments whether FOB prices are rising or falling – which supports Hypothesis 3 but not Hypothesis 2. It must be noted, however, that it is possible that both of these competing inventory management strategies play a role. They may impact price adjustment decisions in opposite directions. Therefore, the desire to maintain inventory (associated with Hypothesis 3) appears to have a stronger influence on wholesale price adjustments, the desire to avoid inventory spoilage (associated with Hypothesis 2) may have a moderating effect on the price adjustments implied by maintaining inventory.

4.4 Chapter Conclusion

This chapter involved an interview of wholesalers to gain a deeper understanding of the fresh vegetable pricing process and of the motivations behind price adjustments. Although responses were mixed, wholesalers agreed that FOB prices were set primarily by grower-shippers rather than wholesalers – in other words, the wholesalers do not benefit from non-competitive markets. Furthermore, most wholesalers indicated that regardless of rising and falling prices, it was important to keep their prices competitive with other wholesalers, and driving wholesaler margins down was not a consideration. It was also found that most produce wholesalers aim to sell vegetables around an average of a 20% markup from their purchase price, regardless of whether FOB prices are increasing or decreasing. Wholesalers reported that it was important to set prices that would allow them to maintain some inventory but not be left with spoiled produce – and that this was the same whether prices were rising or falling. While the interviewed wholesalers generally said that they used the same pricing strategy for all three vegetables, some indicated that the high perishability of romaine lettuce made inventory management a particularly important consideration for its pricing.

V. Empirical Analysis

Research Question 4: What is the empirical evidence on asymmetric price transmission in fresh celery, lettuce, and broccoli markets of California?

This section aims to analyze the relationship between shipping point and wholesale market prices under price shocks. First, the data collection method and the data will be described, then preliminary tests will be conducted, and then the empirical models will be specified and estimated.

5.1 Data

Due to the short-term fluctuations in the supply and demand of perishable commodities, pricing strategies can change multiple times within a month (Brooker, Eastwood, Carver, & Gray, 1997). As noted by Miller and Hayenga (2001), data frequency plays an important role in studies of price transmission asymmetry, as studies using low-frequency data may fail to reject the null hypothesis of symmetry even in the presence of asymmetric price transmission. Thus, this research will use weekly time series data from the Wednesday of each week from July 1 2007-July 1 2017.

This data, provided by the USDA Agricultural Marketing Service, tracks average shipping point (in California and Arizona) and terminal market prices (in Los Angeles) for various agricultural commodities. The prices for cartons of each type of vegetable are given as a range of low to high prices recorded throughout the day (e.g. "Low-High Price: 12.00-13.00"). The midpoint of this range is selected for each observation. Because production of each vegetable moves to different regions of California throughout the year, the shipping point price represents the average across several major shipping points.¹¹ The shipping point averages were weighted using the Agricultural Marketing Service's Movement Reports, which provide volume estimates of transportation of lettuce, broccoli, and celery. The descriptive statistics for the resulting data are given in Table 6.

Table 6: Descriptive Statistics for Shipping Point and Terminal Price Data, July 2007-July 2017

Variable	Mean	Std. Dev.	Min.	Max
Romaine Lettuce				
Shipping point (n = 522)	\$12.77	\$7.81	\$5.70	\$51.66
Terminal market (n = 522)	\$14.49	\$6.91	\$7.00	\$59.00
Celery				
Shipping point (n = 522)	\$12.88	\$7.54	\$5.07	\$54.96
Terminal market (n = 522)	\$14.80	\$7.60	\$6.50	\$60.50
Broccoli				
Shipping point (n = 522)	\$10.10	\$4.25	\$4.63	\$30.75
Terminal market (n = 522)	\$12.44	\$4.34	\$6.50	\$33.00

¹¹ For more detailed information on the data used, see Appendix 3.

5.2 Preliminary Tests

Based on Figures 4-6, all price series appear stationary. Mean and variance do not appear to drift upwards or downwards over time, nor does it appear that they can be predicted by the season or another periodic interval.

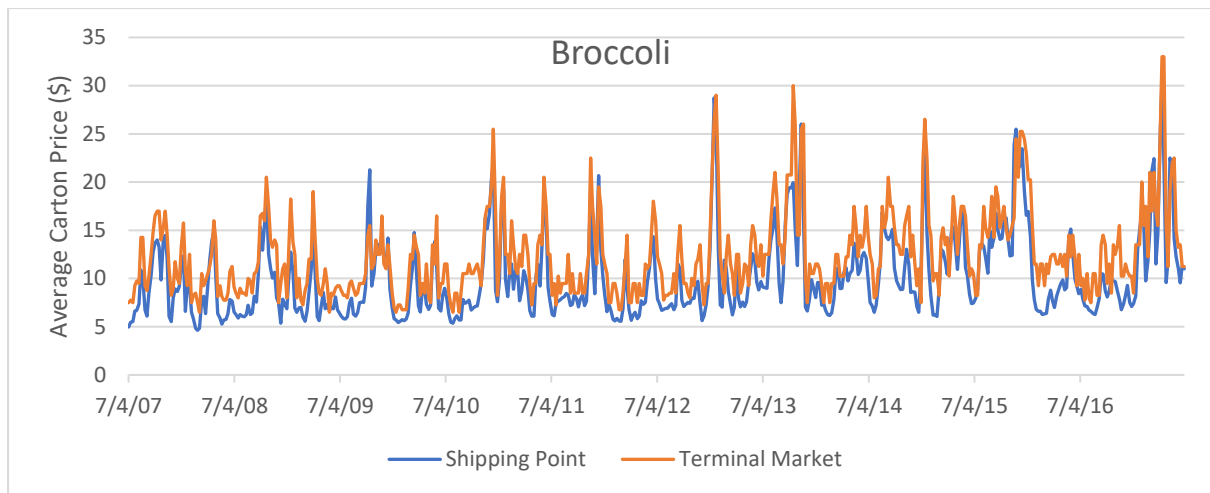


Figure 4: Weekly Prices of Broccoli at Shipping Point and Terminal Market

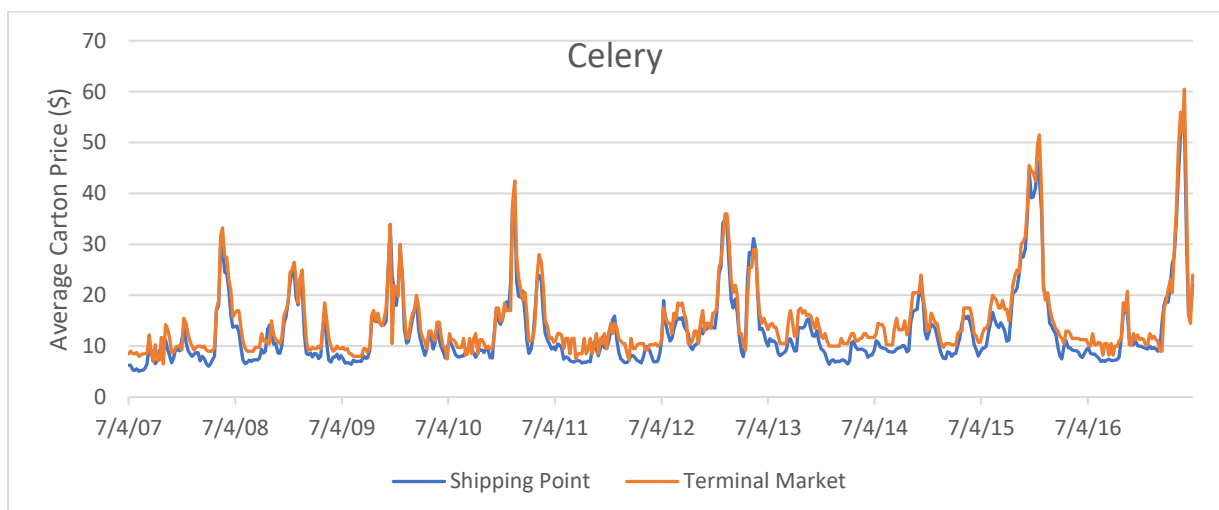


Figure 5: Weekly Prices of Celery at Shipping Point and Terminal Market

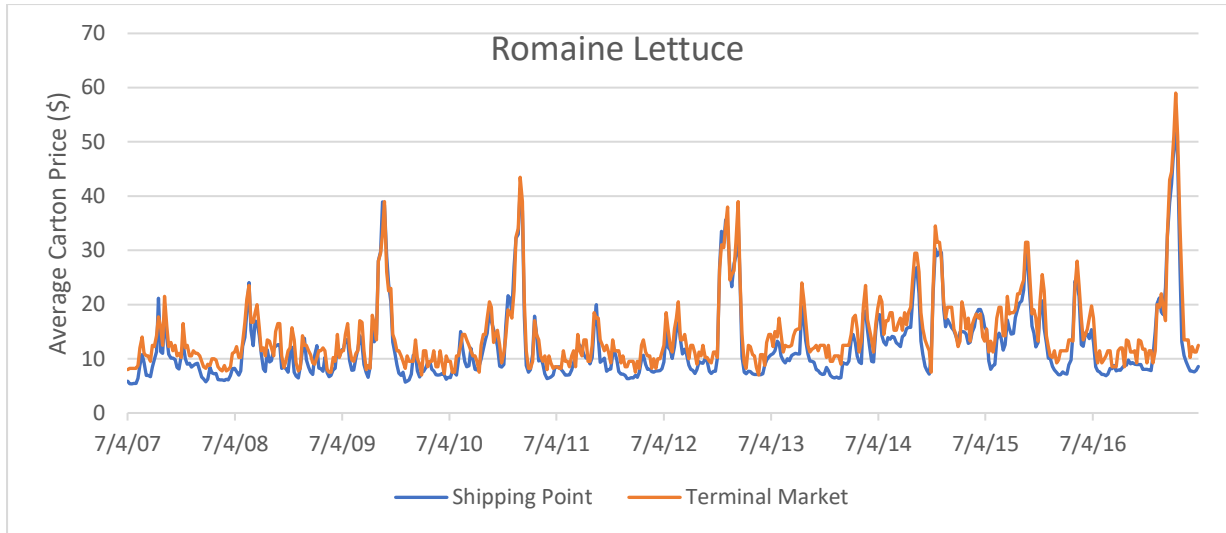


Figure 6: Weekly Prices of Romaine Lettuce at Shipping Point and Terminal Market

Stationarity was confirmed using an Augmented Dickey-Fuller test, which resulted in test statistics far below the 1% critical value of -3.430 for all variables (as shown in Table 7). The price data is thus integrated of order zero. Therefore, an error correction model is not necessary, as the models used do not need to account for non-stationarity or use methods based on cointegration.

Table 7: Augmented Dickey-Fuller Test Statistics

Variable	Test Statistic
Lettuce	
Shipping Point	-6.087
Terminal Market	-6.334
Broccoli	
Shipping Point	-6.609
Terminal Market	-6.681
Celery	
Shipping Point	-5.496
Terminal Market	-5.980

Next, lag orders were selected by minimizing Akaike's Information Criterion for each shipping point and terminal market pair, resulting in a lag of 5 for romaine lettuce, a lag of 3 for broccoli, and a lag of 5 for celery.¹² These lag orders were used to test for Granger causality. Using a 1% significance level, the null hypothesis of no Granger causality was rejected for all vegetables; however, this relationship is weak for lettuce and celery and the null hypothesis is not rejected at a 5% significance level. However, as shown in Table 8, using the 1% significance level it can be said that lettuce shipping point prices Granger-cause lettuce terminal market prices ($p=0.027$), broccoli shipping point prices Granger-cause broccoli terminal market prices ($p=0.267$), and celery shipping point prices Granger-cause celery terminal market prices ($p=0.012$).

¹² Lag order selection is described in greater detail in the appendix – see Appendix 4 for values of Akaike's Information Criterion (AIC) for the shipping point and terminal market prices for each vegetable.

Table 8: Test Results for Granger Causality Between Shipping Point and Terminal Market Price

Granger Causality	χ^2 Test Statistic	Pr.($ \chi^2 >$ Critical Value)
Lettuce		
H ₁ : Shipping Point Price → Terminal Price	4.8764	0.027
H ₁ : Terminal Price → Shipping Point Price	11.661	0.001
Broccoli		
H ₁ : Shipping Point Price → Terminal Price	1.2338	0.267
H ₁ : Terminal Price → Shipping Point Price	13.584	0.000
Celery		
H ₁ : Shipping Point Price → Terminal Price	6.3711	0.012
H ₁ : Terminal Price → Shipping Point Price	21.584	0.000

5.3 Model Specification and Estimation

Because the data is stationary, there is no need to use an error correction model. Instead, a simple autoregressive model or partial adjustment model can be used, depending on the type of symmetry investigated.

As described in Chapters 2.4 and 4.1, inventory-management-driven asymmetry could take the form of distributed lag effect asymmetry, cumulated asymmetry (using period-to-period or cumulative models), or equilibrium adjustment path asymmetry. To investigate these various types of asymmetry, three different models are used for the econometric analysis. The first two models allow for testing of asymmetry in period-to-period variation. This included testing for distributed lag effect asymmetry and cumulated impact asymmetry using period-to-period models (whether positive and negative shipping point prices have different effects on wholesale prices); a period-to-period partial adjustment model enabled testing for equilibrium path adjustment asymmetry (whether the rate of adjustment towards the estimated wholesale price differs depending on whether the previous observed wholesale price was above or below the estimated price). The third model allows for testing of long-run asymmetry by comparing the cumulated impacts of positive and negative shipping point price changes on the wholesale price's deviation from its starting value (in other words, it can test for cumulated impact asymmetry using cumulative models). For all the specifications below, the (wholesale) output price at time t is given by p_t^w , and the (shipping point) input price at time t is given by p_t^s .

A basic autoregressive model is given in Equation 7 below, where the wholesale price at time t is a function of the sum of the wholesale price lagged over m periods ($\sum_{i=1}^m \alpha_i p_{t-i}^w$) and the sum of the current and lagged (over n periods) price changes in the shipping point price ($\sum_{j=0}^n \beta_j \Delta p_{t-j}^s$).

Equation 7: Autoregressive Model for Estimating Wholesale Prices

$$p_t^w = \alpha_0 + \sum_{i=1}^m \alpha_i p_{t-i}^w + \sum_{j=0}^n \beta_j \Delta p_{t-j}^s + \varepsilon_t$$

This equation can be modified to incorporate asymmetries by segmenting the price changes in the shipping point price into positive and negative values, where

$$\Delta p_{t-j}^{s+} = \begin{cases} \Delta p_{t-j}^s & \text{if } \Delta p_{t-j}^s > 0 \\ 0 & \text{otherwise} \end{cases}, \text{ and } \Delta p_{t-j}^{s-} = \begin{cases} \Delta p_{t-j}^s & \text{if } \Delta p_{t-j}^s < 0 \\ 0 & \text{otherwise} \end{cases}.$$

As described in Frey and Manera (2007, p. 354), this can be used to develop a general autoregressive distributed lag model that allows for testing period-to-period asymmetries (Equation 8):

Equation 8: Autoregressive Distributed Lag Model for Testing Period-to-Period Asymmetries

$$p_t^w = \alpha_0 + \sum_{i=1}^m \alpha_i p_{t-i}^w + \sum_{j=0}^n \beta_j^+ \Delta p_{t-j}^{s+} + \sum_{j=0}^p \beta_j^- \Delta p_{t-j}^{s-} + \varepsilon_t.$$

In this equation, which corresponds to Equation 4 from Section 2.2, the wholesale price at time t is a function of a constant α_0 , the sum of the lagged wholesale prices for $i \in (1, m)$, and the sum of the current and lagged positive price changes in the shipping point price for $j \in (0, n)$, the sum of the current and lagged negative price changes in the shipping point price for $j \in (0, q)$, and an error term ε_t .

This model can be used to test short-run asymmetry at a given instant in time ($H_0: \beta_j^+ = \beta_j^-$, which if rejected would indicate distributed lag effect asymmetry) or over a range of periods ($H_0: \sum_{j=0}^n \beta_j^+ = \sum_{j=0}^p \beta_j^-$, which if rejected would indicate cumulated impact asymmetry using a period-to-period model). However, when lag length selection tests were conducted, for all vegetables the optimal lag length that minimized Akaike's Information Criterion for lagged wholesale prices, positive shipping point price changes, and negative price changes was 0.¹³ In other words, in the above regression, optimal lags were $m=1$, $n=0$, and $q=0$.

Thus, summation is not necessary, and the equation estimated is the simplified version of Equation 8, as described in Equation 9:

Equation 9: Autoregressive Model for Testing Period-to-Period Asymmetries Without Lags

$$p_t^w = \alpha_0 + \alpha_i p_{t-i}^w + \beta_j^+ \Delta p_{t-j}^{s+} + \beta_j^- \Delta p_{t-j}^{s-} + \varepsilon_t.$$

Results of running this regression are presented in Table 9.¹⁴

Table 9: Results for Equation 9

	β_j	Std. Error	Test statistic for $H_0: \beta_j^+ = \beta_j^-$	$\Pr(F > c)$
Celery	$\beta_j^+ = 0.9000$	0.0556	0.75	0.3867
	$\beta_j^- = 0.9810$	0.0593		
Lettuce	$\beta_j^+ = 0.9399$	0.0506	4.15	0.0422
	$\beta_j^- = 0.7650$	0.0558		
Broccoli	$\beta_j^+ = 0.7823$	0.0673	9.22	0.0025
	$\beta_j^- = 0.4296$	0.0753		

Thus, for celery, there is symmetry at a given instant in time ($H_0: \beta_j^+ = \beta_j^-$), without a significant difference between the effect of a positive or negative change in the shipping point price on the wholesale price. However, for lettuce, the null hypothesis is rejected at a 5% significance level. If the shipping point price change increases by \$1 relative to the previous price change and all other variables remain unchanged, the wholesale price increases by an average of \$0.94. However, if the shipping point price change decreases by \$1 and all other variables remain unchanged, the wholesale

¹³ AICs for various lag lengths for each vegetable are detailed in Appendix 4. This differs from the AICs that determined the optimal lag lengths used to test for Granger causality because it is based on the variables included in Equation 9, while the AICs calculated earlier only included p_t^w and p_s^w .

¹⁴ Full regression output and hypothesis testing is detailed in Appendix 5-7.

price decreases by an average of only \$0.77. For broccoli, the null hypothesis of symmetry is strongly rejected (at a 1% significance level). If the broccoli shipping point price change increases by \$1 relative to the previous price change and all other variables remain unchanged, the wholesale price increases by an average of \$0.78; however, if the shipping point price change decreases by \$1, the wholesale price decreases by an average of only \$0.43.

To examine if the speed of adjustment towards the long-run equilibrium differs depending on whether the current price is above or below the equilibrium (equilibrium adjustment path asymmetry), a partial adjustment model can be used. For this, first the relationship between wholesale and shipping point prices at time t is estimated, as in Equation 10:

Equation 10: Using Shipping Point Prices to Predict Wholesale Prices

$$p_t^w = \beta p_t^s + \mu_t.$$

Using Equation 10, β values were estimated for each vegetable. For celery, this value is equal to 1.1045; for romaine lettuce, this value is equal to 1.1204, and for broccoli, this value is equal to 1.1815. This means that a \$1 increase in the celery shipping point price increases the wholesale price by an average of \$1.10. $\widehat{p}_t^w = \beta_1 p_t^s$, so the estimated celery wholesale price at time t can be found by multiplying the shipping point price at time t by 1.1045. A \$1 increase in the lettuce shipping point price increases the wholesale price by an average of \$1.12, and a \$1 increase in the broccoli shipping point price increases the wholesale price by an average of \$1.18.

To estimate Equation 11, the residuals $\mu_t (= p_t^w - \widehat{p}_t^w)$ were saved and segmented into positive and negative values, where

$$\mu_t^+ = \begin{cases} \mu_t & \text{if } \mu_t > 0 \\ 0 & \text{otherwise} \end{cases}, \text{ and } \mu_t^- = \begin{cases} \mu_t & \text{if } \mu_t < 0 \\ 0 & \text{otherwise} \end{cases}.$$

Equation 11: Partial Adjustment Model for Testing Equilibrium Path Asymmetry

$$p_t^w = \beta p_{t-1}^w + \phi^+ (\mu_{t-1})^+ + \phi^- (\mu_{t-1})^- + \omega_t.$$

This corresponds to Equation 5 as introduced in Chapter 2.2 in this thesis, which is similar to Equation 3 in Frey and Manera (2007, p. 355). Here, the current wholesale price is predicted by the lagged wholesale price and the lagged positive and negative residuals. By testing the null hypothesis $\phi^+ = \phi^-$, one can investigate whether adjustments towards $\widehat{p}_t^w$ occur at different speeds if p_t^w is greater than or less than $\widehat{p}_t^w$. Results of running this regression are presented in Table 10.

Table 10: Results for Equation 11

	ϕ	Std. Error	Test statistic	Pr(F >c)
Celery	$\phi^+ = -0.7690$	0.1270	1.55	0.2138
	$\phi^- = -1.0094$	0.1039		
Lettuce	$\phi^+ = -0.6843$	0.1175	0.39	0.5307
	$\phi^- = -0.8101$	0.1139		
Broccoli	$\phi^+ = -0.9073$	0.0817	2.24	0.1353
	$\phi^- = -0.6989$	0.0814		

The ϕ values for all vegetables indicate that the value of the lagged residual is negatively correlated with the wholesale price. For celery, for example, for each \$1 increase in the lagged value for $p_t^w - \widehat{p}_t^w$, on average the current wholesale price will be \$0.77 lower; likewise, for each \$1 decrease in the

previous value for $p_t^w - \widehat{p_t^w}$, the current wholesale price will increase by an average \$1.01. However, the results of the hypothesis tests show that for all vegetables, the null hypothesis of symmetry is not rejected.

As shown in Equation 3, which was introduced in Chapter 2.2 of this thesis and is similar to the specification proposed by Houck (1977), this model can also be modified to consider cumulative long-run effects, estimating the change in p_t^w from its initial price p_0^w using the summed positive and summed negative shipping point price changes between the first period ($j=t$) and the current period ($j=0$). This is presented in Equation 12:

Equation 12: Autoregressive Model for Testing Cumulated Price Asymmetries

$$p_t^w - p_0^w = \alpha_0 + \beta^+ \sum_{j=0}^t \Delta p_{t-j}^{s+} + \beta^- \sum_{j=0}^t \Delta p_{t-j}^{s-} + \varphi_t.$$

Symmetry in the cumulative price variations can be tested with the null hypothesis $\beta^+ = \beta^-$. Results for this test are given in Table 11.

Table 11: Results for Equation 12

	$\widehat{\beta}$	Standard Error	Test statistic	Pr(F >c)
Celery	$\widehat{\beta}^+ = 0.9689$	0.0112	10.97	0.0010
	$\widehat{\beta}^- = 0.9666$	0.0113		
Lettuce	$\widehat{\beta}^+ = 0.9286$	0.9286	26.36	0.0000
	$\widehat{\beta}^- = 0.9256$	0.9256		
Broccoli	$\widehat{\beta}^+ = 0.8786$	0.8786	9.32	0.0024
	$\widehat{\beta}^- = 0.8765$	0.0221		

For all variables, the null hypothesis of cumulated symmetry is strongly rejected. The cumulative positive changes in price are more strongly transmitted to the change in wholesale price (from its initial price at the beginning of the data collection period) than are negative changes in price.

5.4 Chapter Conclusion

This chapter described the data collection process and empirical tests for price transmission asymmetry. A decade of shipping point and terminal market price data was analyzed, using a volume-weighted average of various shipping point prices and using terminal market prices from Los Angeles. The autoregressive model identified distributed lag effect asymmetry among lettuce and broccoli, with positive changes more strongly transmitted than negative changes, and symmetric period-to-period price transmission for celery. The partial adjustment model found that there was no equilibrium adjustment path asymmetry for any of the vegetables. The cumulative model found that cumulative positive changes were more strongly transmitted than cumulative negative changes for all three vegetables.

VI. Discussion and Conclusion

This section will revisit each of the research questions and the overarching research objective, summarizing findings and relating them to previous literature. Then, a discussion will identify limitations in this research and outlines recommendations based on the thesis.

6.1 Conclusion

6.1.1 Conclusion on Research Question 1: What is the state of the art of theoretical and empirical vertical price transmission research in fresh produce markets?

Investigating the first research question resulted in three main findings. First, the definition of price transmission asymmetry varies from study to study, and it is critical to precisely identify the types of asymmetry examined. This thesis focused on four types of vertical price transmission asymmetry: distributed lag effect asymmetry, cumulative impact asymmetry using period-to-period models, cumulative impact asymmetry using cumulated models, and equilibrium adjustment path asymmetry. Second, empirical models should be selected based on the specific type of asymmetry as well as the characteristics of the data. For example, most modern empirical tests of price transmission asymmetry rely on cointegration because price series are often non-stationary. Third, two theoretical mechanisms were identified that could lead to price transmission asymmetry between the shipping point and terminal market levels of fresh produce trade: non-competitive markets and inventory management strategies. The other two theoretical mechanisms which were considered are not applicable; sticky prices cannot explain price transmission from shipping point to wholesale markets because prices are adjusted at very frequent intervals, while government intervention cannot explain price transmission in the US fresh produce industry because the government does not directly intervene in this market.

Research on price transmission asymmetry is highly heterogeneous, and does not consistently provide clear definitions for the type of asymmetry investigated. This paper builds on the review papers by Frey and Manera (2007) and Meyer and von Cramon-Taubadel (2004) by explicitly clarifying the distinction between the types of asymmetry considered. While some previous literature outlines various theoretical explanations for vertical price transmission asymmetry (Meyer & von Cramon-Taubadel, 2004; Vavra & Goodwin, 2005), and other literature focuses on the relevance of a single theoretical explanation to a specific market (Ahn & Lee, 2015; Bunte & Peerlings, 2003; Peltzman, 2000), this thesis is unusual in that it compares the relevance of several theoretical explanations for price transmission asymmetry in the context of a specific agricultural market.

6.1.2 Conclusion on Research Question 2: What is the structure of the selected fresh vegetable value chains in California?

To address the second research question, this thesis traced the marketing channels that these vegetables pass through, from grower to consumer. It was discovered that while merchant wholesalers act as middlemen for about 15% of the volume for all US fresh produce as it passes from grower-shippers to retailers and foodservice establishments, these merchant wholesalers handle about 25% of the volume for celery, romaine lettuce, and broccoli. These vegetables are all domestically supplied year-round to wholesalers due to their production in various regions of California and Arizona. Furthermore, although there are at least twenty times as many lettuce, celery, and broccoli growers in California than there are merchant wholesalers for these vegetables at the state's terminal markets, the wholesaling market is highly fragmented and wholesalers do not exert market power.

Although there are several studies on US fresh produce value chains from the turn of the century, and various agricultural statistics are available from sources like Blue Book and USDA, descriptive information about modern fresh produce value chains – especially when focusing on romaine lettuce, celery, and broccoli from California – is scarce. This thesis contributes to the previous research on the

subject by compiling information from various sources and using interview data to update and expand upon the existing published literature.

6.1.3 Conclusion on Research Question 3: What do wholesalers active in the selected fresh vegetable value chains perceive as the primary drivers behind their pricing decisions?

Wholesalers agreed that FOB prices were set primarily by grower-shippers rather than wholesalers – in other words, the wholesalers do not benefit from non-competitive markets and this is not considered a relevant factor in price transmission in this sector. FOB prices – and in turn, wholesale prices – are primarily determined by current supply and demand and anticipated future supply and demand, which they assess mostly via calls to various growers and brokers. Furthermore, most wholesalers indicated that regardless of rising and falling prices, it was important to keep their prices competitive with other wholesalers, and driving wholesaler margins down was not a consideration. It was also found that most produce wholesalers aim to sell vegetables around an average of a 20% markup from their purchase price, regardless of whether FOB prices are increasing or decreasing. Wholesalers reported that it was important to set prices that would allow them to maintain some inventory but not be left with spoiled produce – and that this was the same whether prices were rising or falling. While the interviewed wholesalers generally said that they used the same pricing strategy for all three vegetables, some indicated that the high perishability of romaine lettuce made inventory management a particularly important consideration for its pricing. Thus, inventory management can be considered highly relevant to vertical price transmission in the California fresh vegetable industry, but it is unclear if inventory management in fact acts as a driver of asymmetry. Wholesaler price adjustments in response to FOB price shocks aim to both minimize the risk of spoiled unsold inventory and to avoid running out of inventory – and these opposing inventory management-driven motivations may neutralize each other. Inventory management could result in distributed lag effect asymmetry, cumulated impact asymmetry using period-to-period or cumulative models, or equilibrium adjustment path asymmetry – yet the presence of inventory management strategies does not necessarily imply the presence of any type of asymmetry.

The wholesale interviews focused on gathering information that was not readily available from other sources. There are some published papers that gathered information via produce wholesaler interviews (Calvin et al., 2001; Roberta L Cook, 2004), but these were published over a decade ago and they do not focus on the selected vegetables or on wholesaler pricing behavior. The interview responses thus provide information on wholesale pricing and motivations that is rarely described outside of the industry itself.

6.1.4 Conclusion on Research Question 4: What is the empirical evidence on asymmetric price transmission in fresh vegetable markets of California?

For the fourth research question, USDA price data was used to develop a volume-weighted average of various shipping point prices and to gather Los Angeles terminal market prices from 2007-2017. Distributed lag effect asymmetry was found among lettuce and broccoli, with positive changes more strongly transmitted than negative changes, while distributed lag effect asymmetry was not found for celery. No equilibrium adjustment path asymmetry was found for any of the vegetables. Cumulative asymmetry was found for all three vegetables, using a cumulated model. For each vegetable, cumulative positive changes were more strongly transmitted than cumulative negative changes.

This section adds to the body of empirical price transmission research in fresh produce markets. Distributed lag effect asymmetry and cumulative asymmetry were also found by Girapunthong et al. (2003) in their study of farm-wholesale price transmission in the US fresh tomato market, and Ahn and Lee (2015) also identified distributed lag effect asymmetry and cumulative asymmetry in their study of FOB-wholesale price transmission in the US apple, peach, and grape markets.

6.1.5 Conclusion on Research Objective

The research objective of this paper is to critically examine the leading hypotheses for the drivers behind vertical price transmission asymmetry and assess their applicability to California fresh vegetable supply chains. Three of the leading theoretical drivers of agri-food price transmission – sticky prices, government intervention, and non-competitive markets – were determined not to be relevant for US FOB-wholesale vegetable price transmission. This indicates that theories for price transmission asymmetry must be carefully developed in the context of a market, as these theoretical mechanisms have somewhat limited applicability. Of the four drivers examined, one was considered important by wholesalers: inventory management. Wholesalers emphasized that both maintaining stock and avoiding spoilage were important considerations in their pricing decisions. Because these opposing motivations are both present, they may counteract or partially mask each other's influence on pricing decisions; they render the inventory management hypothesis difficult to interpret. Without empirical analysis, the presence or absence of any type of asymmetric price transmission cannot be established.

The econometric analysis did identify two types of asymmetry. At a given instant in time, positive shipping point price changes are more fully transmitted (than negative shipping point price changes) to wholesale prices for romaine lettuce and broccoli. These differing influences are also evident over the long-run; cumulative shipping point price changes are more fully transmitted to wholesale prices for romaine lettuce, celery, and broccoli. The fact that positive shipping point prices have a stronger impact on wholesale prices suggests that maintaining stock (and thus decreasing prices gradually and increasing prices more rapidly) is the most influential driver of asymmetry present in the market for these vegetables.

6.2 Limitations

The research process did face certain limitations. Publicly available data on market concentration in this industry is limited, and some (e.g. membership, prices, and market share of certain producer's cooperatives) can be tightly guarded. For example, wholesaler market share could not be estimated by asking wholesalers or academic researchers, accessing public statistics, or reviewing published literature; this information was either unknown or kept confidential. A comprehensive insight into the market structure would have enabled a more rigorous comparison of interview results and external data. Descriptions of the industry use various terms, making comparison between resources a challenge; for example, wholesalers are variously referred to as "wholesalers," "merchant wholesalers," "jobbers," "receivers," "distributors" – all of which have slightly different meanings. Furthermore, statistics of agricultural production volumes also vary between sources, so these are best interpreted as estimates. Blue Book provides more comprehensive analysis of the industry than any other single source, but identifying the wholesalers trading a specific vegetable is a challenge because while some firms list all the individual commodities they trade, others simply identify themselves as fruit and vegetable wholesalers.

Most limitations in Chapter 4 of the research were associated with the small group of firms that met the selection criteria and were thus eligible for interviewing. Combined with the low response rate, the sample size was very low and the initial plans for quantitative analysis of a structured survey had to be altered. While the semi-structured interviews were informative for understanding the vegetable pricing process, the evidence produced was more anecdotal than originally intended, and meaningful quantitative survey analysis was not possible. The survey/interview was designed to be brief in order to encourage more responses, but this also means that certain questions had to be prioritized at the expense of a more holistic picture of wholesaler pricing behavior. The presence of social desirability bias is a possibility, as interviewees may have downplayed the market power that wholesalers have.

As noted in Chapter 3, the importance of public FOB and wholesale terminal markets is declining in the fresh produce industry, and thus these prices only represent a subset of produce transactions. FOB prices represent sales from both independent growers and integrated grower-shippers, but only

about 25% of fresh lettuce, celery, and broccoli passes through wholesale markets – which limits the generalizability of results and lowered the external validity more than any other limitation faced by this thesis. Of course, price data in itself is an imperfect representation of the market and is only one indicator of the interactions within an industry. The quality and comparability of publicly available data was also limited. While there is frequently reported data available from the USDA Agricultural Marketing Service, the shipping points aren't always consistent – for example, volume data was reported separately for Coachella Valley, Imperial Valley, and Western Arizona, but price data was only available for the aggregate of all three. With regards to the data aggregation method, because the data used volume estimates to weight the shipping point prices at various locations (and these data points didn't correspond at every period), adjusted weighted averages were used. When there was price data for 90% of shipments by volume at a given time, the data adjustment process was based on the assumption that the remaining 10% had the same price as the weighted average.

6.3 Recommendations

This thesis found price transmission asymmetry in this sector to be primarily driven by wholesaler desire to maintain stock. While the pricing decisions that create this asymmetry are an efficient inventory management strategy for wholesalers under current conditions, purchasers from wholesalers could benefit from changing these conditions. Currently, wholesalers place phone calls to various industry contacts in order to forecast future supply and demand; a more comprehensive and easily accessible system (like a website that publishes up-to-date price and harvest data from many grower-shippers) would enable wholesalers to better plan their purchases without needing to inflate prices to ensure that they do not run out of stock.

Moreover, the interviews and price data revealed that fresh vegetable wholesalers are often able to take advantage of delayed circulation of price information among their customers and continue to sell at a higher price for a short time after the FOB price decreases. Customers at terminal markets, therefore, could benefit from paying more attention to FOB price decreases and publicly available market reports.

As noted in the introduction, identifying price transmission asymmetry and the mechanisms behind it has important implications for policy. Asymmetry driven by non-competitive markets represents inefficiency and could call for increased regulation; however, the presence of inventory-management-driven asymmetry is not an indicator of an inefficient market and is not a cause for concern or increased regulation. However, while this research identified price transmission asymmetry driven only by inventory management strategies, the fresh produce industry is changing rapidly and ongoing monitoring is necessary so that policymakers can make decisions based on up-to-date information. Further research would be aided by the provision of increased public data on the fresh produce market. Specifically, more data is needed at the retail level, as terminal markets are declining in relevance and this trend is expected to continue. Currently, USDA retail-level price data is only available monthly and for a few large regions; by contrast, daily location-specific price data is provided at the FOB and terminal market levels. Likewise, tracking and disseminating information on the market shares of firms in this industry would enable policies to be effectively designed in light of the existing market structure.

Appendix

Appendix 1: Seasonal Shipment Volumes of Broccoli, Celery, and Romaine Lettuce

Appendix 1.1 Broccoli

According to a 1996 report from the University of California, 40% of California's broccoli came from the Central Coast (year-round) and 30% came from the Southern Coast (year-round). The remainder was split evenly between the Central Valley (between October and December) and the Southern Deserts (between December and March) (Le Strange et al., 1996). As shown in the figure below, which tracks national broccoli shipments, while the Central Coast continues to supply about 40% of broccoli, coastal production drops off in the wintertime and the Southern Deserts and Arizona become the nation's dominant broccoli producers. About 20% of broccoli is produced year-round on the Southern Coast, and the Central Valley is not a major production region.

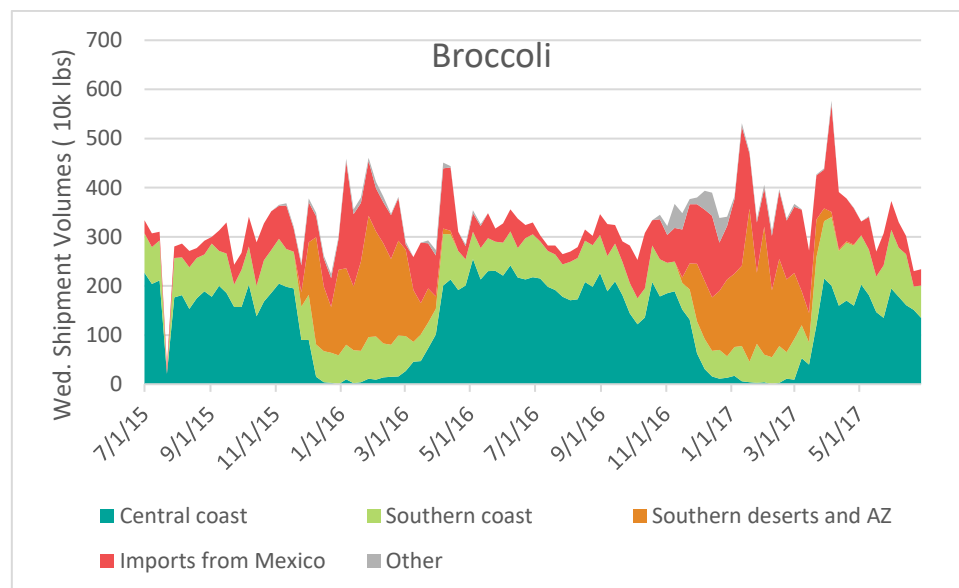


Figure 7: US Seasonal Shipment Volumes of Broccoli. Figure created by author based on USDA Agricultural Marketing Service (2017)

Appendix 1.2 Romaine Lettuce

In 1996, more than half of California's romaine lettuce was produced on the Central Coast (between April and November), although there was a longer season of lower-volume production that took place on the Southern Coast (between February and December). In the winter, production moved to the Southern Deserts (between December and March), and in the transition period between the coast and the desert, lettuce was harvested from the Central Valley (in October, November, and April) (Jackson et al., 1996). As shown in the figure below, while year-round production continues on the Southern Coast and there is some lettuce production in the Central Valley in the spring and fall, about half of the lettuce produced in the US is grown on the Central Coast from April to November, and nearly half of the lettuce produced is grown in the Southern Deserts and Arizona between November and April.

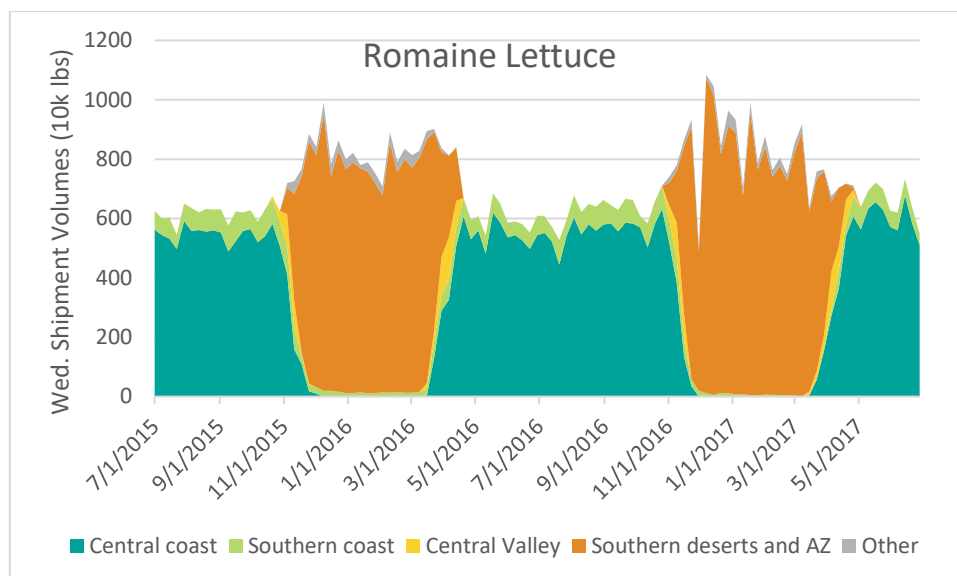


Figure 8: US Seasonal Shipment Volumes of Romaine Lettuce. Figure created by author based on USDA Agricultural Marketing Service (2017)

Appendix 1.3 Celery

In 1996, celery was produced primarily in Central Coast (between June and December) and the Southern Coast (between November and July), with these two regions accounting for nearly 80% of California's celery production. The winter supply was grown in the Southern Deserts (between December and March) (Koike et al., 1996). As shown in the figure below, production patterns remain fairly similar today. Year-round production in the Southern Coast accounts for about 50% of the nation's celery shipments, and another 30% is provided by the Central Coast from June to December. Production in the Southern Deserts and Arizona is now year-round, although it peaks in the winter, and there is also winter production in other regions, including Florida and Mexico.

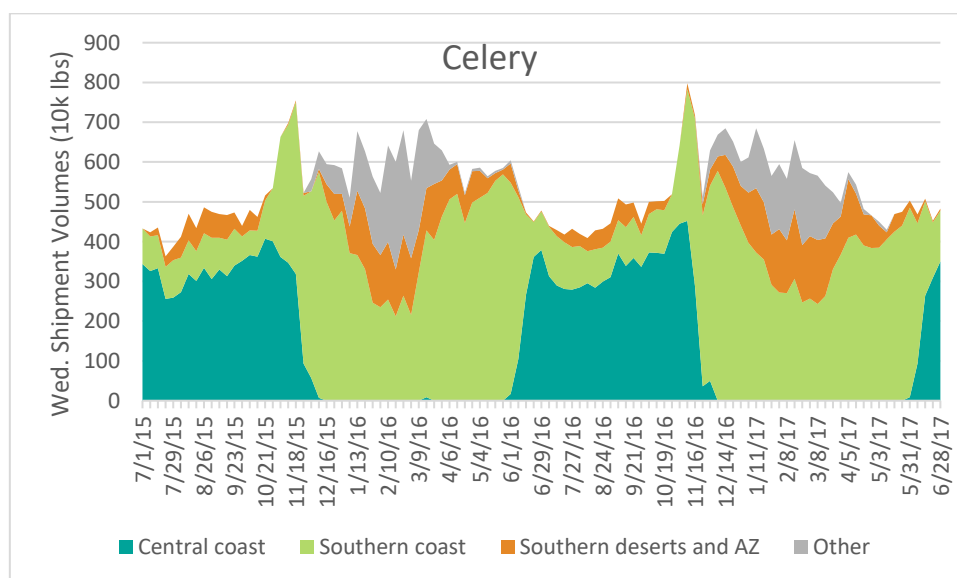


Figure 9: US Seasonal Shipment Volumes of Celery. Figure created by author based on USDA Agricultural Marketing Service (2017)

Appendix 2: Wholesaler Survey Questions

1a. To what extent do the following factors affect how you determine your daily selling prices during a period of *below-average supply* and *above-average demand*?

(Rating choices: Not important/slightly important/moderately important/important/very important)

- Recent price changes among buyers (e.g. retailers)
- Recent price changes among suppliers (e.g. grower-shippers)
- Recent changes in quantity supplied (e.g. among grower-shippers)
- Recent changes in quantity demanded (e.g. among retailers)
- The quality of the available supply
- Short-run variations in my handling costs
- The development of the reference price I use
- Current prices of other wholesalers
- The perishability of the vegetable
- The size of my current inventory

1b. To what extent do the following factors affect how you determine your daily selling prices during a period of *above-average supply* and *below-average demand*?

(Rating choices: Not important/slightly important/moderately important/important/very important)

- Recent price changes among buyers (e.g. retailers)
- Recent price changes among suppliers (e.g. grower-shippers)
- Recent changes in quantity supplied (e.g. among grower-shippers)
- Recent changes in quantity demanded (e.g. among retailers)
- The quality of the available supply
- Short-run variations in my handling costs
- The development of the reference price I use
- Current prices of other wholesalers
- The perishability of the vegetable
- The size of my current inventory

1c. What other factors do you use to determine your selling prices? Could you name and explain them briefly?

(Open-answer question)

1d. Do you take different factors into consideration for pricing celery vs broccoli vs romaine lettuce? If so, how do they differ?

(Open-answer question)

2a. When FOB prices for celery *fall* by 15%, how much do you *decrease* your selling prices? (Choices: Less than 15% - 15% exactly - More than 15%)

2b. To what extent do the following factors affect how much you *decrease* your celery selling prices?

(Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

2c. When FOB prices for celery fall, how quickly do you decrease your selling prices?

(Choices: Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

3a. When FOB prices for celery *rise* by 15%, how much do you *increase* your selling prices? (Choices: Less than 15% - 15% exactly - More than 15%)

3b. To what extent do the following factors affect how much you *increase* your celery selling prices? (Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

2c. When FOB prices for celery rise, how quickly do you increase your selling prices? (Choices: Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

4a. When FOB prices for broccoli *fall* by 15%, how much do you *decrease* your selling prices? (Choices: Less than 15% - 15% exactly - More than 15%)

4b. To what extent do the following factors affect how much you *decrease* your broccoli selling prices?

(Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

4c. When FOB prices for broccoli fall, how quickly do you decrease your selling prices? (Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

5a. When FOB prices for broccoli *rise* by 15%, how much do you *increase* your selling prices? (Choices: Less than 15% - 15% exactly - More than 15%)

5b. To what extent do the following factors affect how much you *increase* your broccoli selling prices?

(Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

5c. When FOB prices for broccoli rise, how quickly do you increase your selling prices? (Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

6a. When FOB prices for romaine lettuce *fall* by 15%, how much do you *decrease* your selling prices? (Choices: Less than 15% - 15% exactly - More than 15%)

6b. To what extent do the following factors affect how much you *decrease* your romaine lettuce selling prices?

(Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

6c. When FOB prices for romaine lettuce fall, how quickly do you decrease your selling prices?

(Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

7a. When FOB prices for romaine lettuce *rise* by 15%, how much do you *increase* your selling prices?

(Choices: Less than 15% - 15% exactly - More than 15%)

7b. To what extent do the following factors affect how much you *increase* your romaine lettuce selling prices?

(Rating choices: Strongly disagree/disagree/neutral/agree/strongly agree)

- I want to avoid undercutting other wholesalers and driving wholesale margins down
- I want to keep my prices competitive with other wholesalers
- I want to minimize risk of spoiled unsold inventory
- I want to avoid running out of inventory

7c. When FOB prices for romaine lettuce rise, how quickly do you increase your selling prices?

(Immediately/later in the same day/within 2-3 days/within 4-7 days/within more than 7 days)

Comments (optional):

8a. For sales of the same volume and quality, do you fix your selling price each day or do you negotiate it individually for each transaction?

(Choices: Fixed selling price for one day/ Varying selling prices depending on negotiation with the client)

8b. For these individual negotiations, which factors are important? Do you consider different factors for celery vs romaine lettuce vs broccoli? (optional)

(Open-answer question)

9a. To what extent do the following groups influence FOB prices?

(Rating choices: Does not influence prices/influences prices slightly/influences prices moderately/influences prices strongly/determines prices completely)

- Growers
- Shippers
- Wholesalers
- Retailers
- Foodservice

10a. What sources do you use to learn about quantity and price changes in celery, lettuce, and broccoli *supply*?

10a. What sources do you use to learn about quantity and price changes in celery, lettuce, and broccoli *demand*?

11a. What percentage of the market do the 5 biggest California romaine lettuce wholesalers control? Please provide an estimate:

11d. What percentage of the market do the 5 biggest California broccoli wholesalers control? Please provide an estimate:

11c. What percentage of the market do the 5 biggest California celery wholesalers control? Please provide an estimate:

Appendix 3: Description of Data

The price and volume data were extracted from the Agricultural Marketing Service's website using web scraping.

Data period: Wednesdays from July 1 2007-July 1 2017. No prices were recorded on the Agricultural Marketing Service on July 4 2007, November 11 2009, July 4 2012, October 2, 9, and 16 2013, December 25 2013, January 1 2014, November 11 2015, November 25 2015, and May 18 2016. For these weeks, data was collected from Tuesday or the next-closest date. Using prices of the aggregated production areas, there is shipping point and terminal market price data for every week in the data period for all vegetables.

	Package type	Size	Type	Shipping point
Celery	Cartons	2 dz	Conventional	Oxnard; Santa Maria; Salinas-Watsonville; Imperial and Coachella Valleys (2008-2009) and Coachella Valley and Arizona (2011-2017)
Lettuce	Cartons	24s	Conventional	Oxnard; Salinas-Watsonville; Imperial, Coachella, and Palo Verde Valleys (2007-2012) and Imperial and Coachella Valleys (2013-2017); Santa Maria; San Joaquin Central Valley; Western Arizona
Broccoli	Cartons	Bchd 14s	Conventional	Salinas-Watsonville; Santa Maria; Imperial and Coachella Valleys (2008-2009) and Coachella Valley & Arizona (2011-2017)

Appendix 4: Lag Order Selection

Appendix 4.1 Akaike's Information Criterion for Shipping Point and Terminal Market Pairs (used to test Granger Causality)

	Lag 1	Lag 2	Lag 3	Lag 4	Lag 5	Lag 6
Romaine Lettuce	9.1991	9.0386	9.0218	9.0197	8.9999*	9.0038
Broccoli	8.7063	8.6054	8.5212*	8.5309	8.5355	8.5449
Celery	8.9668	8.7737	8.7493	8.7480	8.7373*	8.7469

Appendix 4.2 Information Criteria for Lag Selection for Eq. 8

. varsoc celery_tm L.celery_tm d_celery_p d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-4997.67	2759.38	19.2743	19.2871	19.307			

. varsoc celery_tm L.celery_tm L(0/1).d_celery_p d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-5946.69	6568.99	22.9795	22.9956	23.0205			

. varsoc celery_tm L.celery_tm d_celery_p L(0/1).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-6053.08	9469.21	23.3452	23.3612	23.3861			

. varsoc celery_tm L.celery_tm L(0/1).d_celery_p
L(0/1).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-6990.07	21689.6	27.0119	27.0311	27.0611			

. varsoc celery_tm L.celery_tm L(0/1).d_celery_p
L(0/2).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8041.26	73808.8	31.0744	31.0969	31.1318			

. varsoc celery_tm L.celery_tm L(0/1).d_celery_p
L(0/3).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9053.86	231545	35.0555	35.0813	35.1213			

. varsoc celery_tm L.celery_tm L(0/2).d_celery_p
L(0/1).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-7930.38	51041.9	30.7055	30.7281	30.7631			

. varsoc celery_tm L.celery_tm L(0/2).d_celery_p
L(0/2).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8970.42	167671	34.7328	34.7585	34.7985			

. varsoc celery_tm L.celery_tm L(0/2).d_celery_p
L(0/3).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9992.72	514258	38.6914	38.7204	38.7653			

+-----+

. varsoc celery_tm L.celery_tm L(0/3).d_celery_p
L(0/1).d_celery_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8863.29	118403	34.3849	34.4107	34.4507			

. varsoc celery_tm L.celery_tm L(0/3).d_celery_p
L(0/2).d_celery_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9896.71	382061	38.3942	38.4233	38.4683			

. varsoc celery_tm L.celery_tm L(0/3).d_celery_p
L(0/3).d_celery_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10907.3	1.1e+06	42.3152	42.3474	42.3975			

. varsoc celery_tm L(1/2).celery_tm L(0/1).d_celery_p
L(0/1).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8065.25	80970.5	31.167	31.1895	31.2244			

. varsoc celery_tm L(1/2).celery_tm L(0/1).d_celery_p
L(0/2).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9110.71	269506	35.2074	35.2331	35.273			

. varsoc celery_tm L(1/2).celery_tm L(0/1).d_celery_p
L(0/3).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10121.7	846855	39.1902	39.2192	39.2641			

. varsoc celery_tm L(1/2).celery_tm L(0/2).d_celery_p
L(0/1).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9001.65	189198	34.8536	34.8793	34.9193			

. varsoc celery_tm L(1/2).celery_tm L(0/2).d_celery_p
L(0/2).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10037.1	610525	38.863	38.8919	38.9369			

. varsoc celery_tm L(1/2).celery_tm L(0/2).d_celery_p
L(0/3).d_celery_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11059.4	1.9e+06	42.8215	42.8537	42.9036			

```
. varsoc celery_tm L(1/2).celery_tm L(0/3).d_celery_p
L(0/1).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -9932.94 439663 38.5347 38.5637 38.6087 |
+-----+
```

```
. varsoc celery_tm L(1/2).celery_tm L(0/3).d_celery_p
L(0/2).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -10961.5 1.4e+06 42.5253 42.5576 42.6076 |
+-----+
```

```
. varsoc celery_tm L(1/2).celery_tm L(0/3).d_celery_p
L(0/3).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11972.1 4.1e+06 46.446 46.4815 46.5365 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/1).d_celery_p
L(0/1).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -9415.36 937530 36.454 36.4798 36.5198 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/1).d_celery_p
L(0/2).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -10256.2 1.4e+06 39.7106 39.7395 39.7845 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/1).d_celery_p
L(0/3).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11272.5 4.3e+06 43.6462 43.6784 43.7283 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/2).d_celery_p
L(0/1).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -10280.9 1.6e+06 39.8061 39.8351 39.8801 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/2).d_celery_p
L(0/2).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11085.6 2.1e+06 42.9228 42.955 43.005 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/2).d_celery_p
L(0/3).d_celery_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12101.9 6.2e+06 46.8584 46.8938 46.9488 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/3).d_celery_p
L(0/1).d_celery_m
```

```
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11199.1 3.5e+06 43.4462 43.4784 43.5285 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/3).d_celery_p
L(0/2).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12002.6 4.6e+06 46.5643 46.5997 46.6548 |
+-----+
```

```
. varsoc celery_tm L(1/3).celery_tm L(0/3).d_celery_p
L(0/3).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -13009.1 1.3e+07 50.4692 50.5079 50.568 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/1).d_celery_p
L(0/1).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -10752.7 1.1e+07 41.7122 41.7412 41.7862 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/1).d_celery_p
L(0/2).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11579.6 1.5e+07 44.921 44.9532 45.0032 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/1).d_celery_p
L(0/3).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12414.1 2.3e+07 48.1595 48.1949 48.25 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/2).d_celery_p
L(0/1).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -11617 1.8e+07 45.0658 45.098 45.1481 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/2).d_celery_p
L(0/2).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12404.8 2.2e+07 48.1234 48.1589 48.214 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/2).d_celery_p
L(0/3).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -13235.8 3.2e+07 51.348 51.3867 51.4467 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/3).d_celery_p
L(0/1).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12469.8 2.8e+07 48.3754 48.4108 48.4659 |
+-----+
```

```
. varsoc celery_tm L(1/4).celery_tm L(0/3).d_celery_p
L(0/2).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
```

```

|-----+
| 0 | -13249.1 3.4e+07 51.3997 51.4384 51.4984 |
+-----+

```

```

. varsoc celery_tm L(1/4).celery_tm L(0/3).d_celery_p
L(0/3).d_celery_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -14045.5 4.4e+07 54.4902 54.5321 54.5972 |
+-----+

```

```

varsoc lettuce_tm L.lettuce_tm d_lettuce_p d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -5053.51 3421.87 19.4895 19.5023 19.5222 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/1).d_lettuce_p
d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -6058.93 10132.3 23.4129 23.4289 23.4539 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -6133.55 12912 23.6553 23.6713 23.6963 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/1).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -7124.13 36394.7 27.5294 27.5487 27.5787 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/1).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -8199.31 135869 31.6846 31.7071 31.742 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/1).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -9258.7 511422 35.848 35.8737 35.9137 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/2).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -8127.38 109370 31.4676 31.4902 31.5251 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/2).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+

```

```

| 0 | -9187.23 387894 35.5715 35.5973 35.6372 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/2).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+

```

```

|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -10259 1.4e+06 39.7213 39.7503 39.7953 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/3).d_lettuce_p
L(0/1).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -9128.18 330559 35.4116 35.4374 35.4774 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/3).d_lettuce_p
L(0/2).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -10184.8 1.2e+06 39.5108 39.5398 39.5848 |
+-----+

```

```

. varsoc lettuce_tm L.lettuce_tm L(0/3).d_lettuce_p
L(0/3).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -11242.2 4.1e+06 43.6133 43.6455 43.6956 |
+-----+

```

```

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/1).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -8219.46 146860 31.7624 31.7849 31.8198 |
+-----+

```

```

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/1).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -9286.11 530494 35.8846 35.9103 35.9502 |
+-----+

```

```

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/1).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -10343.9 2.0e+06 40.0499 40.0789 40.1238 |
+-----+

```

```

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/2).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -9215.47 432666 35.6807 35.7065 35.7465 |
+-----+

```

```

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/2).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+
| 0 | -10269.3 1.5e+06 39.7612 39.7901 39.8351 |
+-----+

```

```

+-----+
. varsoc lettuce_tm L(1/2).lettuce_tm L(0/2).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11341 5.6e+06 43.911 43.9432 43.9932 |
+-----+

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/3).d_lettuce_p
L(0/1).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -10208.5 1.3e+06 39.6028 39.6318 39.6768 |
+-----+

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/3).d_lettuce_p
L(0/2).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11257.8 4.4e+06 43.6738 43.706 43.7561 |
+-----+

. varsoc lettuce_tm L(1/2).lettuce_tm L(0/3).d_lettuce_p
L(0/3).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -12314.9 1.6e+07 47.7749 47.8104 47.8654 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/1).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -9540.78 1.5e+06 36.9392 36.965 37.0049 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/1).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -10465.4 3.2e+06 40.5199 40.5489 40.5939 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/1).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11530 1.2e+07 44.6423 44.6745 44.7245 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/2).d_lettuce_p
L(0/1).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -10437.3 2.9e+06 40.4112 40.4402 40.4851 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/2).d_lettuce_p
L(0/2).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11339.1 5.5e+06 43.9037 43.9359 43.9859 |
+-----+

```

```

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/2).d_lettuce_p
L(0/3).d_lettuce_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -12402.3 2.0e+07 48.0207 48.0561 48.111 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/3).d_lettuce_p
L(0/1).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11418.1 8.2e+06 44.295 44.3273 44.3773 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/3).d_lettuce_p
L(0/2).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -12318.3 1.6e+07 47.7881 47.8235 47.8786 |
+-----+

. varsoc lettuce_tm L(1/3).lettuce_tm L(0/3).d_lettuce_p
L(0/3).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -13369.8 5.4e+07 51.8673 51.9059 51.966 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/1).d_lettuce_p
L(0/1).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -10896.4 1.8e+07 42.2689 42.2979 42.3429 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/1).d_lettuce_p
L(0/2).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11777.6 3.3e+07 45.6885 45.7208 45.7708 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/1).d_lettuce_p
L(0/3).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -12705.5 7.1e+07 49.2888 49.3243 49.3793 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/2).d_lettuce_p
L(0/1).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -11791 3.5e+07 45.7403 45.7725 45.8226 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/2).d_lettuce_p
L(0/2).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -12648.8 5.7e+07 49.0691 49.1046 49.1596 |
+-----+

. varsoc lettuce_tm L(1/4).lettuce_tm L(0/2).d_lettuce_p
L(0/3).d_lettuce_m
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
+-----+
| 0 | -13570.4 1.2e+08 52.6448 52.6835 52.7436 |
+-----+

```

```
. varsoc lettuce_tm L(1/4).lettuce_tm L(0/3).d_lettuce_p
L(0/1).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -12702.4 7.0e+07 49.2769 49.3123 49.3674 |
+-----+
```

```
. varsoc lettuce_tm L(1/4).lettuce_tm L(0/3).d_lettuce_p
L(0/2).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -13533.6 1.0e+08 52.5023 52.541 52.6011 |
+-----+
```

```
. varsoc lettuce_tm L(1/4).lettuce_tm L(0/3).d_lettuce_p
L(0/3).d_lettuce_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -14429.9 1.9e+08 55.9803 56.0223 56.0873 |
+-----+
```

```
varsoc broccoli_tm L.broccoli_tm d_broccoli_p d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -4648.58 718.748 17.929 17.9419 17.9618 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/1).d_broccoli_p
d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -5533.58 1332.87 21.3845* 21.4005* 21.4255* |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm d_broccoli_p
L(0/1).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -5664.16 2115.58 21.8465 21.8625 21.8874 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/1).d_broccoli_p
L(0/1).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -6532.45 3706.04 25.245* 25.2643* 25.2942* |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/1).d_broccoli_p
L(0/2).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -7573.56 12130 29.2686* 29.2911* 29.326* |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/1).d_broccoli_p
L(0/3).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -8601.27 40203.3 33.3047 33.3305 33.3705 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/2).d_broccoli_p
L(0/1).d_broccoli_m,
```

```
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -7356.11 5534.92 28.484 28.5065 28.5415 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/2).d_broccoli_p
L(0/2).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -8377.63 16925.3 32.4396 32.4653 32.5053 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/2).d_broccoli_p
L(0/3).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -9415.83 55203.5 36.4597 36.4887 36.5336 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/3).d_broccoli_p
L(0/1).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -8170.68 8081.04 31.7003 31.7261 31.7661 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/3).d_broccoli_p
L(0/2).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -9190.19 24707.7 35.6558 35.6848 35.7298 |
+-----+
```

```
. varsoc broccoli_tm L.broccoli_tm L(0/3).d_broccoli_p
L(0/3).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -10208.6 75210.8 39.6068 39.6391 39.6891 |
+-----+
```

```
. varsoc broccoli_tm L(1/2).broccoli_tm L(0/1).d_broccoli_p
L(0/1).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -7640.75 15722.3 29.528* 29.5505* 29.5854* |
+-----+
```

```
. varsoc broccoli_tm L(1/2).broccoli_tm L(0/1).d_broccoli_p
L(0/2).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -8636.81 43245 33.3777* 33.4034* 33.4433* |
+-----+
```

```
. varsoc broccoli_tm L(1/2).broccoli_tm L(0/1).d_broccoli_p
L(0/3).d_broccoli_m,
+-----+
|lag| LL LR df p FPE AIC HQIC SBIC |
|---+-----|
| 0 | -9662.32 143247 37.4132 37.4422 37.4872 |
+-----+
```

```
. varsoc broccoli_tm L(1/2).broccoli_tm L(0/2).d_broccoli_p
L(0/1).d_broccoli_m,
+-----+
```

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8448.01	22221.9	32.7119		32.7376	32.7776		

. varsoc broccoli_tm L(1/2).broccoli_tm L(0/2).d_broccoli_p L(0/2).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9433.5	59109.9	36.528		36.557	36.602		

. varsoc broccoli_tm L(1/2).broccoli_tm L(0/2).d_broccoli_p L(0/3).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10471	192272	40.5454		40.5776	40.6276		

. varsoc broccoli_tm L(1/2).broccoli_tm L(0/3).d_broccoli_p L(0/1).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9260.64	32465.4	35.9288		35.9578	36.0029		

. varsoc broccoli_tm L(1/2).broccoli_tm L(0/3).d_broccoli_p L(0/2).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10244.4	86417	39.7457		39.778	39.828		

. varsoc broccoli_tm L(1/2).broccoli_tm L(0/3).d_broccoli_p L(0/3).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11262.2	262448	43.6945		43.7299	43.785		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/1).d_broccoli_p L(0/1).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-8908.83	132122	34.4945		34.5203	34.5602		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/1).d_broccoli_p L(0/2).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9757.64	207123	37.782		37.8109	37.8559		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/1).d_broccoli_p L(0/3).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10749.3	564291	41.6221		41.6543	41.7043		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/2).d_broccoli_p L(0/1).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0								

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-9678.17	152305	37.4745		37.5035	37.5485		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/2).d_broccoli_p L(0/2).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10522.6	234722	40.7449		40.7771	40.8271		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/2).d_broccoli_p L(0/3).d_broccoli_m,

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11511.5	632766	44.5745		44.6099	44.6649		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/3).d_broccoli_p L(0/1).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10478.7	214300	40.6539		40.6861	40.7362		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/3).d_broccoli_p L(0/2).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11309.9	315722	43.8793		43.9147	43.9698		

. varsoc broccoli_tm L(1/3).broccoli_tm L(0/3).d_broccoli_p L(0/3).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-12290.4	829900	47.6836		47.7223	47.7823		

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/1).d_broccoli_p L(0/1).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10173	1.1e+06	39.4653		39.4943	39.5393		

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/1).d_broccoli_p L(0/2).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11020.1	1.7e+06	42.7524		42.7847	42.8347		

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/1).d_broccoli_p L(0/3).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-11869.8	2.8e+06	46.0495		46.0849	46.14		

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/2).d_broccoli_p L(0/1).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-10940.8	1.3e+06	42.4451		42.4774	42.5274		

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/2).d_broccoli_p L(0/2).d_broccoli_m

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0								

```

|-----+-----|
| 0 | -11783.4 2.0e+06 45.7147 45.7502 45.8052 |
|-----+-----|

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/2).d_broccoli_p
L(0/3).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+-----|
| 0 | -12624.9 3.0e+06 48.9803 49.019 49.0791 |
|-----+-----|

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/3).d_broccoli_p
L(0/1).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+-----|
| 0 | -11712.3 1.5e+06 45.4392 45.4747 45.5297 |
|-----+-----|

```

```

+-----+-----+
. varsoc broccoli_tm L(1/4).broccoli_tm L(0/3).d_broccoli_p
L(0/2).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+-----|
| 0 | -12537.4 2.2e+06 48.641 48.6797 48.7397 |
|-----+-----|

. varsoc broccoli_tm L(1/4).broccoli_tm L(0/3).d_broccoli_p
L(0/3).d_broccoli_m
|lag| LL LR df p FPE AIC HQIC SBIC |
|-----+-----|
| 0 | -13372 3.2e+06 51.8797 51.9216 51.9867 |
|-----+-----|

```

Appendix 5: Stata Output for Equation 9 (Period-to-Period Autoregressive Model)

Source	SS	df	MS	Number of obs	=	521
Model	22125.7325	3	7375.24416	F(3, 517)	=	1425.29
Residual	2675.24214	517	5.17454959	Prob > F	=	0.0000
				R-squared	=	0.8921
				Adj R-squared	=	0.8915
Total	24800.9746	520	47.694182	Root MSE	=	2.2748

lettuce_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
lettuce_tm L1.	.9519077	.0172197	55.28	0.000	.9180786	.9857368
d_lettuce_p	.9398771	.0506184	18.57	0.000	.840434	1.03932
d_lettuce_m	.7649515	.0557804	13.71	0.000	.6553675	.8745356
_cons	.5301997	.2423216	2.19	0.029	.0541436	1.006256

. test(d_lettuce_m=d_lettuce_p)

(1) - d_lettuce_p + d_lettuce_m = 0

F(1, 517) = 4.15
Prob > F = 0.0422

Source	SS	df	MS	Number of obs	=	521
Model	6582.58424	3	2194.19475	F(3, 517)	=	356.09
Residual	3185.68993	517	6.16187608	Prob > F	=	0.0000
				R-squared	=	0.6739
				Adj R-squared	=	0.6720
Total	9768.27417	520	18.7851426	Root MSE	=	2.4823

broccoli_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
broccoli_tm L1.	.8435254	.032078	26.30	0.000	.7805061	.9065447
d_broccoli_p	.7822599	.0672522	11.63	0.000	.6501387	.914381
d_broccoli_m	.4296314	.0753073	5.71	0.000	.2816854	.5775773
_cons	1.615734	.3719645	4.34	0.000	.8849864	2.346482

. test(d_broccoli_m=d_broccoli_p)

(1) - d_broccoli_p + d_broccoli_m = 0

F(1, 517) = 9.22
Prob > F = 0.0025

Source	SS	df	MS	Number of obs	=	521
Model	27436.3563	3	9145.4521	F(3, 517)	=	1832.89
Residual	2579.6413	517	4.989635	Prob > F	=	0.0000
				R-squared	=	0.9141
				Adj R-squared	=	0.9136
Total	30015.9976	520	57.7230723	Root MSE	=	2.2337

celery_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
celery_tm L1.	.9891664	.0158115	62.56	0.000	.9581038	1.020229
d_celery_p	.90001	.0556012	16.19	0.000	.7907779	1.009242
d_celery_m	.9810411	.0593079	16.54	0.000	.864527	1.097555
_cons	.2317711	.2248046	1.03	0.303	-.2098717	.6734138

```
. test( d_celery_m= d_celery_p)
```

```
( 1) - d_celery_p + d_celery_m = 0
```

```
      F( 1, 517) =    0.75
      Prob > F =    0.3867
```

Appendix 6: Stata Output for Equation 11 (Partial Adjustment Model)

```
. reg lettuce_tm lettuce_sp
```

Source	SS	df	MS	Number of obs	=	522
Model	22862.3505	1	22862.3505	F(1, 520)	=	6001.90
Residual	1980.77513	520	3.80918295	Prob > F	=	0.0000
				R-squared	=	0.9203
				Adj R-squared	=	0.9201
Total	24843.1256	521	47.6835425	Root MSE	=	1.9517

lettuce_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
lettuce_sp	.9421925	.0121617	77.47	0.000	.9183004	.9660847
_cons	2.905272	.1721715	16.87	0.000	2.567035	3.243509

```
. reg lettuce_tm L1.lettuce_tm L1.resplus L1.resminus
```

Source	SS	df	MS	Number of obs	=	521
Model	19659.6743	3	6553.22476	F(3, 517)	=	658.98
Residual	5141.30035	517	9.9444881	Prob > F	=	0.0000
				R-squared	=	0.7927
				Adj R-squared	=	0.7915
Total	24800.9746	520	47.694182	Root MSE	=	3.1535

lettuce_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
lettuce_tm L1.	.7832029	.0213703	36.65	0.000	.7412196	.8251862
resplus L1.	-.6842927	.1175222	-5.82	0.000	-.9151724	-.4534131
resminus L1.	-.810083	.1183882	-6.84	0.000	-1.042664	-.577502
_cons	3.557617	.3692289	9.64	0.000	2.832243	4.28299

```
.
. test (L1.resplus= L1.resminus)
```

```
( 1) L.resplus - L.resminus = 0
```

```
F( 1, 517) = 0.39
Prob > F = 0.5307
```

```
. reg broccoli_tm broccoli_sp
```

Source	SS	df	MS	Number of obs	=	522
Model	7598.28689	1	7598.28689	F(1, 520)	=	1800.51
Residual	2194.43668	520	4.22007053	Prob > F	=	0.0000
				R-squared	=	0.7759
				Adj R-squared	=	0.7755
Total	9792.72357	521	18.7960145	Root MSE	=	2.0543

broccoli_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
broccoli_sp	.8976665	.0211552	42.43	0.000	.8561063	.9392266
_cons	3.373763	.2318085	14.55	0.000	2.918366	3.829159

```
. reg broccoli_tm L1.broccoli_tm L1.resplus L1.resminus
```

Source	SS	df	MS	Number of obs	=	521
Model	7037.27883	3	2345.75961	F(3, 517)	=	444.07
Residual	2730.99534	517	5.28238944	Prob > F	=	0.0000
				R-squared	=	0.7204
				Adj R-squared	=	0.7188
Total	9768.27417	520	18.7851426	Root MSE	=	2.2983

broccoli_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
broccoli_tm L1.	.7224753	.0256025	28.22	0.000	.6721777	.7727729
resplus L1.	-.9073176	.081694	-11.11	0.000	-1.067811	-.7468245
resminus L1.	-.6989234	.0813688	-8.59	0.000	-.8587775	-.5390693
_cons	4.063078	.3078542	13.20	0.000	3.458279	4.667877

```
.  
. test (L1.resplus= L1.resminus)
```

```
( 1) L.resplus - L.resminus = 0
```

```
F( 1, 517) = 2.24  
Prob > F = 0.1353
```

```
. reg celery_tm celery_sp
```

Source	SS	df	MS	Number of obs	=	522
Model	28156.3126	1	28156.3126	F(1, 520)	=	7708.32
Residual	1899.41254	520	3.65271642	Prob > F	=	0.0000
				R-squared	=	0.9368
				Adj R-squared	=	0.9367
Total	30055.7251	521	57.6885319	Root MSE	=	1.9112

celery_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
celery_sp	.9755409	.0111113	87.80	0.000	.9537123	.9973695
_cons	2.22887	.1657987	13.44	0.000	1.903152	2.554587

```
. reg celery_tm L1.celery_tm L1.resplus L1.resminus
```

Source	SS	df	MS	Number of obs	=	521
Model	25369.1194	3	8456.37313	F(3, 517)	=	940.83
Residual	4646.8782	517	8.988159	Prob > F	=	0.0000
				R-squared	=	0.8452
				Adj R-squared	=	0.8443
Total	30015.9976	520	57.7230723	Root MSE	=	2.998

celery_tm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
celery_tm L1.	.8282337	.0178069	46.51	0.000	.7932509	.8632165
resplus L1.	-.7689678	.1269642	-6.06	0.000	-1.018397	-.5195385
resminus L1.	-1.009368	.1038874	-9.72	0.000	-1.213461	-.8052747
_cons	2.868615	.3366304	8.52	0.000	2.207283	3.529947

```
.  
. test (L1.resplus= L1.resminus)
```

```
( 1) L.resplus - L.resminus = 0
```

```
F( 1, 517) = 1.55  
Prob > F = 0.2138
```

Appendix 7: Stata Output for Equation 12 (Cumulative Model)

```
. reg c_pwtlesspw0 sum_d_celery_p sum_d_celery_m
```

Source	SS	df	MS	Number of obs	=	522
Model	28195.6155	2	14097.8077	F(2, 519)	=	3933.51
Residual	1860.1096	519	3.58402621	Prob > F	=	0.0000
				R-squared	=	0.9381
				Adj R-squared	=	0.9379
Total	30055.7251	521	57.6885319	Root MSE	=	1.8932

c_pwtlesspw0	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
sum_d_celery_p	.968827	.0111915	86.57	0.000	.9468408	.9908132
sum_d_celery_m	.9666216	.0113311	85.31	0.000	.9443611	.9888821
_cons	-.633783	.171822	-3.69	0.000	-.9713351	-.2962308

```
.
. test(sum_d_celery_p = sum_d_celery_m)

( 1)  sum_d_celery_p - sum_d_celery_m = 0

      F( 1, 519) =    10.97
      Prob > F =    0.0010
```

```
. reg b_pwtlesspw0 sum_d_broccoli_p sum_d_broccoli_m
```

Source	SS	df	MS	Number of obs	=	522
Model	7636.98556	2	3818.49278	F(2, 519)	=	919.31
Residual	2155.73801	519	4.15363778	Prob > F	=	0.0000
				R-squared	=	0.7799
				Adj R-squared	=	0.7790
Total	9792.72357	521	18.7960145	Root MSE	=	2.038

b_pwtlesspw0	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
sum_d_broccoli_p	.8785513	.0219024	40.11	0.000	.835523	.9215796
sum_d_broccoli_m	.8765165	.0221023	39.66	0.000	.8330956	.9199374
_cons	-.0261771	.1840931	-0.14	0.887	-.3878364	.3354822

```
.
. test(sum_d_broccoli_p = sum_d_broccoli_m)

( 1)  sum_d_broccoli_p - sum_d_broccoli_m = 0

      F( 1, 519) =    9.32
      Prob > F =    0.0024
```

```
. reg l_pwtlesspw0 sum_d_lettuce_p sum_d_lettuce_m
```

Source	SS	df	MS	Number of obs	=	522
Model	22958.079	2	11479.0395	F(2, 519)	=	3160.46
Residual	1885.04662	519	3.63207441	Prob > F	=	0.0000
				R-squared	=	0.9241
				Adj R-squared	=	0.9238
Total	24843.1256	521	47.6835425	Root MSE	=	1.9058

l_pwtlesspw0	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
sum_d_lettuce_p	.9285973	.0121673	76.32	0.000	.9046941	.9525005
sum_d_lettuce_m	.9255599	.0123096	75.19	0.000	.9013771	.9497427
_cons	-.2226375	.1707011	-1.30	0.193	-.5579875	.1127125

```
.
```

```
. test(sum_d_lettuce_p = sum_d_lettuce_m)
```

```
( 1) sum_d_lettuce_p - sum_d_lettuce_m = 0
```

```

F( 1, 519) = 26.36
Prob > F = 0.0000

```

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Reference and in-text citation style: APA 6

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