IMPACTS OF FOOD BORNE ILLNESES ON DEMAND AND CONSUMERS' WILLINGNESS TO PAY FOR SENSORY QUALITY IN PEARS

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Abstract

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This dissertation consists of three essays. The first essay is an event analysis of the 2006 *E.coli* O157:H7 outbreak on consumer demand for spinach and lettuce products with retail scanner data. A system of multifactor economic models is formulated as the benchmark and is estimated using a structural modeling approach under a spatial error model scheme with panel data. Results indicate that there were substantial declines in demands for spinach and lettuce products. Gradual recovery patterns are observed over the event window. However, the market responses to the outbreak tended to be distinct across regions and across different categories of products in terms of the patterns and rapidity of demand recovery. In addition, markdown promotions are more effective than price adjustments as a strategy to recover consumer demand.

The second essay applies the event study method to evaluate the impact of the BSE outbreak in North America and the potential structural change in post-BSE cattle trade between the United States and Mexico by analyzing the "Abnormal Imports" of Mexican cattle during and after the period that Canadian cattle were banned. Event analysis suggests

that cattle imports from Mexico remained stable immediately after the BSE outbreak and then decreased afterwards, which suggests that the effects of higher cattle price, reinforced regulations, increase domestic beef supply, and USDA's announcement of the final minimal risk rule tended to dominate substitution effects over time, and that the effects of Canadian beef and cattle trade resumption on Mexican cattle imports are substantial.

The third essay evaluates consumers' willingness to pay (WTP) for Anjou pears with different ripening treatments. Data were collected from a sensory experiment and a consumer survey. The analysis indicates that the "treatment-induced" eating quality significantly affects consumers' WTP. The sensory characteristics *Firmness*, *Sweetness* and *Juiciness*, as well as presence of children under 18 years old in household, are influential factors in determining consumers' WTP. Mean WTP's for the four samples indicate that consumers most like the pears with 6-day ethylene treatment and on average are willing to pay a premium of $0.25/lb compared to the market price.

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CHAPTER ONE

INTRODUCTION

Motivations

Food safety is a serious issue in the United States and around the world. Food borne illness outbreaks create major impacts on human health and result in large economic losses. According to the Centers for Disease Control and Prevention (CDC), food borne illness sickens 76 million Americans, causes 325,000 hospitalizations and thousands of deaths, and costs $44 billion annually. The first two essays in this dissertation focus on analyzing the impacts of food borne illness outbreaks on consumer and import demand, with applications to the U.S. retail fresh produce markets and international cattle markets.

These studies are carried out through the implementation of the event study method. The event study method has been widely applied to price analyses, mostly to financial markets in order to analyze securities performances in response to external shocks. Some researchers have applied the event study method to agricultural markets to investigate the effects of events on prices (Mazzocchi 1999; Thomsen and McKenzie 2001). However, the event study method has rarely been applied to demand analysis owing to certain classic assumptions imposed on the traditional event study method. By relaxing some of these assumptions, this dissertation presents a feasible approach to implementing the event study method to consumer demand analysis.

The first study (chapter two) investigates the effects of the 2006 *E.coli* O157:H7 outbreak on demand for spinach and lettuce products with retail scanner data. This outbreak involved multiple states and caught the attention of the nation. The U.S. Food and Drug Administration

(FDA) warned consumers not to eat any fresh spinach at the beginning of the outbreak. Spinach producers faced a sharply declined demand and enormous sales loss. Although demand gradually recovered after a few weeks, questions remain for producers: How did the market respond to the outbreak in terms of demand reduction and recovery? What strategies are effective in order to recover consumer demand after a food scare? What lessons can one learn from this outbreak? To answer these questions, this study implements the event study method to quantify the impact of this *E.coli* outbreak on demand for spinach and lettuce products using retail scanner data from a well-known national superstore chain. A system of multifactor economic models is formulated as the benchmark. The structural modeling approach and the spatial modeling approach are used to account for potential correlations across branch stores and products. An ARIMA model forecast approach is used to correct the potential dependency of the explanatory variables.

The second study (chapter three) examines how the BSE outbreak in North America affected the live cattle imports from Mexico to the U.S. through two stages: the occurrence of the outbreak in 2003 and the Canadian cattle trade resumption in 2005. In the past decades, the live cattle and beef markets of Canada, Mexico and the United States have become increasingly integrated. However, the markets were severely disrupted in 2003 owing to the outbreak of BSE in North America. Even though the BSE panic abated along with the resumption of live cattle trade between the United States and Canada, whether market integration can continue on its former path remains a concern for policymakers and the U.S. beef industry. This study applies the event study method to evaluate the impact of the BSE outbreak and the potential structural change in post-BSE cattle trade between the United States and Mexico by analyzing "abnormal imports" of Mexican cattle during and after the period that Canadian cattle were banned. This study provides insights concerning the market integration progress of cattle markets in North America by examining cattle trade between the United States and Mexico within the three cattle markets in North America. A simultaneous model is formulated as the benchmark model for the event analysis. A feasible approach is addressed to correct for the problems arising from the usage of a simultaneous benchmark model and the three-stage-generalized-least squares (3SGLS) estimation method in event study.

The third study (fourth chapter) is a relatively independent paper, which investigates consumers' willingness to pay for sensory qualities in Anjou pears with different ethylene treatments. Ethylene treatments have proven an effective way to shorten the conditioning time of Anjou pears and allow market availability of Anjou pears year round (Chen et al. 1996). However, the eating quality of pears may vary as the treatment time differs. It is important for pear producers to gain information regarding the optimal strategy for conditioning with ethylene treatment, which generates the "target" quality that is most preferred by consumers. This study uses sensory analysis and the contingent valuation (CV) method to evaluate consumers' willingness to pay for pears with different levels of ethylene treatment. Data were collected through a taste experiment and a consumer survey. A double-bounded dichotomous choice contingent valuation model is employed to estimate consumers' willingness to pay for Anjou pears and the mean willingness to pay for pears with each of the four levels of ethylene treatment: 6 days, 4 days, 2 days with ethylene, and 7 days without ethylene. The model is specified and estimated under three alternative scenarios and the results are compared.

Summary of Findings

Major findings in the first study of 2006 *E.coli* outbreak include: first, demand for spinach products decreased sharply during the outbreak and then recovered gradually after a few weeks; second, the outbreak's effects on different categories of products were distinct, which were reflected by the pattern and speed of the recovery; third, promotion is more effective than price adjustment in increasing sales, and post-outbreak promotion tends to speed up the demand recovery for non-recalled spinach, but not for recalled spinach; fourth, there is significant evidence of regional differences in terms of state and rural-urban area for some products.

The second event analysis findings include that cattle imports from Mexico tended to remain stable right after the BSE outbreak and then decreased afterwards, which indicates that the effects of higher cattle price, reinforced regulations, increase domestic beef supply, and USDA's announcement of final minimal risk rule tended to dominate the substitution effect over time and that the effect of Canadian beef and cattle trade resumption on Mexican cattle imports is substantial.

The third study on the consumers' willingness to pay for Anjou pears suggests that the "treatment-induced" eating quality significantly affects consumers' willingness to pay. The sensory variables *Firmness*, *Sweetness* and *Juiciness* are influential factors in determining consumers' willingness to pay. Respondents with children under 18 years old have a higher willingness to pay. The mean willingness to pay for pears with the four types of treatments are \$1.74/lb, \$1.53/lb, \$1.19/lb, and \$1.09/lb, respectively. This implies that consumers are willingness to pay the most for the pears with 6-day treatment and on average are willing to pay a premium of \$0.25/lb compared to the market price. The pears without ethylene treatment have the least desirable eating quality. That is, analysis indicates that the 6-day treatment tends to induce the most preferable eating quality of Anjou pears.

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CHAPTER TWO

AN EVENT ANALYSIS OF THE 2006 *E.COLI* OUTBREAK IN SPINACH AND LETTUCE

Summary

The event study method has been widely used for price analysis, but it has rarely been applied to demand analysis. This article addresses feasible approaches to implementing the event study method to consumer demand analysis with relaxation of some assumptions imposed on traditional event studies. The event study method is utilized to investigate the effects of the 2006 *E.coli* O157:H7 outbreak on demands for spinach and lettuce products with the advantages of retail scanner data provided by a well-known national superstore chain. A system of multifactor economic models is formulated as the benchmark and is estimated with panel data using a structural modeling approach under a spatial error model scheme to take care of the potential correlations across groups and products. An ARIMA model forecast approach is used to correct the potential dependency of the explanatory variables. Substantial decline in demands and gradual recovery patterns are observed in spinach and lettuce products over the event window. The market responses to the outbreak tend to be distinct across different categories of products in terms of the patterns and rapidity of demand recovery. Regional differences in response to the outbreak are also indicated by the analyses and supported by the hypotheses testing. In addition, markdown promotion is more effective than price adjustment as a strategy to recover consumer demand.

Introduction

The 2006 *Escherichia coli* O157:H7 (*E. coli*) outbreak in spinach and lettuce provided a wakeup call for consumers and the fresh vegetable and fruit industry. This outbreak involved many states, causing hundreds of infections and hospitalizations, even three cases of death. Indeed, outbreaks of food borne diseases remain a serious concern in the United States. According to the Center for Disease Control (CDC), food borne illness sickens 76 million Americans, causes 325,000 hospitalizations and thousands of deaths, and costs $44 billion annually.

Due to the huge economic losses and concerns in terms of human health, the consequences of food borne illness outbreaks have received a great deal of interests from economists and other researchers. Studies in this area include herbicide contamination of cranberries (Brown 1969), Heptachlor contamination of milk on Oahu, Hawaii (Smith, van Ravenswaay and Thompson 1988), the Alar apples crisis (van Ravenswaay and Hoehn 1991; Herrmann, Warland and Sterngold 1997), Cyclospora and Hepatitis A contamination of strawberries (Richards and Patterson 1999), *E. coli* O157:H7 in ground beef (McKenzie and Thomsen 2001), Salmonella contamination of chicken (Dahlgran and Fairchild 2002), Bovine Spongiform Encephalopathy (BSE) scares (Burton and Young 1996; Burton, Young and Cromb 1999; Verbeke and Ward 2001; McCluskey et al 2005; Oniki 2006). These studies consistently find that consumer demand declines sharply during the scares, and that media had played a crucial role in the evolution of food scares.

Several approaches have been utilized to measure the market impact of food scares. The most commonly used is through the index of media coverage of the incident. Media indices are constructed and used as explanatory variables in model estimation to evaluate the effects of the food scare. Dynamic effects are usually investigated with the inclusion of past values of information indices. While significant impacts of food safety information on consumer demand are found, these impacts tend to be short-lived (Brown and Schrader 1990; Chang and Kinnucan 1991; Capps and Schmitz 1999; Henneberry, Piewthongngam, and Qiang 1999; Flake and Patterson 1999; Piggott and Marsh 2004). Henneberry et al (1999) do not find evidence that risk information has a significant impact on the consumption of fresh produce in the long run. The short-lived effects of food safety information are further supported by Piggott and Marsh (2004) that the meat demand response to food safety concerns is small and there is no apparent lagged effect.

Consumer responses to food scares have also been investigated through surveys. Herrmann, Warland, and Sterngold (1997) examine the public reaction to the 1989 Alar apple crisis by a telephone survey of households in the 48 contiguous states. McCluskey et al (2005) investigate consumer's food safety perceptions and willingness to pay for BSE-tested beef using survey data collected from shoppers at the Seikatsu Club Consumer Cooperative, a grocery store-like setting in Japan. Onyango et al (2007) collect data from a nationally representative sample of 1200 Americans through telephone interviews to investigate the public perceptions on food safety particularly relating to this 2006 *E. coli* outbreak.

Another tool is the event study method. This method was first introduced by Fama et al (1969). Since then, numerous modifications have been developed to address problems stemming from violations of the classical statistical assumptions. Event studies have been widely applied to price analysis. Most of the applications are to financial markets in order to analyze securities performances in response to external shocks. Some researchers apply the event study method to agricultural markets to investigate the effects of events on prices: Mazzocchi (1999) uses this method to access the impact of BSE on cattle prices in Italy; Thomsen and McKenzie (2001) use the method to examine the effect of *E.coli* O157:H7 outbreak on wholesale and form-level beef prices.

However, the event study method has rarely been applied to demand analysis in existing literature due to some assumptions imposed on traditional event studies. For example, most event studies use OLS regression to estimate the benchmark model for price series, assuming that the price series are not correlated. But in demand analysis, structural modeling approach and special estimation techniques are commonly utilized to take care of the potential correlations. Another crucial assumption in event study is that the explanatory variables of the benchmark model have to be independent from the event in order to obtain reliable estimate of the impact on the dependent variable. This assumption is not a problem for the application to financial markets while applying a market model, where the return of the market portfolio is easily available and is not affected by specific events. It is also not a problem for the application to price analysis in agricultural markets when a mean model is used (Thomsen and McKenzie 2001), or when the explanatory variables in benchmark model are considered strictly independent from the event (Mazzocchi 1999). However, in demand analysis, multifactor economic models are often used. If the assumption that the explanatory variables in the model are not affected by the events does not hold, the quantitative effects estimated by event study approach may be biased.

This article addresses feasible approaches to implementing the event study method to demand analysis with relaxation of the assumptions that the explanatory variables have to be independent from the event and that the error terms are not correlated. The event study method is utilized to evaluate the impact of the 2006 *E.coli* O157:H7 outbreak on consumer demands for spinach and lettuce with the advantages of scanner data provided by a well-known national superstore chain. A system of multifactor economic models is formulated as the benchmark and estimated using panel data. Approaches of structural modeling and spatial modeling are used to take care of the potential correlations of error terms across groups and products. An ARIMA model forecast approach is used to correct the potential dependency problem of explanatory variables. The objectives of this study are to identify: (1) how the *E. coli* scare affected the sales of the suspected products -- spinach and lettuce; (2) the rapidity of demand recovery; (3) the effectiveness of price adjustment or promotion during a food scare; and (4) the spatial difference in consumer response across regions. The event analysis on consumer demand has important implications for food producers and retailers in terms of market response to a food borne illness outbreak in fresh produce and the consequent losses in sales, as well as the effectiveness of strategies for recovering demand.

The following sections are organized as follows. In the next section, the 2006 *E.coli* outbreak is briefly reviewed. Then the event study methodology incorporated with the hypothetical benchmark model is introduced. Next, the data, the benchmark model estimation and the results of the event analysis are discussed. Conclusions and implications are presented in the final section.

The 2006 *E.coli* Outbreak in Spinach and Lettuce

The incident was an outbreak of *E. coli* O157:H7 in two phases. The first outbreak in spinach started on September 14, 2006, when the U.S. Food and Drug Administration (FDA) issued an alert to consumers about an *E. coli* O157:H7 outbreak associated with the consumption of bagged fresh spinach in multiple states. *E. coli* O157:H7 is a potentially deadly bacterium that can cause bloody diarrhea and dehydration. Some people can develop a form of kidney failure called Hemolytic Uremic Syndrome (HUS), which is most likely to occur in young children and the elderly. This condition can lead to serious kidney damage and even death. The FDA called for bagged fresh spinach to be removed from grocery store shelves and warned people not to eat fresh spinach or products containing fresh spinach. With rising panic, spinach was pulled from grocery store shelves, and restaurants removed spinach from their menus.

The CDC issued an official health alert on September 14 and began the investigation of the cause of this *E.coli* outbreak. The FDA announced later that the outbreak was traced back to Natural Selection Foods LLC of San Juan Bautista, California. Reports by the CDC, the FDA, and the California Department of Health Services (CDHS) concluded that the probable source of the outbreak was the Paicines Ranch in San Benito County, about 30 miles from California's central coastline, which is an Angus cattle ranch that had leased land to spinach grower Mission Organics. They named the presence of wild pigs on the ranch and the proximity of surface waterways to irrigation wells as potential environmental risk factors. The reports also noted that flaws in the spinach producer's transportation and processing systems could have further spread contamination.

Natural Selection Foods issued a recall of all implicated products on September 15, and four other companies issued secondary recalls because they received the recalled product from Natural Selections. Natural Selection Foods announced on September 18 that its organic produce had been cleared of contamination by an independent agency. On September 29, the FDA downgraded the warning to be only against specific brands packaged on specific dates, instead of all fresh spinach. By October 6, the outbreak of *E.coli* O157:H7 in spinach had involved 26 states, leading to 199 cases of infections, 102 hospitalizations, 31 cases of HUS (kidney failures) and three deaths.[1]

Less than a week after the downgraded warning on fresh spinach, FDA issued a recall in lettuce grown in the Salinas Valley in California over concerns about *E.coli* contamination on October 8. The recall covered green leaf lettuce sold from October 3 to October 6 under a popular brand in grocery stores in Arizona, California, Idaho, Montana, Nevada, Oregon and Washington. A few weeks after, a subsequent *E.coli* outbreak linked to Taco Bell and Taco John's restaurants involving in 5 states was found to be caused by the prepackaged iceberg lettuce, which resulted in 71 infections, 53 hospitalized cases, and 8 cases of kidney failure. According to the CDC, illness onset dates ranged from November 20 to December 6. It was estimated that farmers in California faced up to $74 million in losses due to this *E. coli* outbreak.

Event Study Methodology

This paper uses an event study method to investigate the effect of the 2006 *E.coli* outbreak in spinach on consumer demand. The idea of the method is straightforward. First a benchmark model is specified and estimated over a period prior to the event. Using the estimates from the benchmark, forecasts of demand are generated over the event window, which represent the expected demand without the occurrence of the event. Then the Abnormal Returns (AR), which represent quantitative estimates of the event effect, are obtained as the actual demand minus the predicted demand over the event window.

Approach

The event study approach incorporated with the hypothetical benchmark is described as

[1] The above information is based on the *FDA News*.

follows. First, define the events and identify the corresponding estimation window and event window. In this study, the event is the *E.coli* outbreak in two principal phases. The estimation window is the period of time prior to the occurrence of the event, and the event window is the period during which the event occurred. Since the outbreak in spinach first occurred on September 14, 2006, which is in the middle of the 37th week, the event day is defined as the 37th week. Set t = 0 for the 37th week, the estimation window is then defined as the first to the 35th weeks, or t = (-36, -2), and the event window as the 36th to the 51st weeks, or t = (-1, 14), which includes both phases for spinach and lettuce. The event window is specified one week ahead to account for the possibility that consumers were aware of the incident before the formal announcement by FDA.

Second, specify the benchmark model and estimate the parameters over the estimation window.

$$R_{jit} = X_{jit}\beta_j + \varepsilon_{jit}, \qquad \forall\ t \in \text{the estimation window} \tag{2.1}$$

In this study, since the outbreak was related to bagged spinach and lettuce, the demands for the following four categories of products are of interest: non-recalled bagged spinach, recalled bagged spinach, bulk spinach and lettuce. Panel data from 29 branches of the superstore chain are used for model estimation. Thus R_{jit} is the weekly sold quantity of the j^{th} product, j = 1, 2, 3, 4, in the i^{th} store, i = 1, 2,…,29, at week t. X_{jit} is the explanatory variables; and β_j is the corresponding coefficients to be estimated for the j^{th} product.

Some assumptions imposed on traditional event studies are relaxed that the explanatory variables have to be independent from the event, and that the error terms ε's are identically and independently normally distributed. The approach of correcting the dependency of explanatory variables will be discussed in the following section. Moreover, assume that $\varepsilon_j \sim N(0, \Omega_j \otimes \mathrm{I}_\mathrm{T})$, where $\Omega_j \neq \sigma^2 I_n$, with n is the number of stores and T is the number of weeks over the estimation window, and that ε_j's are potentially correlated. That is, the covariance matrix of error terms for each product is assumed to have an unknown structure, and the error terms are allowed to be correlated across products. Thus the model will be estimated using a structural modeling approach with an unknown covariance matrix $\Phi \otimes \mathrm{I}_\mathrm{T}$, where Φ is a symmetric, positive definite matrix having the following form:

(2.2) $$\Phi = \begin{bmatrix} \Omega_{11} & \Omega_{12} & \Omega_{13} & \Omega_{14} \\ & \Omega_{22} & \Omega_{23} & \Omega_{24} \\ & \cdots & \Omega_{33} & \Omega_{34} \\ & & & \Omega_{44} \end{bmatrix}$$

Where the diagonal element $\Omega_{jj} = \Omega_j$, is the covariance matrix for the j^{th} product defined above, and the off-diagonal element Ω_{jl}, $j \neq l$, is the cross-product covariance matrix.

Model in (2.1) can then be written in a structural form:

(2.3) $$R = X\beta + \varepsilon$$

Where $R = (R_1, R_2, R_3, R_4)'$, $X = \begin{bmatrix} X_1 & 0 & 0 & 0 \\ 0 & X_2 & 0 & 0 \\ 0 & 0 & X_3 & 0 \\ 0 & 0 & 0 & X_4 \end{bmatrix}$, X_j representing the regressors in the j^{th} equation, $\beta = (\beta_1, \beta_2, \beta_3, \beta_4)'$, $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4)'$ and $\varepsilon \sim N(0, \Phi \otimes \mathrm{I}_\mathrm{T})$, Φ is defined in (2.2). A two-step Generalized Least Squares (GLS) method will be used for the estimation. A consistent estimator of β is $\hat{\beta} = [X'(\hat{\Phi} \otimes \mathrm{I}_\mathrm{T})^{-1} X]^{-1} X'(\hat{\Phi} \otimes \mathrm{I}_\mathrm{T})^{-1} R$, where $\hat{\Phi}$ is a consistent estimator for Φ . An asymptotically consistent estimator of $COV(\hat{\beta})$ is $[X'(\hat{\Phi} \otimes \mathrm{I_T})^{-1} X]^{-1}$.

Third, the "normal returns" are estimated, which are the expected returns without the occurrence of the event over the event window.

(2.4) $$\hat{R}_{jit} = X^*_{jit} \hat{\beta}_j, \qquad t \in \text{the } \textit{event window,}$$

Where X^*_{jit} denotes the matrix of regressors used to forecast normal returns over the event window. Then the estimated covariance matrix of $\hat{R}_{jit}$ is $C\hat{O}V(\hat{R}) = X^*[X'(\hat{\Phi} \otimes \mathrm{I_T})^{-1} X]^{-1} X^{*}{}'$. Then the abnormal returns (*AR*), which are the differences between the actual returns and the estimated normal returns over the event window, can be expressed as:

(2.5) $$AR_{jit} = R_{jit} - \hat{R}_{jit}$$

An estimate of the covariance matrix of AR_j is: $C\hat{O}V(AR_j) = \hat{\Omega}_{jj} \otimes \mathrm{I}_{T_2} + X^*_j [X_j{}'(\hat{\Omega}_{jj} \otimes \mathrm{I}_T)^{-1} X_j]^{-1} X^{*}_j{}'$, where T_2 is the number of weeks during the event window. The estimated variances of AR_{jit}'s are the diagonal elements of $C\hat{O}V(AR_j)$, denoted by $\hat{V}(AR_{jit})$.

Next, the average abnormal returns (*AAR*) are calculated across groups for each product. The AR_{jit}'s are aggregated across stores at a time point and then averaged to get a measure of the average impact on an individual store. The AAR_{jt}'s can be expressed as:

(2.6) $$AAR_{jt} = \frac{\sum_{i=1}^{n} AR_{jit}}{n}.$$

As the potential correlations between the error terms have been corrected with the GLS estimation, the AR_{jit} 's are assumed to be independent. Then the estimated variance of AAR_{jt} can be expressed as: $\hat{V}(AAR_{jt}) = \frac{1}{n^2}\sum_{i=1}^{n}\hat{V}(AR_{jit})$.

Finally, the cumulative average abnormal return (*CAAR*) is calculated over the event window to obtain an overall measure of the impact of the event. The *CAAR* for the j^{th} product can be expressed as:

(2.7) $$CAAR_j(\tau_1, \tau_2) = \sum_{t=\tau_1}^{\tau_2} AAR_{jt} \ .$$

Given that AAR_{jt} 's are independent, the estimated variance of $CAAR_j(\tau_1, \tau_2)$ can now be computed as:

(2.8) $$\hat{\sigma}_j^{\,2}(\tau_1, \tau_2) = \sum_{t=\tau_1}^{\tau_2} \hat{V}(AAR_{jt})$$

Hypotheses in Event Study

The following hypothesis is of interest to test the significance of the impact:

(2.9) H_0: $CAAR_j(\tau_1, \tau_2) = 0$

H_a: $CAAR_j(\tau_1, \tau_2) \neq 0$

AAR_{jt} 's are assumed to be normally distributed. Under the null hypothesis, the following statistic is obtained:

(2.10) $$\frac{CAAR_j(\tau_1, \tau_2)}{\left[\hat{\sigma}_j^{\,2}(\tau_1, \tau_2)\right]^{1/2}} \overset{a}{\sim} N(0, 1)$$

The null hypothesis can be rejected if the statistic is considerable large, which implies that the impact of the event is significant.

Extended hypotheses could be conducted according to the interest of analysis. In this study, whether there are regional differences in terms of consumer responses to the *E.coli* outbreak is of interest. As the 29 branch stores are located in different cities from three western states: Washington, Oregon and California, with approximately half from urban area and half from rural area, the following hypothesis expresses whether there is a difference across states:

(2.11) $\quad H_0$: $CAAR_{CA} = CAAR_{WA} = CAAR_{OR}$

H_a: $CAAR_{CA} \neq CAAR_{WA}$, or $CAAR_{CA} \neq CAAR_{OR}$, or $CAAR_{WA} \neq CAAR_{OR}$

Where *CA, WA* and *OR* represent California, Washington and Oregon, respectively. For urban versus rural difference, the hypothesis is:

(2.12) $\quad H_0$: $CAAR_{UR} = CAAR_{RU}$

H_a: $CAAR_{UR} \neq CAAR_{RU}$

where *UR* and *RU* represent urban area and rural area, respectively. A *Wald* test can be used to test the above hypotheses of regional differences. The statistic is:

$$W = (R * \underrightarrow{CAAR})' \left[R' \hat{\Sigma} R \right]^{-1} (R * \underrightarrow{CAAR}) \sim \chi_{(q)} \qquad (2.13)$$

where $R = \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix}$, $\underrightarrow{CAAR} = \left[CAAR_{CA} \quad CAAR_{WA} \quad CAAR_{OR} \right]'$ for testing (2.11), and $R = \left[1 \quad -1 \right]$, $\underrightarrow{CAAR} = \left[CAAR_{UR} \quad CAAR_{RU} \right]'$ for testing (2.12), and q is the number of constraints. The $\hat{\Sigma}$ is the covariance matrix of $\underrightarrow{CAAR}$. Assuming that the *CAAR*'s are independent, $\hat{\Sigma}$ is a diagonal matrix with diagonal elements $\hat{\sigma}_j^2$ from (2.8), where j = *CA, WA, OR, UR* or *RU.* The *Wald* statistic is chi-squared distributed under the null hypothesis.

Data

The data for the event study are retail scanner data of sales of selected spinach and lettuce products in 2006, which was provided by a well-known national superstore chain. The dataset contains information about the transaction date, the quantities sold, the total amounts, and the markdowns of selected types of spinach and lettuce from 29 branch stores, totaling 1,116,302 observations. The 29 stores are located in 29 different cities in Washington, California and Oregon, with ten stores from Washington, nine from Oregon, and ten from California, where the contaminated products originated.[2] The stores were selected to well represent the three states geographically (see Appendix Figure 2.A1), with approximately half from the urban area and half from the rural areas.[3]

First the sales for 16 fresh spinach products and 18 fresh lettuce products,[4] which are the products supplied in the superstores during 2006, are identified by matching the universal product codes (UPC) provided by the stores with the records of sales. The sales of products are further classified into four categories: non-recalled bagged spinach, recalled bagged spinach, bulk spinach, and lettuce. The identification of the recalled bagged spinach is according to the

[2] Initially we had 30 stores with 10 from each state, but one store located at Eugene in Oregon was dropped because of the data missing problem.

[3] The criterion used to classify urban area against rural area is that the population of the city is greater than 70,000. The information about the cities that the selected stores located in is presented in Appendix, Table A1.

[4] These selected products are pure spinach or pure lettuce products, excluding mixed salads that contain spinach or lettuce, in which the sold quantity of spinach or lettuce is not clearly indicated.

FDA announcements of the recalled products.[5] The variations of unit prices and transactions across products within a category are considerably large. To avoid potential distortion in the average prices, the major brands for each category are selected to account for at least 95% of the market share according to the transactions. There are 15 of these major brands or types of products, with five for non-recalled bagged spinach, three for recalled-bagged spinach, two for bulk spinach, and five for bulk lettuce (see Appendix Table 2.A2).

For all the bagged products, the quantity is scaled by weight to be consistent with the bulk products. According to the weekly pricing cycle of the stores, the sales and the quantity sold per store are aggregated by week, totaling 51 weeks (without the half weeks at the beginning and the end of the year). Price is then calculated as the weighted average price across UPC for each category, which is derived by dividing the total amounts by the total quantity sold in the store in a certain week. Similarly, the average markdown is calculated by dividing the total markdowns by the total quantity sold in a week. Thus data used for analysis are a panel dataset with 29 groups and 51 periods for each of the four categories, including variables of week, store, sold quantity (in lbs), average price (in dollars), average markdown (in dollars), as well as indicators of the regional information (state, rural or urban area).

Missing value issues arise because for some weeks, there are no observations for certain stores and certain categories. The explanation is that no transactions occurred during the week in that store for certain category. This is most common in the 38th and 39th weeks, during the period the *E. coli* outbreak occurred. For those missing values before the outbreak, the sold

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[5] A report from Food and Drug Administration (FDA), "FDA Announces Findings from Investigation of Foodborne *E. coli* O157:H7 Outbreak in Spinach", September 29, 2006.

quantity is set to be zero and the price is set to be the state average price for that category during the week, which is calculated by dividing the total weekly sales of the state by the total quantity sold for certain category. However, during the outbreak, since no transactions occurred throughout all the stores, the state average prices are not attainable. Consequently, the average price of the week before and the week after is used based on availability for missing prices and markdowns during the outbreak period.

The variable descriptions and the summary statistics for the data are presented in Tables 2.1 and 2.2. The quantity aggregated over the three states, the average price and markdown against time are plotted in Appendix Figure 2.A2. Some interesting findings emerge on the first glance at the graphs. First of all, drop in demand is found in all the spinach products after the outbreak occurs at 37th week. Second, the volume of decline in demand in recalled spinach seems much smaller compared with the other two spinach products, apparently because there is a decreasing trend in the demand for recalled spinach prior to the outbreak due to the higher prices, and the demand has been very low before the outbreak occurs. Third, the consumption of lettuce drops at the 36th week due to the relatively higher price at that week, but shows an increasing trend since 37th week, although the average price is still very high. The sales of lettuce reach a peak at the 39th week and then start falling from the 40th week, right after the FDA lifted the warning on fresh spinach and announced that most of the spinach products were safe to eat. However, the decreasing trend continues till the end of the year because of the subsequent recall on lettuce on October 8 and a second *E.coli* outbreak in lettuce from November to December.

Model Estimation for Event Study

Benchmark Model Specification and Preliminary Tests

The following specification of the benchmark model is considered:

$$(2.14)\quad \begin{aligned} R_1 &= \beta_{10} + \beta_{11}P_1 + \beta_{12}P_2 + \beta_{13}P_3 + \beta_{14}P_4 + \beta_{15}MK_1 + \beta_{16}LAGR_1 + \varepsilon_1 \\ R_2 &= \beta_{20} + \beta_{21}P_1 + \beta_{22}P_2 + \beta_{23}P_3 + \beta_{24}P_4 + \beta_{25}MK_2 + \beta_{26}LAGR_2 + \varepsilon_2 \\ R_3 &= \beta_{30} + \beta_{31}P_1 + \beta_{32}P_2 + \beta_{33}P_3 + \beta_{34}P_4 + \beta_{35}MK_3 + \beta_{36}LAGR_3 + \varepsilon_3 \\ R_4 &= \beta_{30} + \beta_{41}P_1 + \beta_{42}P_2 + \beta_{43}P_3 + \beta_{44}P_4 + \beta_{45}LAGR_4 + \beta_{46}LLAGR_4 + \varepsilon_4 \end{aligned}$$

Where j = 1, 2, 3, 4*,* represent non-recalled spinach, recalled spinach, bulk spinach and lettuce, respectively; R_j is the quantity sold weekly in the store for the j^{th} category; P_1 is the weekly average price of non-recalled bagged spinach; P_2 is the weekly average price of recalled bagged spinach; P_3 is the weekly average price of bulk spinach; P_4 is the weekly average price of lettuce; MK_j is the weekly average markdown of the j^{th} category; $LAGR_j$ is the first lag of R_j, i.e., the quantity sold in the previous period in the store, for the j^{th} category; $LLAGR_j$ is the second lag of quantity. The second lag of quantity is added in the last equation due to the evidence of first order autocorrelation, and the markdown variable is omitted because of the multicollinearity problem.

Given the panel data, a series of tests are performed to choose among the pooled OLS, Fixed Effect (FE) model and Random Effect (RE) model based on the above specification of the model. A Loss-of-fit F-test to test for the significance of the group effects is performed:

$$F_{nT-(n+k)}^{n-1} = \frac{(e_r' e_r - e_u' e_u)/(n-1)}{e_u' e_u /(nT-(n+k))}$$

Where e_u is the FE residuals and e_r is the pooled OLS residuals. The large statistics for the four equations indicate that the group effects are significant and a FE model is preferable. Then a Hausman test is performed choosing between FE and RE models:

$$(b_{FE} - b_{RE})'\left(Var(b_{FE}) - Var(b_{RE})\right)^{-1}(b_{FE} - b_{RE}) \sim \chi^2_{(k)}$$

Where the intercept and dummy variables are not included in b's and $Var(b)$'s, and k is the number of parameters excluding the intercept. The test statistics are considerable large, which indicate that the FE model is the appropriate model.

The benchmark model is then modified as:

$$
\begin{aligned}
R_1 &= \sum_{i=1}^{29} \alpha_{1i} + \sum_{k=1}^{4} \beta_{1k} P_k + \beta_{15} MK_1 + \beta_{16} LAGR_1 + \varepsilon_1 \\
R_2 &= \sum_{i=1}^{29} \alpha_{2i} + \sum_{k=1}^{4} \beta_{2k} P_k + \beta_{25} MK_2 + \beta_{26} LAGR_2 + \varepsilon_2 \\
R_3 &= \sum_{i=1}^{29} \alpha_{3i} + \sum_{k=1}^{4} \beta_{3k} P_k + \beta_{35} MK_3 + \beta_{36} LAGR_3 + \varepsilon_3 \\
R_4 &= \sum_{i=1}^{29} \alpha_{4i} + \sum_{k=1}^{4} \beta_{4k} P_k + \beta_{45} LAGR_4 + \beta_{46} LLAGR_4 + \varepsilon_4
\end{aligned}
\tag{2.15}
$$

In traditional event studies, a necessary condition for the specification of the benchmark model is that the explanatory variables must be independent from the event, i.e., they should not be affected by the occurrence of the event. However, in the economic model above, the prices, markdowns, or lagged sold quantity are potentially affected by the event of the *E. coli* outbreak. Intuitively, sales are likely to decrease after the outbreak, so that the predicted sold quantities for the later periods based on the declined demand earlier would be biased. Moreover, price adjustments and promotions might be more frequent after food scares in order to recover consumer demands. A feasible approach will be discussed later to correct the potential bias caused by endogeneity of the explanatory variables, which allows the specification of benchmark model to be extended without the restriction of the independence of explanatory variables.

Next, Likelihood Ratio Tests are performed to check for the panel-level heteroskedasticity and cross-sectional correlation within the panel data. The large statistics indicate that there exist panel level heteroskedasticity and cross-sectional correlation problems in each of the equations in (2.15). Thus the symmetric, positive definite covariance matrix Ω_{jj} in (2.2) has the following form:

$$(2.16) \qquad \Omega_{jj} \otimes \mathrm{I}_{\mathrm{T}} = \begin{bmatrix} \sigma_{11}\mathrm{I}_T & \sigma_{12}\mathrm{I}_T & \sigma_{13}\mathrm{I}_T & \cdots & \sigma_{1n}\mathrm{I}_T \\ & \sigma_{22}\mathrm{I}_T & \sigma_{23}\mathrm{I}_T & \cdots & \sigma_{2n}\mathrm{I}_T \\ & & \sigma_{33}\mathrm{I}_T & \cdots & \sigma_{3n}\mathrm{I}_T \\ & \cdots & & \cdots & \cdots \\ & & & & \sigma_{nn}\mathrm{I}_T \end{bmatrix}$$

Where j = 1, 2, 3, 4, n is the number of stores, T is the periods that used for estimation, the diagonal elements represent the variance of store i, and the off-diagonals represent the covariance of store i and store h, $i \neq h$, which are non-zero with the presence of the cross-sectional correlation.

A Lagrange Multiplier test developed by Breusch and Pagan (1980) is performed to test for correlation across equations. The error terms of the four equations are found to be highly correlated, which indicates that a structural modeling approach is preferable.

Model Estimation

Based on the results of the tests, a two-step GLS estimation method is used as well as the structural modeling and the spatial modeling approaches to take care of the panel issues and correlation across equations. First of all, Φ defined in (2.2) has to be consistently estimated, which requires consistently estimating each element in Φ. Let us first consider the off-diagonal elements, Ω_{jl}, where $j \neq l$. Assume that the error terms are only correlated across products within the same store, but the correlation parameters are allowed to vary for different stores (heteroskedasticity for cross-sectional correlation). Thus $\hat{\Omega}_{jl}$ is a diagonal matrix with a form:

(2.17) $$\hat{\Omega}_{jl} \otimes \mathrm{I_T} = \begin{bmatrix} \delta_1 \mathrm{I}_T & 0 & 0 & \dots & 0 \\ & \delta_2 \mathrm{I}_T & 0 & \dots & 0 \\ & & \delta_3 \mathrm{I}_T & \dots & 0 \\ & \dots & & \dots & \dots \\ & & & & \delta_n \mathrm{I}_T \end{bmatrix}$$

Where $\delta_i = \frac{e_{ji}' e_{li}}{T}$, e_{ji}, e_{ji} are the residuals from OLS regression for store i in the j^{th}, l^{th} equation, respectively.

The estimation of the diagonal elements of Φ, $\hat{\Omega}_{jj}$, is more complicated when taking into account the cross-sectional correlation within panels, i.e., correlations between stores. The approach of using residuals from OLS regression does not work since there are too many parameters and it turns out that the estimated covariance matrix $\hat{\Phi} \otimes \mathrm{I_T}$ is not positive definite. Given that the 29 stores are from different cities of the three states, the stores are most likely to be spatially correlated. Thus for each for the four equations, a spatial error model is considered:

(2.18) $$\begin{aligned} R_j &= X_j \beta_j + \varepsilon_j \\ \varepsilon_j &= \rho_j (W \otimes \mathrm{I_T}) \varepsilon_j + u_j \end{aligned}$$

Where $u_j \sim N(0, \varphi_j \otimes \mathrm{I}_T)$, φ_j is a diagonal covariance matrix to allow for heteroskedasticity; ρ_j is the autoregressive parameter to be estimated, such that $\rho_j > 0$ represents a positive spatial autoregressive process, $\rho_j < 0$ represents a negative spatial autoregressive process, and $\rho_j = 0$ represents there is no spatial autocorrelation; W is the weighting matrix based on the pair-wise distances between stores.

To define the weighting matrix W, first the latitudes and longitudes for each city where a store is located are obtained from the U.S. Census Bureau webpage. The pair-wise distances in miles between stores can be approximately calculated according to the formula: DISTANCE = 3963.1 * arcos[sin(A)sin(C)+cos(A)cos(C)cos(B-D)], where A, C are latitudes and B, D are longitudes of the two cities, respectively. The elements in W are then defined as the inverse of the pair-wise distances in a sense that the correlation gets smaller as the two stores are further.

Rearrange (2.18) to get $\varepsilon_j = \left[\mathrm{I}_{\mathrm{n}\times\mathrm{T}} - \rho_j (W \otimes \mathrm{I}_\mathrm{T})\right]^{-1} u_j$, then the model in (2.18) is equivalent to

(2.19) $$R_j = X_j \beta_j + \left[\mathrm{I}_{\mathrm{n}\times\mathrm{T}} - \rho_j (W \otimes \mathrm{I}_\mathrm{T})\right]^{-1} u_j$$

Where

(2.20) $$COV(R_j) = COV(\varepsilon_j)$$

$$= \left[\mathrm{I}_{\mathrm{n}\times\mathrm{T}} - \rho_j (W \otimes \mathrm{I}_\mathrm{T})\right]^{-1} COV(u_j) \left[\mathrm{I}_{\mathrm{n}\times\mathrm{T}} - \rho_j (W \otimes \mathrm{I}_\mathrm{T})\right]^{-1}{}'$$
$$= \left[(\mathrm{I}_\mathrm{n} - \rho_j W)^{-1} \varphi_j (\mathrm{I}_\mathrm{n} - \rho_j W)^{-1}{}'\right] \otimes \mathrm{I}_\mathrm{T}$$

Note that Ω_{jj} in (2.16) now has the form: $\Omega_{jj} = (\mathrm{I}_\mathrm{n} - \rho_j W)^{-1} \varphi_j (\mathrm{I}_\mathrm{n} - \rho_j W)^{-1}{}'$.

To estimate Ω_{jj}, the first step is to find $\hat{\varphi}_j$ and $\hat{\rho}_j$. $\hat{\varphi}_j$ can be easily estimated using the residuals from OLS regression, such that its diagonal element $\hat{\varphi}_{ji} = \frac{e_{ji}' e_{ji}}{T}$, where e_{ji} is the residuals from OLS regression for the i^{th} store in the j^{th} equation. Then $\hat{\rho}_j$ is estimated by a grid search using the Qnewton minimization procedure in GAUSS to minimize the Sum of Square Errors (SSE) for each equation:

$$SSE_j = (R_j - X_j b_j)' \{[(\mathrm{I}_\mathrm{n} - \rho_j W)^{-1} \hat{\varphi}_j (\mathrm{I}_\mathrm{n} - \rho_j W)^{-1}{}'] \otimes \mathrm{I}_\mathrm{T}\}^{-1} (R_j - X_j b_j)$$

Where b_j is the OLS estimates for β_j.

Then Ω_{jj} can be estimated as:

(2.21) $$\hat{\Omega}_{jj} = (\mathrm{I_n} - \hat{\rho}_j W)^{-1} \hat{\varphi}_j (\mathrm{I_n} - \hat{\rho}_j W)^{-1}{}'$$

Thus, the estimated covariance matrix for the equation system is:

(2.22) $$\hat{\Phi} \otimes \mathrm{I_T} = \begin{bmatrix} \hat{\Omega}_{11} & \hat{\Omega}_{12} & \hat{\Omega}_{13} & \hat{\Omega}_{14} \\ & \hat{\Omega}_{22} & \hat{\Omega}_{23} & \hat{\Omega}_{24} \\ & \cdots & \hat{\Omega}_{33} & \hat{\Omega}_{34} \\ & & & \hat{\Omega}_{44} \end{bmatrix} \otimes \mathrm{I_T}$$

Where $\hat{\Omega}_{jj}$ and $\hat{\Omega}_{jl}$ are estimated in (2.17) and (2.21) above.

Now an estimate for β can be obtained:

(2.23) $$\hat{\beta} = [X'(\hat{\Phi} \otimes \mathrm{I_T})^{-1} X]^{-1} X'(\hat{\Phi} \otimes \mathrm{I_T})^{-1} R$$

As the estimation window is defined as the first to the 35th weeks, or t = (-36, -2), the estimation is then based on a panel dataset with 29 store and 35 weeks for the four categories of products, totaling 4060 observations. The results of estimation are presented in Table 2.3. The own prices and markdowns are all statistically significant at 0.01 level. The substitution effect between spinach and lettuce is significant, while it is not across categories of spinach. Bulk spinach has the greatest markdown effect on consumer demand among the three categories of spinach products, as the price of bulk spinach is much lower compared to bagged spinach. That is, for the same units of markdown, the percentage decrease in price of bulk spinach is much larger than those of bagged spinach. Except for the non-recalled spinach, the coefficients of lag quantity are all significant at 0.01 level, which indicates that the demand for other products are all highly correlated to that of the previous periods. Table 2.3 also contains the elasticities estimated at the sample means. Bagged spinach tends to have unit elasticity, while lettuce is inelastic. All the spinach products are highly sensitive to markdown, especially the bulk spinach. It is interesting to observe that the demands are much more sensitive to markdowns than prices, which may have a psychological implication that people are much happier to see a product on sales than a price adjustment. That is, promotion is a more effective way to boost up sales of spinach products than price adjustment.

Price Analysis

As discussed in the earlier section, the potential dependency problem of the explanatory variables has to be corrected. The approach is using ARIMA forecast to "eliminate" the effect of the event on prices. ARIMA model has been proven to be a powerful tool for price analysis and has been widely applied to price forecasts in economic and financial analysis. First the state averaged prices and markdowns are compared with the "national"[6] averaged prices and markdowns over weeks and they are found to have very similar patterns, i.e., the pricing strategy of the superstore are quite consistent across the three states and the national average prices and markdowns well represent the pricing behaviors. Thus, the series of national averaged prices and markdowns prior to the event are used to fit in *ARIMA(p, d, q)* model:

(2.24) $$\phi(B)(1-B)^d X_t = \theta(B)a_t,$$

where B is the lag operator; $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$ representing the *AR(p)* factor; $\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q$ representing the *MA(q)* factor; $(1-B)^d X_t$ is the d^{th} differenced series to insure stationarity, and a_t is the white noise series. First the Dickey-Fuller test is

[6] "National" averaged price is the average price of all stores in the three states.

performed and results indicate that all the price series are non-stationary. Thus the price series are differenced until they all become stationary. Then appropriate ARMA models for the differenced prices and markdowns series are chosen based on the Akaike's (1974) Information Criterion (AIC) and Schwarz's (1978) Bayesian Information Criterion (SBC). [7] The estimated ARIMA models for the price and markdown series are presented in Table 2.4.

Next, an intervention analysis is conducted on prices and markdowns based on the model:

(2.25) $$X_t = \zeta_t + N_t,$$

where N_t is the term that follows *ARIMA(p,d,q)*, and $\zeta_t = P_t^{\mathrm{T}}$ is a point input accounting for the intervention effect in a way such that $P_t^T = \begin{cases} 0, t \neq T \\ 1, t = T \end{cases}$. Here T denotes the period in which the intervention starts. In this case, T = -1 since t = 0 is set for the event day 37th week, and the event window is specified one period ahead as t = (-1, 14). ζ_t can take different forms to stand for different types of the effect. For example, $\zeta_t = \frac{\omega_0}{1-B} P_t^T = \omega_0 (1 + B + B^2 + ...) P_t^T$ implies checking for a constant "permanent" effect, that is, the event has a quantitatively equivalent effect on all the periods after the occurrence of the event[8]; $\zeta_t = \frac{\omega_0}{1-\delta B} P_t^T = \omega_0 (1 + \delta B + \delta^2 B^2 + ...) P_t^T$ is checking for a diminishing "permanent" effect if

[7] The ARIMA models are selected on the basis of minimum AIC and SBC, i.e, -2ln(L)+2k^2 and -2ln(L)+kln(n), respectively, where L is the maximum likelihood, k is the number of parameters and n is the number of observations.

[8] $BP_t^T = P_{t-1}^T = \begin{cases} 0, t-1 \neq T \\ 1, t-1 = T \end{cases} = \begin{cases} 0, t \neq T+1 \\ 1, t = T+1 \end{cases}$, and so on.

$\delta < 1$; and $\zeta_t = \omega_0(1+\delta B)P_t^T$ considers that the event only affects the current and the next periods, etc. The effect of the intervention is considered to be significant if the coefficients in ξ_t are statistically significant. The *E.coli* outbreak is not found to have a "permanent" effect on the demand for the four categories of products. To check for the short term effect, ξ_t starts with the form: $\zeta_t = \omega_0(1+\gamma_1 B+\gamma_2 B^2+...+\gamma_{14}B^{14})P_t^T$, checking for significance of the individual terms, which checks for the significant effect of the outbreak on each individual period over the event window. Then the process is replicated by removing the last term every time. The purpose of this intervention analysis is to identify the weeks during which the price and markdown are significantly affected by the outbreak, i.e., notable price adjustments and big promotions after the outbreak. The significantly affected weeks indicated by the intervention analysis are presented in Table 2.5. The weeks with big promotion (signals as higher markdown, lower price) are all indicated as "outliers", which implies an irregular promotion circle during the normal period. Thus, this analysis is to quantify the effect of the outbreak by estimating the reduction in demand as if there is no big promotion going on after the outbreak.

For those weeks identified to have been affected, the *ARIMA(p,d,q)* models is used to forecast the predicted values, i.e., the expected prices and markdowns, assuming absence of the outbreak. For consecutive weeks that had been affected, dynamic forecasts are used for the prediction, i.e., the predicted value of current week is computed using the forecasted values of the previous periods instead of the actual values. For those weeks that prices and markdowns are not statistically significantly affected by the outbreak, the actual values are kept. In this way, the explanatory variables can now be regarded as "independent" from the event since the potential impact of the outbreak has been eliminated by the predicted values for those significant weeks.

Results of Event Study Analysis

The predicted sold quantities during the event window are generated[9] using the explanatory variables with the forecasted values for those significant affected weeks. Again, a dynamic forecast is used for computing the predicted quantities, i.e., the lag of the predicted quantity is used instead of the actual lagged quantity for the forecasts so that the *AR*'s will not be biased due to the decreased demands after the outbreak. Then the *AR*'s are obtained as the actual minus predicted.

For purposes of comparison, the *AR*'s are aggregated (1) across three states to approximately represent the nation; (2) by state; (3) by area and then averaged across stores to get the *AAR*, then finally aggregated over the event window to obtain the *CAAR*. As the scale of sales varies notably across products, e.g., the sales of bulk lettuce is much greater than the other three, and sales of non-recalled spinach is greater than the recalled spinach since it includes more brands, the absolute values of *AAR*'s do not provide a good measurement for comparing the effects across products. To make the *AAR*'s and *CAAR*'s comparable across products, first the average of the quantities sold in the previous three periods before the outbreak for each product is calculated, and then the *AAR*'s are divided by the three-period averaged quantity of the corresponding product to approximately represent a "percentage change" in consumptions.

National AAR and CAAR

Figure 2.1 shows the national *AAR's* (in percentage) over the event window for the four categories: non-recalled bagged spinach, recalled bagged spinach, bulk spinach, and lettuce.

[9] Negative predicted values occur through the prediction. Since sold quantities could not be less than 0, the negative values are set to be 0.

There are some interesting implications from these plots. First, the drastic drop in demand for all types of spinach can be observed after the outbreak, such that non-recalled spinach decreases by about 80% a week at the peak, recalled spinach 150%, and bulk spinach over 100%[10]. The percentage of decrease is largest in the recalled spinach because the corresponding demand has been very low prior to the outbreak due to the higher prices. Second, a gradual recovery pattern is found in all the spinach products, while the bulk spinach seems to be the one that recovers fastest, and the recalled brands do not seem to improve much till the end of the year. Third, there seem to be two "outliers" in the graphs, one is at the 43rd week of non-recalled spinach and the other is at the 45th week of recalled spinach. These outliers are because of the big promotions during these weeks. Recall that this analysis has eliminated the irregular pricing factors and assumes no unusual promotions going on after the outbreak. But in fact, there were some big promotions for bagged spinach after the outbreak in order to recover demand, especially for the recalled brands.

In the Appendix. Figure 2.A2 shows that there is a big markdown and the price is unprecedentedly low at the 45th week for recalled spinach over the three states. The promotions did increase the sales of both recalled and non-recalled bagged spinach for the current period, and the promotion tends to speed up the recovery of demand for non-recalled spinach, but not for the recalled spinach, as the demand for recalled products remains low after the promotion. Fourth, the *AAR*'s of lettuce for the 36th and 37th weeks are negative because the prices are unusually high at these two weeks, which apparently suppresses the actual demand, while the forecasted prices are used to forecast demand for these two weeks due to their unusual patterns

[10] Note that here the "percentage" is not the real percentage of decrease, but a measurement of *AAR* based on the previous sales.

from the previous periods. However, as a substitute of spinach, lettuce does show an increasing trend in sales since the 37^{th} week. Although the percentage of increase is less than 20%, it is a notable amount given that the sales level of lettuce before the outbreak is 741 lbs per store per week on average, while it is only 58 lbs for non-recalled spinach, 5 lbs for recalled spinach, and 40 lbs for bulk spinach. The demand for lettuce then starts declining from 40^{th} week, in which the FDA issued a recall on some lettuce products. A further drop is observed at the 47^{th} week, when the second *E.coli* outbreak was found in lettuce, and the demand for lettuce was not recovered till the end of the year.

The national cumulative average abnormal returns (*CAAR*) for the four categories over the event window are shown in Figure 2.2. The overall impacts of the outbreak can be observed from the graph. The total reductions in demands for non-recalled spinach, recalled spinach, bulk spinach and lettuce are estimated to be 621%, 1074%, 551% and 185%. In addition, as the *CAAR*'s represent the "percentage changes" in demand, individual producers and suppliers can obtain an approximate measurement of the total sales loss over the event window through multiplying the *CAAR* by the average sales of the previous three periods before the outbreak for each product. For example, for the current 29 branches of the superstore chain in the three western states, the estimated losses in sales during the event window (through September to December) for non-recalled spinach, recalled spinach, bulk spinach and lettuce are \$1466, \$418, \$293, and \$2019 per store. Based on these estimates, if the superstore chain has 1500 branches, the total losses in sales are approximately \$2.2 million, \$0.63 million, \$0.44 million and \$3 million for the four categories of products, which reaches a total of \$6.3 million of sales loss. If consumer responses are assumed to be similar across the nation,[11] according to the 2002 Economic Census, which indicates that there are 95,362 grocery stores in the United State, conservative estimates of the total losses of sales of spinach and lettuce products across the nation are $140 million, $40 million, $28 million and $193 million, totaling over $400 million.[12]

Comparisons of AAR by Regions

Figure 2.3 shows the *AAR's* for the four categories by state over the event window. Though the curves in Figure 2.3 intercross during the event window, there is evidence of the different responses across states for some products. California, the state from which the contaminated products originated, does not show a stronger response in terms of reduction in demands for spinach products in the first phase of the outbreak, but it does for lettuce product during the secondary phase. Washington seems to react most intensely to the outbreak in terms of reduction in demand for spinach products, while Oregon shows a mildest response, such that by the end of the 40th week, Oregon has almost recovered its demand for bulk spinach and recalled spinach. It is interesting to find that California is the one that responds least to the promotion in recalled spinach, while Washington is the most active one. The demand for lettuce tends to increase in all states during the 37th to 39th weeks, and the substitution effect is especially clear in Washington.

The *AAR*'s for the four categories over the event window are presented in Figure 2.4 by area. Generally speaking, the difference between urban and rural area in terms of response to the

[11] Although it might not be the case according to the analysis of regional difference, the estimates provide an approximate measurement of the total loss in sales of spinach and lettuce products.

[12] Note that these estimates are based on selected types of spinach and lettuce products, excluding mixed salad products that contain spinach or lettuce.

outbreak does not seem to be notable. Rural area tends to respond a little stronger in deduction of demands for recalled and bulk spinach.

Hypothesis Testing

Hypothesis tests are constructed based on (2.9) through (2.13). First, the hypothesis of significance of the outbreak impacts is tested. The individual national *AAR*'s through 36th week to 51st week, i.e., over the event window t = (-1, 14) and the z-statistics are presented in Table 2.6. The results suggest that the impact of outbreak is overall significant on all the products throughout the event window. The *AAR*'s at 36th week are not significant for both recalled and bulk spinach, which implies less possibility of the leakage of information and the suddenness of the outbreak. The *AAR* for lettuce at 39th week is positive and significant, indicating the substitution effect between spinach and lettuce.

To investigate the rapidity of recovery, the *CAAR*'s are calculated by aggregating *AAR*'s approximately by month. The *CAAR*'s and the z-statistics over different event windows are presented in Table 2.7. Again, the impact of the events is found to be significant on each of the spinach products, but tend to diminish over time. That is, although the *CAAR*'s for all spinach products still remain negative till the end of the year, the magnitudes decline over time, which indicates a gradual recovery pattern. While for the lettuce products, situation tends to be worsened due to the secondary outbreak.

In order to test for regional differences, *Wald* tests based on (2.11) to (2.13) are conducted, and the results are presented in Table 2.8. There is evidence of state and urban-rural differences in some of the products. That is, the extent to which consumers responded to the *E. coli* outbreak varied across regions. Specifically, the difference across states is found in recalled and bulk spinach, as well as lettuce, but not in non-recalled spinach and lettuce. The difference in areas is not significant in non-recall spinach and lettuce, but significant in recalled and bulk spinach such that the rural area tends to buy less after the outbreak.

Conclusions

The 2006 *E. coli* outbreak in California spinach and lettuce caught the attention of the nation. The purpose of this article is to investigate how the outbreak affected the demands for spinach and lettuce products. The event study method is utilized with relaxation of the assumptions that the explanatory variables have to be independent from the event and the error terms are not correlated. The benchmark model is estimated using a structural modeling approach under a spatial model scheme to take care of the potential correlations across stores and products. An ARIMA model forecast approach is used to correct the dependency problem of the explanatory variables. Major findings are as follows. First, demand for spinach products decreased sharply during the outbreak and then recovered gradually after a few weeks. The conservative estimates of total sales losses for selected non-recalled spinach, recalled spinach, bulk spinach and lettuce during the event window are \$140 million, \$40 million, \$28 million and \$193 million, totaling over \$400 million across the nation. Second, the outbreak's effects on different categories of products were distinct, which were reflected by the pattern and speed of the recovery. The bulk spinach tended to recover fastest, while the recalled brands did not seem to improve much till the end of the year, with an exception at the 45th week, which the big promotion in recalled brands boosted up the sales temporarily. Demand for lettuce tended to increase during the first phase of the outbreak, which indicates a substitution effect of lettuce for spinach, then started decreasing because of the consequent outbreak in lettuce, and the demand did not fully recover till the end of the year. Third, promotion is more effective than price adjustment in boosting up sales, and post-outbreak promotion tends to speed up the demand recovery for non-recalled spinach, but not for recalled spinach. Fourth, significant evidence of regional differences in terms of state and rural-urban area was found for some products. California, the state from which the contaminated products originated, did not show a stronger response in terms of reduction in demands for spinach products, but it does for lettuce. Washington tended to show a most intense response to the outbreak in spinach, while the response of Oregon was mildest. By the end of the 40^{th} week, Oregon had almost recovered its demand for bulk spinach and recalled spinach. Moreover, promotion after the outbreak tended to be more effective in Washington, while less effective in California. The regional difference is less significant between urban and rural areas.

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Table 2.1 Variable Descriptions

Variable	Description
R1	Quantity of selected non-recalled bagged spinach sold by a store weekly, in lbs
R2	Quantity of selected recalled bagged spinach sold by a store weekly, in unit of lbs
R3	Quantity of selected types of bulk spinach sold by a store weekly, in unit of lbs
R4	Quantity of selected types of lettuce sold by a store weekly, in unit of lbs
P1	Average weekly price of selected non-recalled bagged spinach in a store, in U.S. dollars
P2	Average weekly price of selected recalled bagged spinach in a store, in U.S. dollars
P3	Average weekly price of selected bulk spinach in a store, in unit of U.S. dollars
P4	Average weekly price of selected lettuce in a store, in unit of U.S. dollars
MK1	Average weekly markdown of selected non-recalled bagged spinach in a store, in U.S. dollars
MK2	Average weekly markdown of selected recalled bagged spinach in a store, in U.S. dollars
MK3	Average weekly markdown of selected bulk spinach in a store, in U.S. dollars
MK4	Average weekly markdown of selected lettuce in a store, in U.S. dollars

Table 2.2 Summary statistics of variables (1^{st} – 51^{th} weeks)

Variable	Obs	Mean	Std. Dev.	Min	Max
R1	1479	40.555	32.323	0.000	241.272
R2	1479	12.201	15.037	0.000	130.375
R3	1479	36.968	30.254	0.000	176.000
R4	1479	625.275	287.164	108.000	2026.000
P1	1421	5.184	1.108	2.181	9.560
P2	1450	7.012	1.540	2.903	9.307
P3	1479	1.366	0.257	0.790	5.981
P4	1479	1.413	0.334	0.635	2.262
MK1	1479	0.731	0.916	0.000	4.142
MK2	1479	0.531	0.920	0.000	5.170
MK3	1479	0.028	0.093	0.000	0.700
MK4	1479	0.067	0.111	0.000	0.603

Table 2.3 Benchmark Model Estimation

	Non-recalled Spinach				Recalled Spinach			
	Coefficient		Std	Elasticity	Coefficient		Std	Elasticity
P1	-8.6558	***	0.4425	-0.9500	0.1267		0.2076	0.0409
P2	-0.7622	**	0.3074	-0.1025	-2.6964	***	0.2113	-1.0652
P3	-3.3082		3.0609	-0.0938	-1.4198		1.8405	-0.1182
P4	12.7917	***	1.2934	0.3849	4.5506	***	0.7583	0.4026
MKj	8.7429	***	0.4658	8.7432	4.9838	***	0.2599	4.9839
LAGRj	0.0073		0.0194	-	0.1206	***	0.0229	-
LLAGRj	-		-	-	-		-	-
ρ	0.5389		-	-	0.2489		-	-
R^2	0.7786				0.6552			

	Bulk Spinach				Lettuce			
	Coefficient		Std	Elasticity	Coefficient		Std	Elasticity
P1	0.3145		0.2310	0.0397	-5.2188	**	2.0690	-0.0431
P2	-0.0339		0.2244	-0.0052	3.0330	*	1.8379	0.0307
P3	-22.1422	***	3.6061	-0.7213	-76.9303	***	21.7933	-0.1644
P4	4.7029	***	0.9281	0.1625	-66.8532	***	7.8329	-0.1515
MKj	27.9991	***	5.2000	27.9872	-		-	-
LAGRj	0.1915	***	0.0278	-	0.4206	***	0.0284	-
LLAGRj	-		-	-	0.2828	***	0.0291	-
ρ	0.4767		-	-	0.7099		-	-
R^2	0.8627				0.9227			

***, **, * denotes significance at .01, .05, .1 level, respectively.

Table 2.4 Estimated ARIMA Models for Prices and Markdowns

Variable	ARIMA Model	Estimated ARIMA model
P1	(1,1,0)	$(1+0.4396B)(1-B)X_t = a_t$
P2	(3,2,(5))	$(1-0.3417B+0.5014B^2-0.6022B^3)(1-B)^2 X_t = (1+0.7939)a_t$
P3	(0,1,1)	$(1-B)X_t = (1-0.6465B)a_t$
P4	(1,2,0)	$(1-0.4926B)(1-B)^2 X_t = a_t$
MK1	(0,0,0)	$X_t = a_t$
MK2	(0,1,1)	$(1-B)X_t = (1-0.5634B)a_t$
MK3	((4),1,0)	$(1+0.3465B^4)(1-B)X_t = a_t$
MK4	(0,1,1)	$(1-B)X_t = (1-0.7501B)a_t$

Table 2.5 Significantly Affected Weeks by Intervention Analysis

Variable	ARIMA Model	Intervention (Significant Weeks)
P1	(1,1,0)	t = 6 (43rd week)
P2	(3,2,(5))	t = -1,0,4,8 (36th,37th,41st,45th weeks)
P3	(0,1,1)	t = 0,1,9 (37th,38th,46th weeks)
P4	(1,2,0)	t = -1,0 (36th,37th weeks)
MK1	(0,0,0)	t = 6,7,9,10 (43rd,44th,46th,47th weeks)
MK2	(0,1,1)	t = -1,4,8 (36th,41st,45th weeks)
MK3	((4),1,0)	t = 0,9 (37th,46th weeks)
MK4	(0,1,1)	t = -1,2 (36th,39th weeks)

Table 2.6 “National” Average Abnormal Returns and Z-statistics over the event window 36th to 51st weeks

		Non-recalled spinach		Recalled Spinach		Bulk Spinach		Lettuce	
T	**week**	AAR	Z-stat	AAR	Z-stat	AAR	Z-stat	AAR	Z-stat
-1	36	-0.1816 ***	-3.4437	-0.3118	-0.915	-0.0888	-1.604	-0.1286 ***	-5.9171
0	37	-0.6047 ***	-11.4605	-1.4053 ***	-4.12	-0.4926 ***	-8.895	-0.0484 **	-2.2291
1	38	-0.7397 ***	-14.0186	-1.3766 ***	-4.037	-1.003 ***	-17.93	-0.0102	-0.4679
2	39	-0.7104 ***	-13.4484	-1.0325 ***	-3.025	-0.6911 ***	-12.47	0.0887 ***	4.0812
3	40	-0.6755 ***	-12.7802	-0.7759 **	-2.272	-0.3738 ***	-6.738	-0.0889 ***	-4.083
4	41	-0.4921 ***	-9.3163	-0.5257	-1.54	-0.4269 ***	-7.7	-0.1173 ***	-5.3919
5	42	-0.5141 ***	-9.7298	-1.0171 ***	-2.979	-0.4014 ***	-7.241	-0.1199 ***	-5.5075
6	43	0.0301	0.5696	-1.0074 ***	-2.953	-0.3482 ***	-6.285	-0.1638 ***	-7.5285
7	44	-0.2702 ***	-5.1176	-0.9649 ***	-2.827	-0.2762 ***	-4.981	-0.1202 ***	-5.5157
8	45	-0.3759 ***	-7.1203	2.6899 ***	7.881	-0.1808 ***	-3.262	-0.1423 ***	-6.5278
9	46	-0.1618 ***	-3.0653	-0.8808 **	-2.58	-0.1288 **	-2.32	-0.1061 ***	-4.8611
10	47	-0.3136 ***	-5.9453	-0.8557 **	-2.508	-0.2727 ***	-4.914	-0.2298 ***	-10.548
11	48	-0.2673 ***	-5.0605	-0.6621 *	-1.94	-0.1614 ***	-2.909	-0.1501 ***	-6.8719
12	49	-0.2669 ***	-5.0507	-0.7916 **	-2.318	-0.2059 ***	-3.707	-0.1903 ***	-8.704
13	50	-0.3667 ***	-6.939	-0.9222 **	-2.7	-0.3321 ***	-5.981	-0.2197 ***	-10.045
14	51	-0.303 ***	-5.7339	-0.9022 **	-2.641	-0.1267 **	-2.283	-0.1003 ***	-4.5816
CAAR		-6.2134 ***	-24.3594	-10.7419 ***	-23.6	-5.5104 ***	-25.58	-1.8473 ***	-18.053

***, **, * denotes .01, .05, .1 significance level, respectively.

Table 2.7 Cumulative Average Abnormal Returns (monthly) and Z-statistics

Event Interval	Non-recalled Spinach		Recalled Spinach		Bulk Spinach		Lettuce	
	CAAR	Z-stat	CAAR	Z-stat	CAAR	Z-stat	CAAR	Z-stat
t = (-1,3)	-2.9119 ***	-24.6694	-4.9022 ***	-6.4257	-2.6493 ***	-21.3422	-0.1873 ***	-3.8538
t = (0,3)	-2.7303 ***	-25.854	-4.5904 ***	-6.726	-2.5605 ***	-23.0458	-0.0588	-1.3518
t = (4,7)	-1.2463 ***	-11.7999	-3.5151 ***	-5.149	-1.4527 ***	-13.1032	-0.5213 ***	-11.9714
t = (8,11)	-1.1186 ***	-10.5952	0.2914	0.4269	-0.7438 ***	-6.7021	-0.6283 ***	-14.4016
t = (12,14)	-0.9367 ***	-10.2328	-2.6159 ***	-4.4216	-0.6647 ***	-6.9118	-0.5104 ***	-13.4683

***, **, * denotes .01, .05, .1 significance level, respectively.

Table 2.8 *Wald* Tests for Regional Differences over the event window

	Non-Recalled spinach	Recalled spinach	Bulk spinach	Lettuce
State	5.2693	108.6828 **	134.9777 **	8.3705 **
Area	0.3251	30.4762 **	4.9421 **	1.5782

Note: $\chi_{1,0.95} = 3.84$, $\chi_{2,0.95} = 5.99$

Figure 2.1 "National" Average Abnormal Returns (*AAR*)

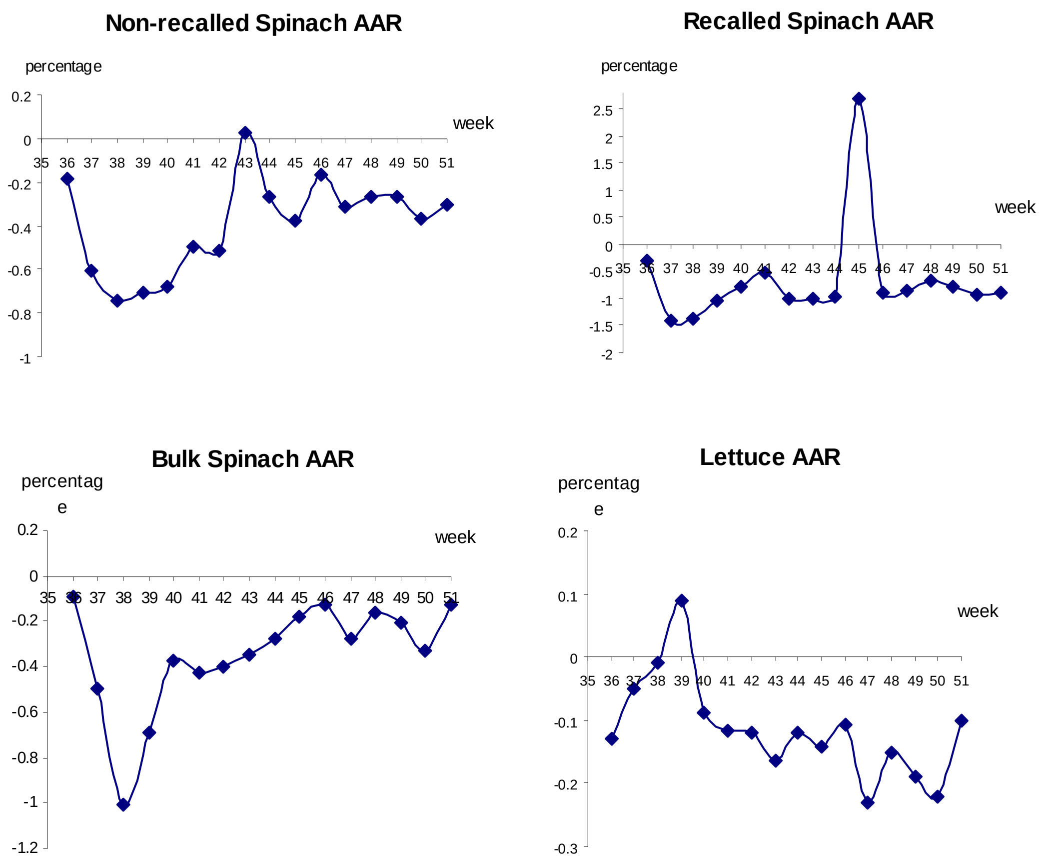


Figure 2.2 National Cumulative Average Abnormal Returns (*CAAR*)

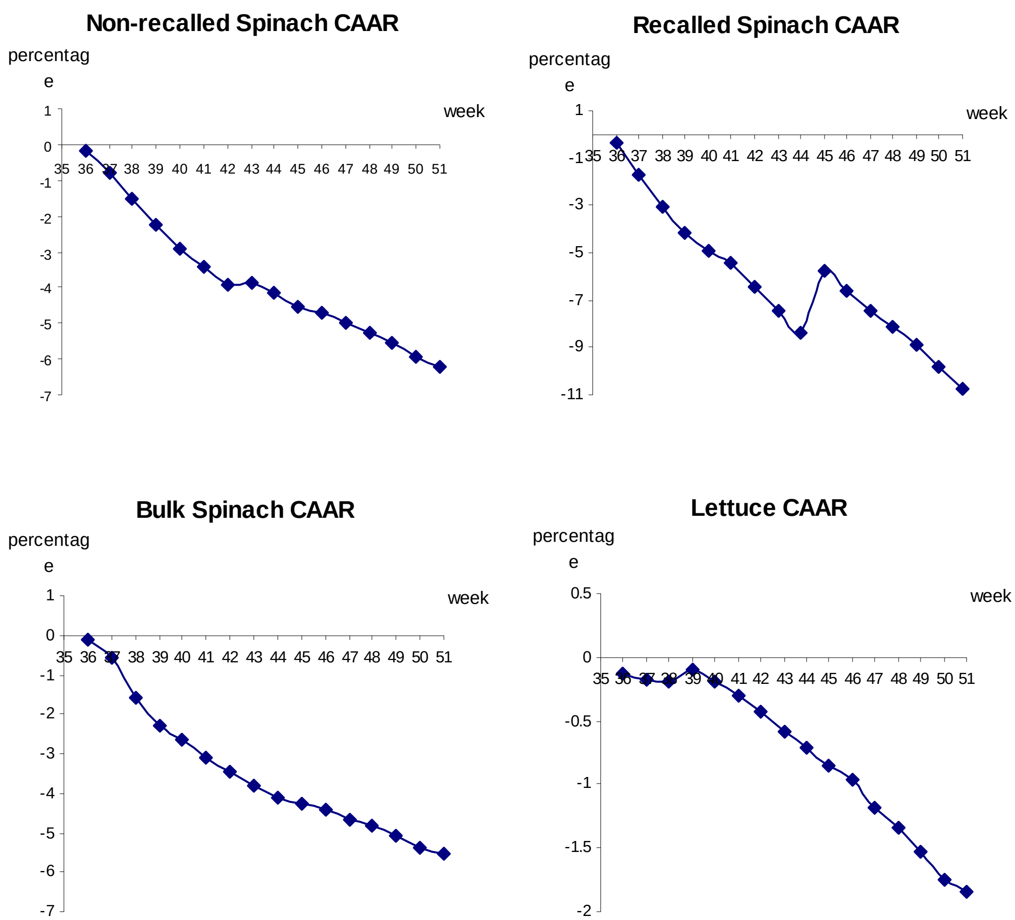


Figure 2.3 Average Abnormal Returns (*AAR*) by State

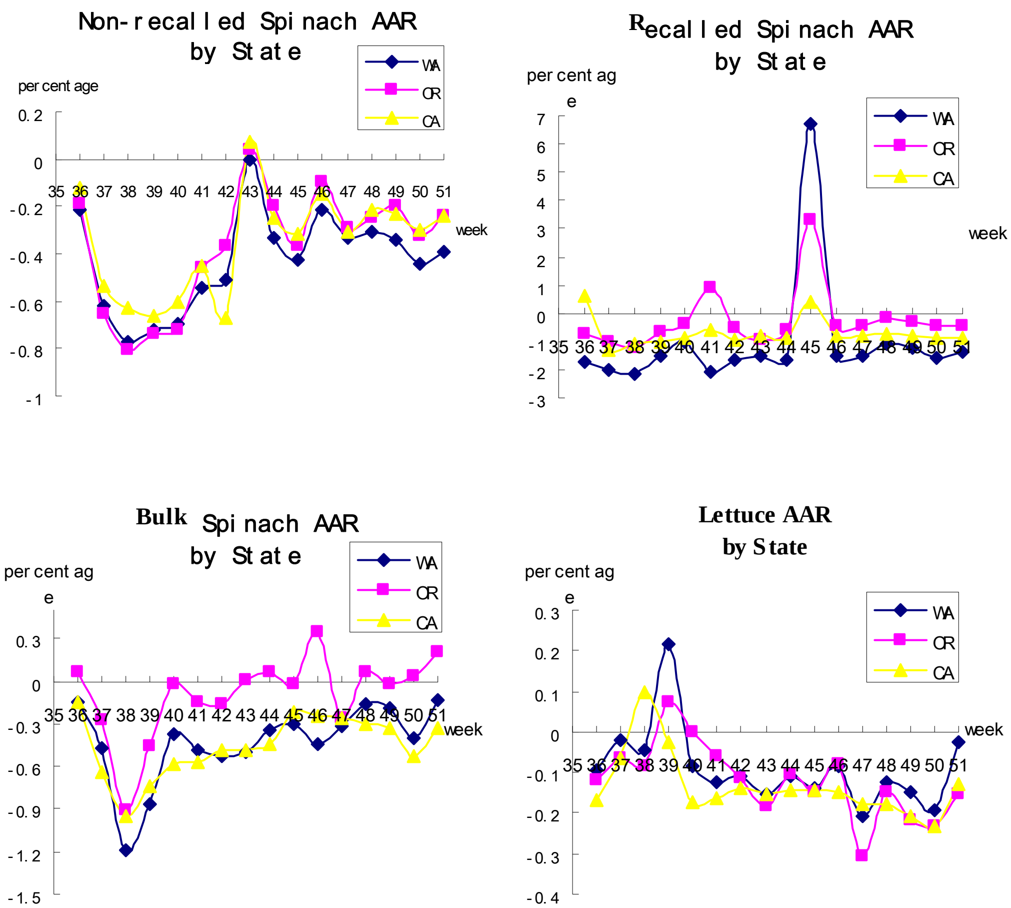
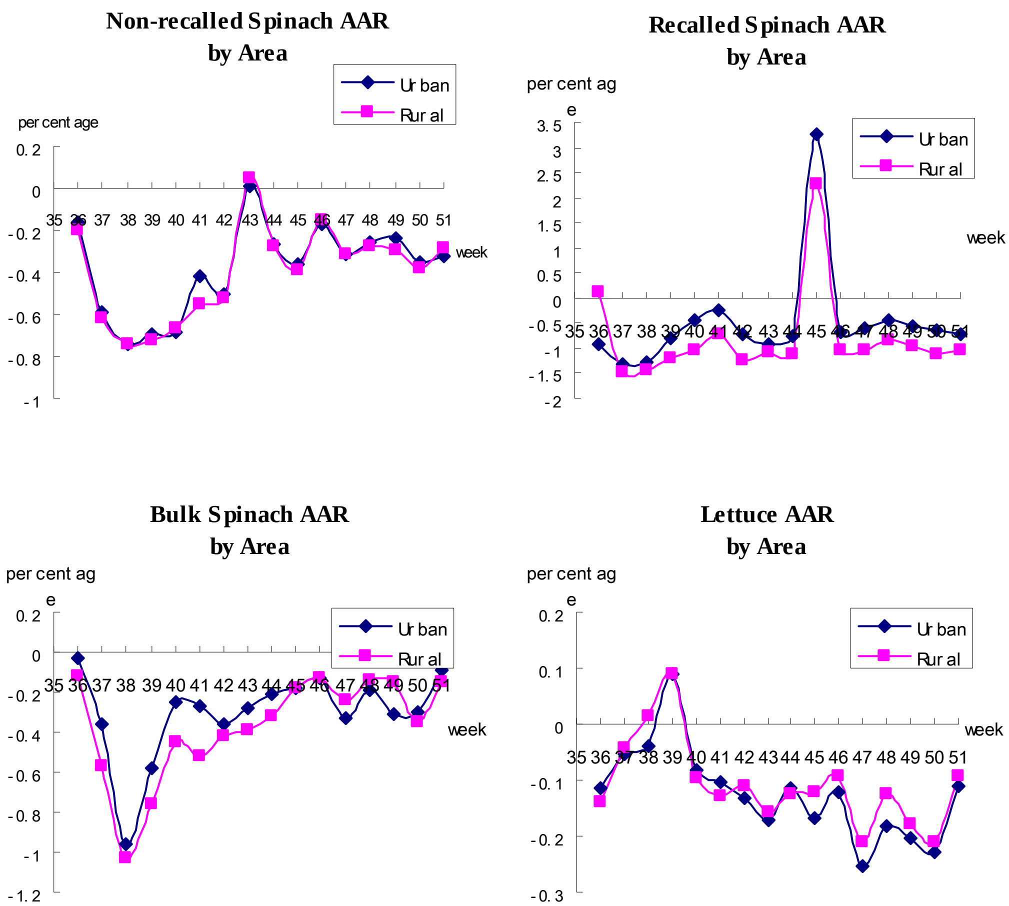


Figure 2.4 Average Abnormal Returns (*AAR*) by Area



Appendix

Table 2.A1 Information on the Selected Stores

Store	Located State	Located Area	Located City	Population
1	CA	Urban	Los Angeles	3,849,378
2	CA	Urban	Fresno	1,002,284
3	CA	Urban	San Jose	929,936
4	CA	Urban	San Diego	1,258,603
5	CA	Urban	Sacramento	476,343
6	CA	Urban	Chico	84,396
7	CA	Rural	Barstow	21,119
8	CA	Rural	Arcata	16,651
9	CA	Rural	King city	11,094
10	CA	Rural	Morro Bay	10,350
11	WA	Urban	Seattle	582,454
12	WA	Urban	Aberdeen	202,370
13	WA	Urban	Spokane	202,000
14	WA	Urban	Everett	101,800
15	WA	Urban	Yakima	71,845
16	WA	Rural	Walla Walla	30,883
17	WA	Rural	Longview	35,570
18	WA	Rural	Wenatchee	27,856
19	WA	Rural	Pullman	24,675
20	WA	Rural	Omak	4,721
21	OR	Urban	Madras	<70,000
22	OR	Urban	Portland	562,690
23	OR	Urban	Salem	149,305
24	OR	Urban	Bend	75,290
25	OR	Rural	Klamath Falls	20,720
26	OR	Rural	Roseburg	20,017
27	OR	Rural	Pendleton	17,310
28	OR	Rural	Lincoln	7,437
29	OR	Rural	Burns/rural	3,064

Table 2.A2 Selected Brands/Types of Products

Brand/Type	Frequency of transaction	Market Percent	Cumulative Frequency	Cumulative Percent
		Category 1: Non-recalled Bagged Spinach		
1	**37553**	**35.27**	**37553**	**35.27**
2	**36840**	**34.6**	**74393**	**69.87**
3	**12477**	**11.72**	**86870**	**81.59**
4	**10330**	**9.7**	**97200**	**91.29**
5	**8250**	**7.75**	**105450**	**99.04**
6	1030	0.97	106480	100
7	2	0	106482	100
8	1	0	106483	100
		Category 2: Recalled Bagged Spinach		
1	**22827**	**68.13**	**30768**	**91.83**
2	**7941**	**23.7**	**7941**	**23.7**
3	**2738**	**8.17**	**33506**	**100**
		Category 3: Bulk Spinach		
1	**48623**	**94.9**	**48623**	**94.9**
2	**2422**	**4.73**	**51045**	**99.63**
3	134	0.26	51179	99.89
4	55	0.11	51234	100
5	1	0	51235	100
		Category 4: Lettuce		
1	**412648**	**45.79**	**412648**	**45.79**
2	**141513**	**15.7**	**554161**	**61.49**
3	**124674**	**13.83**	**678835**	**75.32**
4	**109859**	**12.19**	**788694**	**87.51**
5	**99056**	**10.99**	**887750**	**98.5**
6	7516	0.83	895266	99.33
7	1530	0.17	896796	99.5
8	1142	0.13	897938	99.63
9	1087	0.12	899025	99.75
10	937	0.1	899962	99.85
11	647	0.07	900609	99.92
12	396	0.04	901005	99.96
13	104	0.01	901109	99.97
14	43	0	901152	100
15	2	0	901154	100
16	2	0	901156	100
17	1	0	901157	100
18	1	0	901158	100

Note: The brands/types in bold are the selected brands/types.

Figure 2.A1 Location of Selected Stores

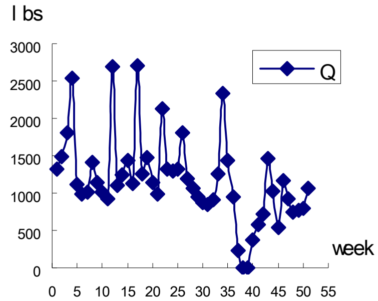
Washington

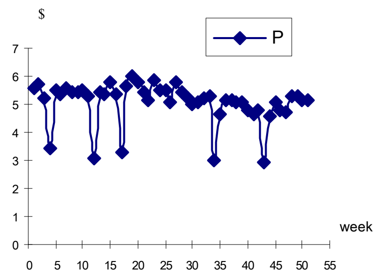
Oregon

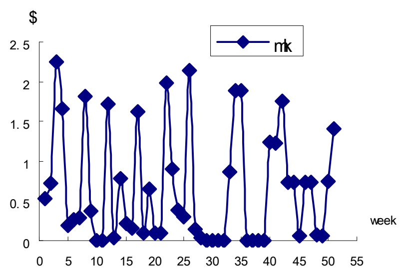
California

Figure 2.A2 Aggregated Quantities Over Three States and Average Prices

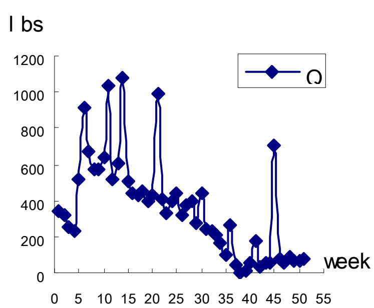
Non-recalled Spinach:

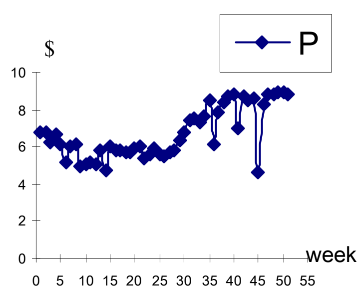


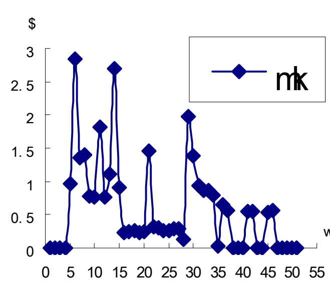




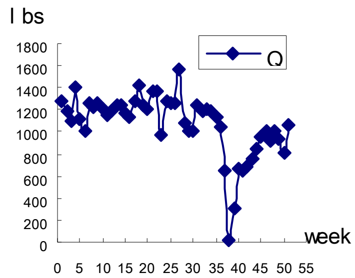
Recalled Spinach:

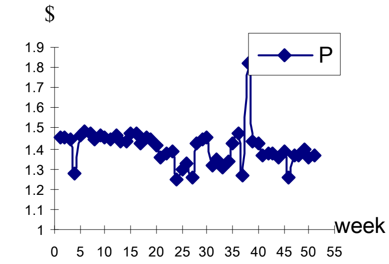


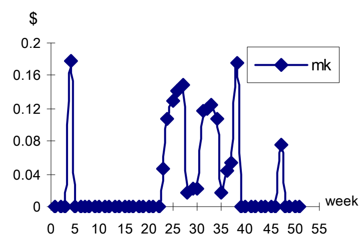




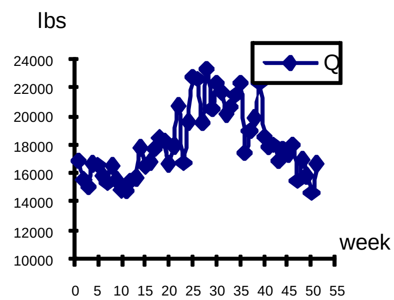
Bulk Spinach:

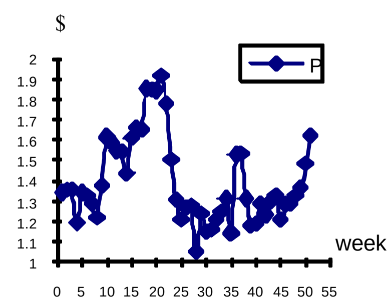


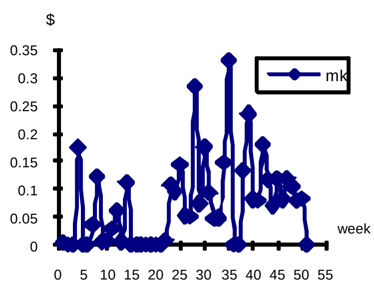




Lettuce:







CHAPTER THREE

DOES BSE CHANGE THE STRUCTURE OF CATTLE TRADE?

AN EVENT STUDY OF CATTLE IMPORTS FROM MEXICO

Summary

The live cattle and beef markets of Canada, Mexico and the United States have become increasingly integrated in the past decades. The markets were severely disrupted in 2003 due to the outbreak of BSE in North America. Even though the BSE panic tended to cease after the resumption of live cattle trade between the United States and Canada, whether or not the market integration can continue on its former path remains a concern of many policymakers and economists. In this paper, the event study method is applied to evaluate the impact of the BSE outbreak and the potential structure change in post-BSE cattle trade between the United States and Mexico by analyzing the "abnormal imports" of Mexican cattle during and after the period that Canadian cattle were banned. A simultaneous model is formulated as the benchmark model for the event analysis. A feasible approach is addressed to correct the problems arising from the usage of a simultaneous benchmark model and the three-stage-generalized least squares (3SGLS) estimation method in event study. Event analysis shows that cattle imports from Mexico tended to remain stable right after the BSE outbreak and then decreased afterwards, which indicates that the interaction of effects of higher cattle price, reinforced safety regulations, increase domestic beef supply, and USDA's announcement of the final minimal risk rule tended to dominate the substitution effect over time. Results indicate that the effect of Canadian cattle trade resumption on Mexican cattle imports was substantial.

Introduction

The recently confirmed new cases of mad cow disease in Canada once again raise concerns about the trade and markets integration in North America. On June 23 and August 15, 2008, Canadian officials announced two new cases of bovine spongiform encephalopathy (BSE), commonly known as mad cow disease, which are the 13^{th} and the 14^{th} BSE cases found in Canada since 2003. The Canadian Food Inspection Agency (CFIA) claimed that Canada remains recognized as a “controlled risk” country for BSE by the World Organization for Animal Health (OIE), and that the recent cases should not have significant impact on exports of Canadian cattle or beef. Nevertheless, according to the ABC Rural Archive and Bloomberg news, Australia banned Canadian beef imports, and live cattle futures for October delivery experienced the largest drop since July 14, which fell 2.05 percent to $1.0585 a pound on the Chicago Mercantile Exchange.

The live cattle and beef markets of Canada, Mexico and the United States have become increasingly integrated in the past decades. Each year, the United States imports a large number of live cattle from Canada and Mexico and exports beef to these two primary cattle trading partners. Before 2003, the United States imported over 2.2 million head of fed cattle from Canada and Mexico every year. The markets were severely disrupted in 2003 by the outbreak of BSE in Canada and the United States. In May, 2003, Canada reported the discovery of a single BSE case and several additional cases followed. Live cattle imports from Canada to the United States were banned after the confirmation of the first Canadian BSE case. Though the U.S. border reopened to Canadian beef very soon in September, Canadian live cattle were not allowed in until July, 2005. During this period, as no BSE case was reported in Mexico, the cattle imports from Mexico to the United States were not interrupted. The BSE panic tended to cease after the resumption of live cattle trade between the United States and Canada. However, whether or not the market integration can continue on its former path remains a concern of many policymakers and economists. With the recurrence of the new BSE cases in Canada recently, this concern may be getting more intense.

The economic impacts of BSE have been widely investigated by economists (Burton and Young 1996; Verbeke and Ward 2001; Herrmann, Thompson and Krischik-Bautz 2002; Piggott and Marsh 2004; Leeming and Turner 2004; McCluskey Grimsrud Ouchi and Wahl 2005; Peterson, Hikaru and Chen 2005; Devadoss, Holland, Stodick and Ghpsh 2006; Lloyd, McCorriston, Morgan and Rayner 2006; Saghaian 2007). Most of these studies focus on price and demand shocks for beef and other meats. For example, Burton and Young (1996) examine the impact of BSE on demand for beef and other meats in Great Britain, and they find that BSE in Europe had both significant short-run and long-run effects on the market share of beef. Piggott and Marsh (2004) analyze consumers' demand for meat products in response to publicized food safety information. Their study reveals that BSE in U.S. had significant impact on consumer demand, but these larger impacts tend to be short-lived. Devadoss et al. (2006) utilize a general equilibrium model to assess the effect of the 2003 BSE in U.S. on foreign and domestic demands. They find a 90% decline in foreign demand and a 10% decline in domestic demand and conclude that only a considerable reduction in domestic demand will result in a economic hardship in the U.S. beef and cattle industry. For the price aspect, Saghaian's study (2007) addresses the dynamic impact of the 2003 BSE discovery on beef price adjustment. McCluskey et al. (2005) evaluate the effects of BSE in Japan on consumers' willingness to pay for beef and they find that consumers are willing to pay a premium for BSE-tested beef. Leeming and Turner (2004) find evidence of joint endogeneity of prices and a significant negative effect of the 1996

BSE crisis on beef price and a significant positive effect on lamb price in UK.

Some studies have specifically focused on BSE and live cattle issues (Mazzocchi 1999; Paiva 2003; Rude, Carlberg and Pellow 2007; Mattson and Koo 2007; Jin, Power and Elbakidze 2008; Marsh, Brester and Smith 2008). Mazzocchi (1999) examines the impacts of the 1996 BSE crisis on the Modena cattle market prices using an event study methodology. He finds that the BSE negatively affected market prices, and that some species showed sign of recovery after the first three months. Paiva (2003) and Jin et al. (2008) study the effects of BSE on U.S. live cattle futures prices. Mattson and Koo (2007) evaluate the effects of lifting trade restrictions after BSE on U.S. cattle and beef prices, and they find that the trade resumption of Canadian cattle and beef would lower prices of cattle and beef. Marsh et al. (2008) examine the effects of BSE in North America on U.S. feeder cattle prices. Their results indicate that the reactions of foreign governments in terms of reduction in demand for U.S. beef were greater than the reactions of U.S. households. Rude et al (2008) investigate the post-BSE Canadian cattle markets, processing capacity and cattle prices. They find that expanded slaughter capacity improves fed cattle prices, but reduced ability to export lower quality beef and increased import competition from commercial grade beef depress cattle prices.

However, there have been limited publications on BSE and the cattle trade between the United States and Mexico. As a matter of fact, Mexico has been one of the primary cattle and beef trading partners of the U.S. for decades, and it is expected to remain an important source of feeder cattle for the U.S. In this article, the event study method is applied to evaluate the impact of the BSE outbreak and the potential structure change in post-BSE cattle trade between the United States and Mexico by analyzing the “abnormal returns” of Mexican cattle imports, namely, “Abnormal Imports”, during and after the period that Canadian cattle were banned. As these three markets are becoming increasingly integrated, both import price and demand for Mexican cattle are potentially affected by the ban of Canadian cattle through 2003 to 2005. Demand for Mexican cattle might shift up as a substitution for Canadian cattle, however, price could be driven up as demand increased. Moreover, the BSE scares and the reinforced safety inspections and regulations on cattle imports after the outbreak could possibly depress the live cattle imports from other countries. Potential changes in the Mexican cattle import pattern would depend on the interactions of these effects.

The objectives of this study are to identify: (1) whether or not U.S. demand for Mexican cattle was affected by the 2003 BSE outbreak, as the Canadian cattle were banned through May 2003 to June 2005; (2) whether or not the cattle trade resumption between the United States and Canada in 2005 has affected U.S. cattle imports from Mexico. This paper contributes to the current literature in the following ways. First, this article formulates a simultaneous model to examine the factors that affect the live cattle imports from Mexico. Empirical results indicate that the simultaneous model yields good estimates for Mexican cattle imports. Second, unlike the previous implementations of the event study method, which often used the market model as the benchmark and OLS estimation, this study formulates a simultaneous model as the benchmark for event analysis. The corresponding approach is addressed to correct the problems arising from the usage of a multi-factor simultaneous economic model as the benchmark and the 3SLS method for estimation. Third, this paper investigates the impact of BSE on cattle imports from Mexico by setting the two time points as event days: May 2003, when the outbreak occurred and Canadian cattle were banned, and July 2005, when the cattle trade resumed between the United States and Canada. This provides perspectives concerning the integration progress of cattle markets in North America by examining the cattle trade between the United States and Mexico in a picture of the three cattle markets in North America, as these markets are becoming more integrated.

In the following sections, the background of the cattle trade in North America is briefly reviewed, then the event study methodology is introduced and data are discussed. This is followed by the benchmark model formulation and estimation over the estimation window, and discussion of the results of event analysis. The conclusions of this study are summarized in the final section.

The Cattle Trade in North America

The United States has the largest feed-cattle industry in the world and is the world's largest producer of beef, primarily high-quality, grain-fed beef for domestic use and exportation. Canada and Mexico have been two primary feeder cattle suppliers of the U.S. for decades. Prior to the 2003 BSE discoveries, the U.S. imported over two million head of cattle from Canada and northern Mexico each year, with Canada and Mexico each supplying about half of the animals. The cattle imported from Canada tend to be animals for immediate slaughter, of which roughly two-thirds were fed steers and heifers and one-third were cows. Those imported from Mexico tend to be lighter cattle, destined for pasture, further finishing and slaughter within the United States. Most Mexican cattle primarily originate in the northern Mexican states. That is because, in the arid and semi-arid states of northern Mexico, the seasonal lack of water limits both forage and grain, and few of the young calves can be fed to maturity either on grass or in feedlots. Thus, most of the calves in this region are exported to the United States for further pasture and finishing to produce beef.

On May 20, 2003, Canadian officials announced that a single BSE-infected cow was discovered in Alberta, Canada. A ban on imports of Canadian beef and cattle by the U.S. immediately followed.

In late December, 2003, the United States confirmed that a dairy cow in Washington State, which had been found to have BSE, was imported from Canada. Right after the 2003 discovery, the U.S. announced a series of new regulations and testing procedures in order to enhance protections against the spread of BSE.

On August 8, 2003, the United States relaxed its ban on Canadian deboned beef from cattle certified less than 30 months old. Imports of Canadian deboned beef resumed in September. However, the progress of cattle trade resumption remained slow. In November, the USDA's Animal and Plant Health Inspection Service (APHIS) published a proposed "minimal risk rule"[1], which lifted the ban of imports of Canadian cattle less than 30 months old. But the implementation of this rule was postponed by a lawsuit and injunction by the Ranchers Cattlemen Action Legal Fund United Stock-growers of America (R-CALF USA) who was seeking a temporary restraining order to prevent the USDA from allowing the importation of live cattle from Canada. In December, 2004, the USDA announced the final rule establishing minimal risk regions for BSE, again, including Canada as one such region. Implementation of the rule was supposed to be on March 7, 2005. However, the U.S. District Court for the District of Montana granted a temporary injunction to prevent implementation of this rule and the U.S. Senate voted 52 to 46 to disapprove it. On March 17, the U.S. Department of Justice, on behalf of the USDA, filed a request with the U.S. Court of Appeals asking that the court overturn the

[1] The proposed minimal risk rule created a new category of "low-incidence countries" of BSE. These countries were recognized as presenting a minimal risk of introducing BSE into the U.S., and cattle trade with the countries in this category was allowed.

decision issued by the U.S. District Court in Montana. In April, the USDA announced that Canada, Mexico and the United States had established a harmonized approach to BSE risk mitigation to more effectively address any BSE risk in North America. In July, 2005, the minimal-risk regions rule was published, and the U.S. border was reopened to Canadian live cattle under 30 months of age.[2]

Before 2003, cattle exports amounted to 25% - 40% of Canada's domestic total slaughter, which primarily went to the United States. The cattle trade ban led to rapid growth in the Canadian cattle inventory during this interim.[3] These animals flooded across the U.S. border as soon as the ban was lifted. During the second half of 2005, over 500,000 Canadian cattle entered the U.S., and about 100,000 head per month continued entering despite the subsequent BSE cases in Canada.

The annual U.S. live cattle imports from Canada and Mexico over the period from 1989 to 2006 are presented in Figure 3.1. Cattle imports from Canada show a fluctuating, but clearly strong upward trend from 1989 to May 2003, when the first BSE case was found and imports of Canadian cattle were banned. Annual live cattle imports from Canada averaged 1.09 million animals from 1989 to 2002 and reached a peak of 1.68 million in 2002. The cattle imports from Mexico showed a relatively stable trend over the years but a very strong seasonal variation in the past decades (Figure 3.2), which depended principally on weather, the financial situation of Mexico cattle farmers, and the price of feeder cattle in the Southwestern United States. There was a dramatic increase in trade in 1995 after NAFTA was implemented the previous year. Live cattle imports from Mexico then declined significantly in 1996 and 1997 because of lower prices

[2] Kenneth et al (2006), "An Economic Chronology of Bovine Spongiform Encephalopathy in North America".

[3] Monte Vandeveer (2007), "Livestock and Meat Trade: A Look at the Effects of BSE".

and a reduced inventory of animals in Mexico due to financial stress and drought in various states in northern Mexico. The impact of BSE on Mexican cattle imports is not clearly shown in the graphs, which calls for further analysis to reflect the interaction effects of various factors.

Event Study Methodology

To examine the response of cattle imports from Mexico to the ban of Canadian cattle in 2003 and to the trade resumption in 2005, the event study methodology is used for the analysis. Event study has a long history. It was first introduced by Fama, Fisher, Jensen and Roll (FFJR) (1969). A number of modifications in the method have been developed to take care of some violations of the classical statistical assumptions[4], e.g., the abnormal return estimates are cross-sectionally correlated, correlated across time, or have greater variance during the event period than the event periods. Event studies have been widely applied to price analysis. Most of the applications are to financial markets in order to analyze securities performances in response to external shocks. Some researchers apply the event study method to agricultural markets to investigate the effects of events on prices: Mazzocchi (1999) uses this method to access the impact of BSE on cattle prices in Italy; Thomsen and McKenzie (2001) use the method to examine the effect of *E.coli* O157:H7 outbreak on wholesale and form-level beef prices.

However, the event study method has rarely been applied to demand analysis in existing literature due to some assumptions imposed on traditional event studies. For example, most event studies use OLS regression to estimate the benchmark model for price series, assuming that the

[4] The classic assumptions for linear models apply, i.e., $E(\varepsilon) = 0$, $Cov(\varepsilon) = \sigma^2 I$, and the matrix of explanatory variables X has full column rank.

price series are not correlated. But in demand analysis, structural modeling approach and special estimation techniques are commonly utilized to take care of the potential correlations. Another crucial assumption in event study is that the explanatory variables of the benchmark model have to be independent from the event in order to obtain reliable estimate of the impact on the dependent variable. This assumption is not a problem for the application to financial markets while applying a market model, where the return of the market portfolio is easily available and is not affected by specific events. It is also not a problem for the application to price analysis in agricultural markets when a mean model is used (Thomsen and McKenzie 2001), or when the explanatory variables in benchmark model are considered strictly independent from the event (Mazzocchi 1999). However, in demand analysis, multifactor economic models are often used. If the assumption that the explanatory variables in the model are not affected by the events does not hold, the quantitative effects estimated by event study approach may be biased. This article addresses feasible approaches to implementing the event study method to demand analysis with relaxation of these assumptions.

The procedure of event study method is as follows: First, define the event of interest and identify the estimation window and event window. The estimation window is a period of time prior to the occurrence of the event. The benchmark model is estimated over this window to obtain the estimates of parameters. The event window is the period surrounding the occurrence of certain event. In this study, the event day is defined as May 2003. Set $t = 0$ for the event day May 2003, the estimation window is then defined through Jan 1989 to Apr 2003, or $t = (-172, -1)$, and data over this period would be used for estimation. The two event windows in this study include: May 2003 to June 2005, or $t_1 = (0, 26)$, which is to examine the impacts of BSE outbreak and the trade bans of Canadian cattle, and July 2005 to December 2006, or $t_2 = (27,$

44), during which the Canadian cattle trade resumed after the outbreak.

Second, specify the benchmark model and estimate the parameters over the estimation window. Assume a linear factor model[5]:

(3.1) $$I_{t1} = X_{t1}\beta_D + \varepsilon_{t1}, \qquad t_1 \in \text{estimation window}$$

$$E(\varepsilon) = 0 \quad \text{and} \quad Cov(\varepsilon) = \sigma^2\psi_D \neq \sigma^2 I.$$

where I_{t1} is the monthly imports of Mexican cattle, X_{t1} represents the multiple factors that affect the cattle imports, and β_D is a vector of parameters to be estimated for the import demand function. One of the classical assumptions in generalized linear model is relaxed here: the error terms are not identically independently distributed. In this paper, a simultaneous model is used as the benchmark and correlation across equations is considered. Moreover, evidence of first order autocorrelation is found after the three-stage least squares (3SLS) estimation. Thus, a three stage generalized least squares (3SGLS) method is used to estimate the benchmark model in order to address the first order correlation problem in a simultaneous model.

Recall that to correct for the first order autocorrelation, the model in (3.1) is transformed using a weighting matrix $c(\rho_D)$ such that:

(3.2) $$c(\rho_D)I_{t1} = c(\rho_D)X_{t1}\beta_D + c(\rho_D)\varepsilon_{t1}$$

or, $$I_{t1}^* = X_{t1}^*\beta_D + \varepsilon_{t1}^* \qquad t_1 \in \text{estimation window}$$

Note that $\psi_D^{-1} = c(\rho_D)'c(\rho_D)$, where $\sigma^2\psi_D$ is the covariance matrix defined in (3.1), and

[5] A linear benchmark model is commonly used in event studies. The argument of the usage of a linear model is that it is the first order approximation of the Taylor Series expansion for any underlining nonlinear specifications. If a nonlinear benchmark model is used, the computation of covariance can be adjusted using the delta method.

$c(\rho_D)$ has a form as follows:

(3.3)
$$c(\rho_D) = \begin{bmatrix} \sqrt{1-\rho_D{}^2} & 0 & 0 & 0 & ... & 0 \\ -\rho_D & 1 & 0 & 0 & ... & 0 \\ 0 & -\rho_D & 1 & 0 & ... & 0 \\ ... & & & ... & & ... \\ 0 & ... & 0 & -\rho_D & 1 & 0 \\ 0 & ... & 0 & 0 & -\rho_D & 1 \end{bmatrix}$$

The covariance matrix of the error terms for the system equations is specified as:

(3.4)
$$\Phi = \begin{bmatrix} \psi_S & \psi_{SD} \\ \psi_{DS} & \psi_D \end{bmatrix}$$

$$= \begin{bmatrix} \sigma_S \otimes \begin{bmatrix} 1 & -\rho_S & 0 & ... & 0 \\ -\rho_S & 1+\rho_S{}^2 & -\rho_S & ... & 0 \\ 0 & -\rho_S & 1+\rho_S{}^2 & ... & 0 \\ ... & ... & ... & ... & ... \\ 0 & 0 & ... & 1+\rho_S{}^2 & -\rho_S \\ 0 & 0 & ... & -\rho_S & 1 \end{bmatrix}^{-1} & \sigma_{SD} \otimes I_n \\ \sigma_{DS} \otimes I_n & \sigma_D \otimes \begin{bmatrix} 1 & -\rho_D & 0 & ... & 0 \\ -\rho_D & 1+\rho_D{}^2 & -\rho_D & ... & 0 \\ 0 & -\rho_D & 1+\rho_D{}^2 & ... & 0 \\ ... & ... & ... & ... & ... \\ 0 & 0 & ... & 1+\rho_D{}^2 & -\rho_D \\ 0 & 0 & ... & -\rho_D & 1 \end{bmatrix}^{-1} \end{bmatrix}$$

where ρ_S, ρ_D, σ_S, σ_{SD}, σ_{DS} and σ_D can be estimated using residuals $\hat{e}_S$ and $\hat{e}_D$ from 3SLS estimation:

$$\hat{e}_S(t) = \hat{\rho}_S \hat{e}_S(t-1) + u_t,$$

$$\hat{e}_D(t) = \hat{\rho}_D \hat{e}_D(t-1) + v_t,$$

$$\hat{\sigma}_S = \hat{e}_S{}'\hat{e}_S / n,$$

$$\hat{\sigma}_D = \hat{e}_D{}'\hat{e}_D / n,$$

$$\hat{\sigma}_{SD} = \hat{\sigma}_{DS} = \hat{e}_S{}'\hat{e}_D / n .$$

The estimates of $\beta = (\beta_S, \beta_D)'$ for the system equations can be obtained as:

(3.5) $$\hat{\beta} = (X_{t1}{}'\hat{\Phi}^{-1}X_{t1})^{-1} X_{t1}{}'\hat{\Phi}^{-1} I_{t1} .$$

An asymptotically consistent estimator of $COV(\hat{\beta})$ is $(X_{t1}{}'\hat{\Phi}^{-1}X_{t1})^{-1}$, where $\hat{\Phi}$ is a consistent estimator of the covariance matrix defined in (3.4).

Third, estimate the "Normal Imports", which are the expected imports without the occurrence of the event over the event window.

(3.6) $$\hat{I}_{t2} = X_{t2}\hat{\beta}_D ,$$

and

(3.7) $$c(\hat{\rho}_D)\hat{I}_{t2} = c(\hat{\rho}_D) X_{t2}\hat{\beta}_D ,$$

or equivalently, $\hat{I}^*_{t2} = X^*_{t2}\hat{\beta}_D ,$ $\quad t_2 \in \textit{event window}$

where X_{t2} denotes the matrix of regressors used to forecast normal imports over the *event window*. Then the estimate of the covariance matrix of $\hat{I}^*_{t2}$ is:

(3.8) $$C\hat{O}V(\hat{I}^*_{t2}) = [c(\hat{\rho}_D)X_{t2}](X_{t1}{}'\hat{\psi}_D{}^{-1}X_{t1})^{-1}[c(\hat{\rho}_D)X_{t2}]',$$

Where $$\hat{\psi}_D = \hat{\sigma}_D \otimes \begin{bmatrix} 1 & -\hat{\rho}_D & 0 & \cdots & 0 \\ -\hat{\rho}_D & 1+\hat{\rho}_D{}^2 & -\hat{\rho}_D & \cdots & 0 \\ 0 & -\hat{\rho}_D & 1+\hat{\rho}_D{}^2 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1+\hat{\rho}_D{}^2 & -\hat{\rho}_D \\ 0 & 0 & \cdots & -\hat{\rho}_D & 1 \end{bmatrix}.$$

Fourth, compute the "Abnormal Imports", which are the differences between the actual imports and the estimated normal imports over the event window.

(3.9) $$AI_{t2} = I_{t2} - \hat{I}_{t2},$$

and

(3.10) $$AI^*_{t2} = I^*_{t2} - \hat{I}^*_{t2} = c(\hat{\rho}_D)AI_{t2},$$

An estimate for the covariance matrix of AI^*_{t2}'s is:

(3.11) $$\begin{aligned} C\hat{O}V(AI^*_{t2}) &= COV(I^*_{t2}) + COV(\hat{I}^*_{t2}) \\ &= c(\hat{\rho}_D) * \hat{\psi}_D * c(\hat{\rho}_D)' + [c(\hat{\rho}_D)X_{t2}](X_{t1}'\hat{\psi}_D^{-1}X_{t1})^{-1}[c(\hat{\rho}_D)X_{t2}]' \end{aligned}$$

Note that AI_{t2}'s are not independent across time if first order autocorrelation exists, but AI^*_{t2}'s are. The variances of AI^*_{t2}'s are then the diagonal elements of $C\hat{O}V(AI^*_{t2})$, denoted by $\hat{V}(AI^*_{t2})$.

Fifth, "Cumulative Abnormal Imports", the abnormal imports are aggregated over the interval of the event window to obtain an overall measure of the impact of the event.

(3.12) $$CAI(\tau_1,\tau_2) = \sum_{t2=\tau_1}^{\tau_2} AI^*_{t2}$$

Since AI^*_{t2}'s are independent, the estimated variance of $CAI(\tau_1,\tau_2)$ can now be computed as:

(3.13) $$\sigma^2(\tau_1,\tau_2) = \sum_{t2=\tau_1}^{\tau_2} \hat{V}(AI^*_{t2})$$

Finally, the following hypothesis is of interest to test the significance of the impact:

(3.14) H_0: $CAI(\tau_1,\tau_2) = 0$

H_a: $CAI(\tau_1,\tau_2) \neq 0$

Under the null hypothesis,

(3.15) $$\frac{CAI(\tau_1,\tau_2)}{[\sigma^2(\tau_1,\tau_2)]^{1/2}} \overset{a}{\sim} N(0,\,1)$$

The null hypothesis can be rejected if the statistic is considerable large, which implies that the impact of the event is significant.

Benchmark Model Specification

Previous papers have built up models in various ways to characterize U.S. imports demands for live cattle, though most of the papers focus on cattle trade between the United States and Canada. Among these studies, Brester, Marsh and Smith (1999) estimated U.S. import demand for Canadian live cattle as a function of the prices of Canadian live cattle, U.S. boxed beef at the retail level, price of beef by-products, lagged U.S. fed cattle marketings and dummy variables representing U.S. tariffs on cattle imports and seasonality. Wachenheim, Mattson, and Koo (2004) use similar models to estimate the inverse demand function for Canadian cattle and the Canadian export supply function. Based on these previous studies, a simultaneous model consisting of the supply (export) and the demand (import) equations is formulated to estimate U.S. imports demand for Mexican cattle.

The supply (export) E_M is considered to be affected by the following factors: (a) export price of Mexican cattle, *PMCATT*; (b) exchange rate between the United States and Mexico, *ERM*; (c) the import price of corn from the United States to Mexico, denoted by *PCORNIM*; (d) lag values of quantity imported, E^S_{M-1}, E^S_{M-12}, which take into account two possible effects: dynamic effect and monthly seasonal effect, respectively.

The demand (import) I_M is hypothesized to vary with respect to: (a) import price of Mexican cattle, *PMCATT*; (b) import price of Canadian cattle, *PCCATT* ; (c) exchange rate between the United States and Mexico, *ERM*; (d) price of corn in the United States, *PCORN*; (e) price of beef in the United States, *PBEEF*. (f) lag values of quantity, I_{M-1}, I_{M-12}.

$$(3.16)\begin{cases} E_M = \gamma_0 + \gamma_1 PMCATT + \gamma_2 ERM + \gamma_3 PCORNIM + \gamma_4 E_{M-1} + \gamma_5 E_{M-12} + \varepsilon_E \\ I_M = \beta_0 + \beta_1 PMCATT + \beta_2 PCCATT + \beta_3 ERM + \beta_4 PCORN + \beta_5 PBEEF + \beta_6 I_{M-1} + \beta_7 I_{M-12} + \varepsilon_I \\ E_M = I_M \end{cases}$$

The supply of Mexican cattle is expected to have a positive relation with the price of cattle. The exchange rate is considered affecting export positively because higher exchange rate means a depreciation of Mexican peso, which encourages export. There are two reasons that the import price of corn in Mexico is used as a factor here. First, corn is the most common feeder grain for live cattle. Thus it can be viewed as an input for the product, cattle. Second, northern Mexico is deficit in feeder grain and it imports mostly from the United States. As an input, the price of imported corn is considered having a negative relation with supply. Moreover, since significant lags are often associated with international trade in basic commodities for the sake of partial adjustment, it is crucial to include in the model the lag value of quantity, E^S_{M-1}, which is expected to have a positive coefficient, to reflect the dynamic effect. The 12th-order lag value, E^S_{M-12}, which denotes the imported quantity of the same month of the previous year, is used to represent the monthly seasonal effect. Usually, E^S_{M-12} is considered being positively related to the current supply.

In the factor demand equation, the United States plays a role as a producer, and the demand for Mexican cattle is viewed as the demand for an input. The United States imports live cattle, which are then grazed and slaughtered to produce beef. Consequently, *PMCATT* and *PCORN* are the prices for the two inputs: live cattle and feeder corn; and *PBEEF* is the price of beef. Based on economic theory, quantity demand is expected to be negatively related to the price of Mexican cattle and the price of feeder corn and be positively related to the price of beef. The coefficient for Canadian cattle price should be positive, since Canadian cattle are substitutes for Mexican cattle. The exchange rate should have a positive effect on demand, since an increase in the exchange rate indicates an appreciation of U.S. dollar, which stimulates the import demand. In general, the lag value of quantity does not affect demand as greatly as it does supply, i.e., consumer's current demand does not tend to be determined by last period's demand. However, in this case, since live cattle are storable goods, the current demand is affected by the stock of live cattle. Thus, the lagged value of quantity is included in the demand model. Again, the 12^{th} order lag of imported quantity is included to reflect the monthly seasonal effect.

In traditional event studies, a necessary condition for the specification of the benchmark model is that the explanatory variables must be independent from the event, i.e., they should not be affected by the occurrence of the event. However, in the simultaneous model above, the cattle prices, the beef prices, or lagged quantities are potentially affected by the BSE outbreak. If prices or imports are depressed by the event, the predicted imports for the later periods based on the declined imports earlier would be biased. In this analysis, a feasible approach is implemented (discussed in later section) to correct the potential bias caused by the dependency of the explanatory variables on the event, which allows the specification of benchmark model to be extended without the restriction of the independence of explanatory variables.

Data

Monthly data from January 1989 to December 2006 for relevant variables were collected from the U.S. Department of Agriculture (USDA) Economic Research Service (ERS) website. Variable descriptions and summary statistics are presented in Tables 3.1 and 3.2.

The monthly quantity of cattle imports/exports is in units of thousand head. The price of cattle is the average price per head, which is calculated by dividing the total value by the total imported quantity, i.e. U.S. dollar/head. The exchange rate is the local Mexico currency (peso) per U.S. dollar. The imported price of feeder corn in Mexico is in Mexico Peso per bushel. The price of corn in the United States is in U.S. dollar per short ton. As for the price of beef, the wholesale price in the United States is used, which is the average value of beef as it leaves the packing plant, measured in cents per pound of retail weight. The prices in the supply function are deflated by monthly Mexican CPIs, and the prices in the demand function are deflated by monthly U.S. CPIs.

Model Estimation

Monthly data over the period January 1989 to April 2003 before the Canadian BSE case, which represents a "normal period", are used for estimation. Durbin-Wu-Hausman tests show that the price of Mexican cattle, *PMCATT*, is endogenous in the model. To address the issue of endogeneity of Mexican cattle prices and the potential cross-sectional correlation between the supply and demand equations, three-stage least squares (3SLS) method is first used to estimate the supply and demand functions simultaneously. Evidence of first order autocorrelation is found in the residuals obtained from 3SLS estimation (see Figure 3.3). Thus, the three stage generalized least squares (3SGLS) method described in (3.2) - (3.5) is used to estimate the benchmark model. The estimation results are presented in Table 3.3. Some of the explanatory variables are insignificant in the factor demand equation. As the variance of $\hat{\beta}$ directly affects the variances of the abnormal imports, AI_{t2}^{*}'s, according to equation (3.11), these insignificant terms result in inefficiency in evaluating the significance of the abnormal imports. Considering the relative importance of Mexican cattle price and beef price based on the production theory, we retain the variables *PMCATT* and *PBEEF* in the model, and the price of Canadian cattle (*PCCATT*) and exchange rate (*ERM*) are removed. The reduced model is then estimated using 3SGLS method again. The results are presented in Table 3.3. Table 3.3 also contains elasticity estimates for the export supply and import demand for live cattle, evaluated at the sample data means.

All estimates have the expected sign. For the supply function, estimates are all highly significant. The own-price elasticity for the supply of live cattle is 1.6, indicating an elastic export supply, i.e., live cattle supply in northern Mexico is sensitive to price changes. The price of imported feeder corn is significant with a negative sign that reflects the role of feeder corn as an input for live cattle product. The supply of Mexican cattle is also very sensitive to the price change in imported corn with an elasticity of -1.7. The significance of exchange rate implies that exchange rate is a crucial factor that affects the live cattle supply from Mexico. The estimates for E_{M-1} and E_{M-12} are also highly significant, which reveals the partial adjustment in the international market and reflects a strong monthly seasonal effect in live cattle trade.

In terms of demand, the Mexican cattle price is insignificant in both the full model and the reduced model, which implies that the cattle price is not a crucial factor that affects the import demand for Mexican cattle. The estimated coefficient for the price of feeder corn is significant with a negative sign in both scenarios, reflecting the role of feeder corn as an input. The price of beef becomes significant in the reduced model with a positive sign, which reflects the role of beef as an output in live cattle trade, and the demand is highly sensitive to beef price with an elasticity of 2.35. Partial adjustments and strong monthly seasonal effect are also reflected in imports demand.

Event Analysis

As discussed in the earlier section, the potential dependency problem of the explanatory variables has to be addressed before the abnormal imports are obtained. The approach is using ARIMA model forecast to "eliminate" the effect of the event on prices. ARIMA model has been proven to be a powerful tool for price analysis and it has been widely applied to price forecasts in economic and financial analysis. First, the series of all explanatory variables except *PMCATT*[6] prior to the event are used to fit in the *ARIMA(p, d, q)* model:

(3.17) $$\phi(B)(1-B)^d X_t = \theta(B)a_t,$$

where $\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$, $\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q$, B is the lag operator, $\phi(B)$ and $\theta(B)$ represent the *AR(p)* factor and the *MA(q)* factor, respectively, $(1-B)^d X_t$ is the d^{th} differenced series to insure stationarity, and a_t is the white noise series. The appropriate *ARIMA* models for series of the explanatory variables including *PCIM, ERM, PCORN, PBEEF* are based on the Akaike's (1974) Information Criterion (AIC) and Schwarz's (1978) Baysian Information Criterion (SBC).[7] The estimated *ARIMA* models are presented in Table 3.4.

Secondly, an intervention analysis is conducted on the above explanatory variables based on the model:

(3.18) $$X_t = \zeta_t + N_t,$$

---

[6] Due to the endogeneity of Mexican cattle price (*PMCATT*) and the 3SLS estimation method, the method for correcting *PMCATT* would be different from the other exogenous explanatory variables.

[7] The ARIMA models are selected on the basis of minimum AIC and SBC, i.e., $-2\ln(L)+2k^2$ and

where N_t is the noise term follows *ARIMA(p,d,q)* decided above, and $\zeta_t = P_t^{\mathrm{T}}$ is a point input accounting for the intervention effect in a way such that $P_t^T = \begin{cases} 0, t \neq T \\ 1, t = T \end{cases}$. Here *T* denotes the period in which the intervention starts. In this case, *T* = 0 since *t* = 0 is set for the event day of the outbreak – May 2003. ζ_t can take different forms to stand for different types of the effect. For example, $\zeta_t = \frac{\omega_0}{1-B} P_t^T = \omega_0 (1 + B + B^2 + ...) P_t^T$ implies checking for a constant "permanent" effect, that is, the event has a quantitatively equivalent effect on all the periods after the occurrence of the event[8]; $\zeta_t = \frac{\omega_0}{1-\delta B} P_t^T = \omega_0 (1 + \delta B + ...) P_t^T$ is checking for a diminishing "permanent" effect if $\delta < 1$; and $\zeta_t = \omega_0 (1 + \delta B) P_t^T$ considers that the event only affects the current and the next periods, and so on. The effect of the intervention is considered to be significant if the coefficients in ξ_t are statistically significant. The purpose of the intervention analysis is to identify the months over which the explanatory variables are significantly affected by the outbreak. The significantly affected months indicated by the intervention analysis are present in Table 3.5. The imported corn price in Mexico and the exchange rate did not seem to be affected by either the outbreak of BSE or the cattle trade resumption between the United States and Canada. The outbreak had some impacts on the prices of corn but the effects tend to be short-lived. The price of beef decreased temporarily in response to the December 2003 BSE

-ln(L)+kln(n), respectively, where L is the maximum likelihood, k is the number of parameters and n is the number of observations.

[8] $BP_t^T = P_{t-1}^T = \begin{cases} 0, t-1 \neq T \\ 1, t-1 = T \end{cases} = \begin{cases} 0, t \neq T+1 \\ 1, t = T+1 \end{cases}$, and so on.

case in the U.S. The prices of corn and beef were not affected by the trade resumption.

Thirdly, for those months that are identified to be have affected, the *ARIMA(p,d,q)* models are used to forecast the predicted values, i.e., the expected prices for imported corn in Mexico, the expected exchange rate, the expected prices of corn and beef in the United States, assuming absence of the outbreak for those months. For consecutive months that were affected, a dynamic forecast is used for the prediction, i.e., the predicted value of current week is computed using the forecasted values of the previous periods instead of the actual values. For those months that the prices and exchange rates are not statistically significantly affected by the outbreak, which are indicated by the intervention analyses, the actual values are kept. In this way, all the explanatory variables, except for *PMCATT*, can now be regarded as "independent" from the event since the impact of the outbreak has been eliminated by the predicted values for those "significant" months.

Fourth, due to endogeneity problem of the prices of Mexican cattle, *PMCATT*, and the 3SGLS estimation method, dynamic forecasting are used to compute the predicted values of *PMCATT* and I_M alternatively based on (3.19) and (3.20). First the variable *PMCATT* in the demand function is regressed against all the other exogenous variables, *PCORNIM, ERM, PCORN, PBEEF,* I_{M-1}, and I_{M-12} over the estimation window, and the following estimates are obtained[9]:

$$\begin{aligned} PMCATT &= \underset{(50.077)}{242.149} + \underset{(0.048)}{0.219}PCORNIM - \underset{(2.332)}{6.403}ERM - \underset{(0.201)}{0.559}PCORN \\ &\quad + \underset{(0.226)}{0.868}PBEEF - \underset{(0.062)}{0.109}\hat{I}_{M-1} + \underset{(0.061)}{0.178}\hat{I}_{M-12} + \varepsilon \end{aligned} \tag{3.19}$$

[9] The values in parentheses are standard errors.

The R-square statistic is 0.66.

$$I_M = -52.115 - 0.437 P M\hat{C}ATT - 0.512 PCORN + 1.393 PBEEF \tag{3.20}$$
$$\quad (39.449) \quad (0.335) \qquad\qquad (0.222) \qquad\qquad (0.698)$$
$$+0.228 \hat{I}_{M-1} + 0.599 \hat{I}_{M-12} + \varepsilon$$
$$(0.072) \qquad (0.071)$$

Since the lagged I_M's are included for the prediction of *PMCATT*, alternative dynamic forecast is used for *PMCATT* and I_M: for t = 0, $PMCATT_{t=0}$ is predicted with actual lagged quantities,[10] as well as the other variables, which have been corrected the dependency problem in the last step. Then $I_{M\,t=0}$ is predicted with the predicted $PMCATT_{t=0}$. For t = 1, follow the same step, except that the predicted $I_{M\,t=0}$ is used instead of the actual to forecast $PMCATT_{t=1}$. Then $I_{Mt=1}$ is predicted with the forecasted $PMCATT_{t=1}$. Replicate for t = 1, …, 12. For t > 12, predicted $I_{M\,-12}$'s are used instead of the actual values.

The forecasts for PMCATT and I_M over the two event windows (May 2003 to June 2005 and July 2005 to December 2006) are estimated using the above method. Then the abnormal imports for Mexican cattle (AI^*) are obtained as the actual minus predicted. The actual Mexican prices versus the forecasts are plotted in Figure 3.4. The plot shows that over the first event window, the actual Mexican cattle prices tend to be higher than the predicted, while over the second event window, the predicted prices capture the actual prices very well. This may imply that after the discovery of BSE in Canada, the prices of Mexican cattle were raised up due to increased demand, and Canadian cattle resumption drove the Mexican cattle price back to pre-BSE level.

[10] When t = 0, the lagged quantities are prior to the event, thus the actual values are used.

The AI^*'s over the event windows are plotted in Figure 3.5. The AI^*'s and the Z-statistics through the two event windows are presented in Tables 3.6 and 3.7, respectively. From Figure 3.5, one can see that the abnormal imports for Mexican cattle tend to remain stable the first a few months after the outbreak and then show a decreasing trend afterwards. After cattle trade resumed between the United States and Canada in July 2005, the AI_{t2}^*'s tend to be more negative. These results indicate that right after the outbreak, the effects of higher cattle price and reinforced regulations might have counteracted the substitution effect. Thus, the change in demand for Mexican cattle is not distinct. The discovery of BSE in the U.S. in December 2003 led to the bans imposed by importers of U.S. beef, triggering an increase in domestic beef supply and a drop-off in beef price, which drove down the demand for Mexican cattle. As the USDA announced the final minimal risk rules in December 2004, with the expectation that the cattle trade between the United States and Canada would resume very soon, demand for Mexican cattle declined further. As the Canadian cattle came in, Mexican cattle imports were depressed down below the pre-BSE level. The abnormal imports over the first event window are not statistically significant except for a few months, while the AI^*'s over the second event window are most negative and significant at .05 level, which indicates a substantial decrease in Mexican cattle imports after the cattle trade resumption between the United States and Canada.

For interests of comparison, the event windows are further divided into some sub-windows (approximately by year). *CAI*'s are aggregated over these sub-windows, and hypothesis tests are constructed according to (3.14) and (3.15). The results of hypothesis tests are presented in Table 3.8. Over the first event window, the *CAI* for the first year after the outbreak is negative but insignificant. For the next year, it is negative and significant. The overall *CAI* for the first event window is -337 and significant at 0.1 level, which indicates that the interactions of effects of higher cattle price, reinforced regulations, increase in domestic beef supply, and announcement of final minimal risk rule had dominated the substitution effect over time. The *CAI*'s over the second event window are all negative and highly significant, which indicates that the effect of Canadian cattle trade resumption on Mexican cattle imports is substantial, and the demand for Mexican cattle had dropped below the pre-BSE level.

Conclusions

Cattle markets in North America have become more integrated over time. The process of integration was interrupted in 2003, owing to the BSE outbreak. Even though the live cattle trade resumed in 2005 between the United States and Canada, whether or not the market integration could continue on its former path remains a concern of many governors and economists. The recent recurrence of BSE cases in Canada highlighted this concern. To investigate the potential structural changes in cattle imports from Mexico to the United States during and after the BSE outbreak, this study implements an event study of the impact of BSE on Mexican cattle imports. A simultaneous model consisting of a supply function and a demand function is formulated as the benchmark model. The econometric analysis shows that imports of Mexican cattle depend on price of corn, price of beef, and lags of imports. Partial adjustments and strong monthly seasonal effects in cattle trade are revealed in the study. Demand is sensitive to beef price changes. The event study analysis shows that over the period that Canadian cattle were banned due to BSE, imports of Mexican cattle remained stable at the beginning and then decreased by the end, which implies that the effects of higher cattle prices, reinforced regulations, increase in domestic beef supply, and announcement of the final minimal risk rule tended to dominate the substitution effect over time. After the trade resumption between the United States and Canada, imports from Mexico had decreased below the pre-BSE level.

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Table 3.1 Variables Descriptions

Variable	Descriptions
E_M/I_M	Quantity of live cattle exported/imported from Mexico into the United States
PMCATT	Price of cattle imported from Mexico (in U.S. dollars per head)
PCCATT	Price of cattle imported from Canada (in U.S. dollars per head)
PCORNIM	Import price of feeder corn from the United States to Mexico (in Mexico Peso/bu.)
PCORN	Price of feeder corn in the United States (in US cents/bu.)
PBEEF	Price of beef in the United States (wholesale value, in cents per pound)
ERM	Exchange rate of U.S. dollar to Mexico pesos
E_{M-1}/I_{M-1}	The 1th order lag value of quantity of live cattle exported/imported from Mexico
$E_{M-1}I_{M-12}$	The 12th order lag value of quantity of live cattle exported/imported from Mexico

Table 3.2 Summary Statistics of Variables

Variable	Obs	Mean	Std	Min	Max
E_M/I_M	172	84.47	56.09	0.23	270.14
PMCATT	172	321.34	41.36	217.00	414.40
PCCATT	172	715.80	64.18	546.50	844.80
PCORN	172	83.69	22.16	43.20	138.40
PBEEF	172	174.75	14.19	147.00	207.20
ERM	172	10.55	1.45	8.57	16.14
PCORNIM	172	115.06	15.73	89.40	182.60
USCPI	172	89.69	9.98	70.31	107.02
MEXCPI	172	58.16	34.86	13.70	116.40

Table 3.3 Estimation Results of Mexican Cattle Export/Imports

Supply

Variable	Estimation of full model (3SGLS) Coefficient	Std	t-ratio	p-value	Elasticity	Estimation of reduced model (3SGLS) Coefficient	Std	t-ratio	p-value	Elasticity
Intercept	-101.324***	36.490	-2.777	0.006	-	-81.629**	33.770	-2.417	0.016	-
PMCATT	0.227***	0.063	3.622	0.000	1.701	0.226***	0.068	3.347	0.001	1.635
PCORNIM	-0.654***	0.185	-3.545	0.000	-1.763	-0.657***	0.199	-3.295	0.001	-1.697
ERM	11.496***	3.614	3.181	0.002	1.113	9.604***	3.378	2.843	0.004	0.810
E_{M_1}	0.322***	0.060	5.411	0.000	0.469	0.350***	0.058	6.047	0.000	0.475
E_{M_12}	0.509***	0.058	8.756	0.000	0.411	0.493***	0.057	8.681	0.000	0.412
ρ_D	0.409***	0.072	5.660	0.000	-	0.403***	0.072	5.540	0.000	-
R-squares	0.645					0.653				

Demand

Variable	Estimation of full model (3SGLS) Coefficient	Std	t-ratio	p-value	Elasticity	Estimation of reduced model (3SGLS) Coefficient	Std	t-ratio	p-value	Elasticity
Intercept	-144.856**	62.220	-2.328	0.020	-	-52.115	39.449	-1.321	0.186	-
PMCATT	-0.377	0.399	-0.944	0.345	-1.601	-0.438	0.336	-1.303	0.192	-1.343
PCORN	-0.620***	0.226	-2.749	0.006	-0.597	-0.512**	0.222	-2.306	0.021	-0.439
PBEEF	1.201	0.733	1.638	0.101	2.617	1.394**	0.699	1.995	0.046	2.350
PCCATT	0.076	0.055	1.396	0.163	0.629	-	-	-	-	-
ERM	5.373	3.520	1.527	0.127	0.532	-	-	-	-	-
I_{M_1}	0.245***	0.083	2.958	0.003	0.356	0.228***	0.072	3.148	0.002	0.407
I_{M_1}	0.600***	0.090	6.703	0.000	0.531	0.599***	0.071	8.433	0.000	0.480
ρ_S	0.514***	0.068	7.560	0.000	-	0.499***	0.069	7.240	0.000	-
R-squares	0.664					0.635				

***, **, * denotes significance at .01, .05, .1 level, respectively.

Table 3.4 Estimated ARIMA Models for Explanatory Variables (Except *PMCATT*)

Variable	**ARIMA Model**	**Estimated ARIMA model**
PCORNIM	((1,3),1,0)	$(1+0.1894B+0.2203B^{3})(1-B)X_t = -6.1873 + a_t$
ERM	((1,4),1,0)	$(1-0.1284B+0.1855B^{4})(1-B)X_t = a_t$
PCORN	(1,1,0)	$(1-0.2329B)(1-B)X_t = a_t$
PBEEF	((12),1,1)	$(1-0.2043B^{12})(1-B)X_t = (1+0.2528B)a_t$

Table 3.5 Significantly Affected Months by Intervention Analysis

Variable	ARIMA Model	Intervention (Significant Months)
PCIM	((1,3),1,0)	–
ERM	((1,4),1,0)	–
PCORN	(1,1,0)	t = 4,5,6,7
PBEEF	((12),1,1)	t = 7,8,9,10

Table 3.6 Abnormal Imports of Mexican Cattle Over the First Event Window: t = (0, 25) (May 2003 – June 2005)

T	MMM/YY	AI*	z-stat	p-value
0	May-03	7.009	0.228	0.820
1	Jun-03	-29.035	-0.797	0.425
2	Jul-03	-7.339	-0.205	0.837
3	Aug-03	-19.893	-0.532	0.595
4	Sep-03	0.095	0.003	0.998
5	Oct-03	70.802*	1.946	0.052
6	Nov-03	21.260	0.585	0.559
7	Dec-03	-6.707	-0.176	0.861
8	Jan-04	-82.076**	-2.296	0.022
9	Feb-04	29.352	0.816	0.415
10	Mar-04	9.766	0.267	0.789
11	Apr-04	-33.374	-0.859	0.390
12	May-04	-36.568	-0.978	0.328
13	Jun-04	-9.253	-0.257	0.797
14	Jul-04	-1.921	-0.054	0.957
15	Aug-04	-17.495	-0.488	0.626
16	Sep-04	9.263	0.259	0.796
17	Oct-04	17.850	0.482	0.630
18	Nov-04	11.468	0.316	0.752
19	Dec-04	-44.073	-1.197	0.231
20	Jan-05	-84.444**	-2.301	0.021
21	Feb-05	9.130	0.248	0.804
22	Mar-05	-16.547	-0.447	0.655
23	Apr-05	-35.664	-0.961	0.337
24	May-05	-30.337	-0.826	0.409
25	Jun-05	-68.049*	-1.901	0.057

***, **, * denotes significance at .05, .1 level, respectively.

Table 3.7 Abnormal Imports of Mexican Cattle Over the Second Event Window: t = (26, 43) (July 2005 – Dec 2006)

T	MMM/YY	AI*	z-stat	p-value
26	Jul-05	-84.012***	-2.934	0.003
27	Aug-05	-86.528***	-2.579	0.010
28	Sep-05	-79.535**	-2.312	0.021
29	Oct-05	-43.313	-1.214	0.225
30	Nov-05	6.748	0.186	0.852
31	Dec-05	-51.039	-1.388	0.165
32	Jan-06	-109.650***	-3.105	0.002
33	Feb-06	-76.115**	-2.160	0.031
34	Mar-06	-40.293	-1.178	0.239
35	Apr-06	-80.752**	-2.402	0.016
36	May-06	-108.226***	-3.156	0.002
37	Jun-06	-111.763***	-3.189	0.001
38	Jul-06	-105.972***	-3.117	0.002
39	Aug-06	-74.723**	-2.206	0.027
40	Sep-06	-75.886**	-2.275	0.023
41	Oct-06	-41.778	-1.253	0.210
42	Nov-06	10.168	0.305	0.761
43	Dec-06	-70.954**	-2.110	0.035

***, **, * denotes significance at .05, .1 level, respectively.

Table 3.8 Cumulative Abnormal Imports of Mexican Cattle and Z-statistics

Event Window		CAI	Z-stat	P-value
t=(0,11)	05/2003 -- 04/2004	-40.139	-0.319	0.749
t=(12,25)	05/2004 -- 06/2005	-296.642**	-2.171	0.030
t=(0,25)	05/2003 -- 06/2005	-336.781*	-1.814	0.069
t=(26,37)	07/2005 -- 06/2006	-864.478***	-7.239	0.000
t=(26,43)	07/2005 -- 12/2006	-1223.623***	-8.437	0.000

***, **, * denotes significance at 0.05, 0.1 level, respectively.

Figure 3.1 U.S. Annual Live Cattle Imports from Canada and Mexico (1989-2006)

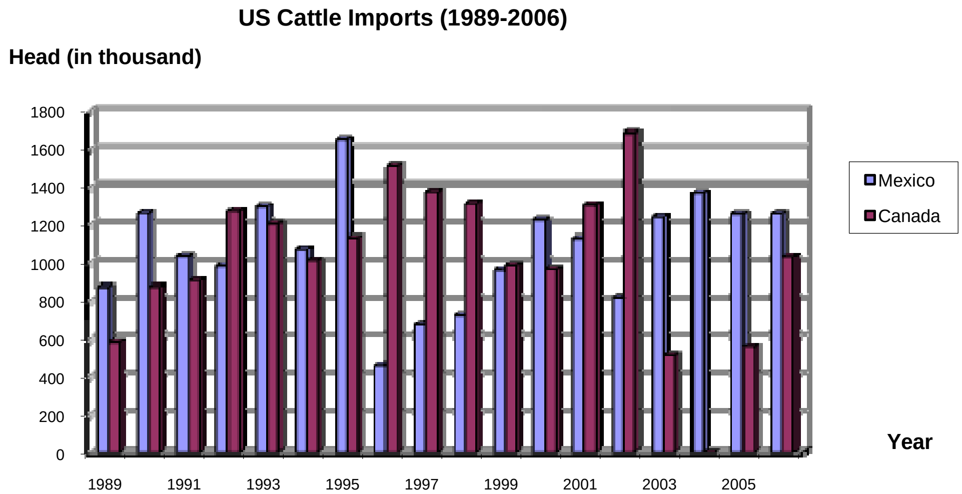
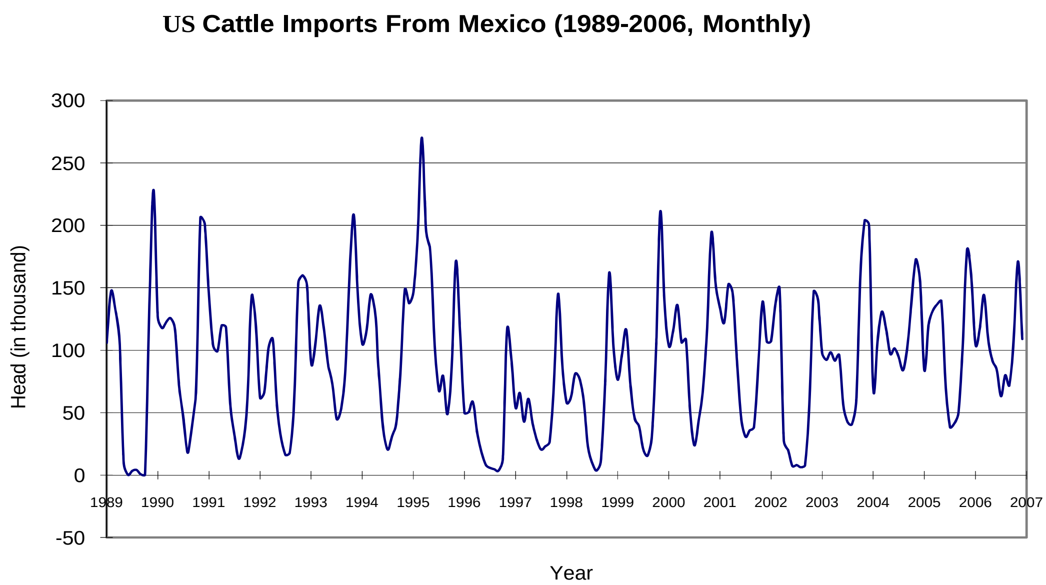


Figure 3.2 U.S. Monthly Live Cattle Imports from Canada and Mexico (1989-2006)



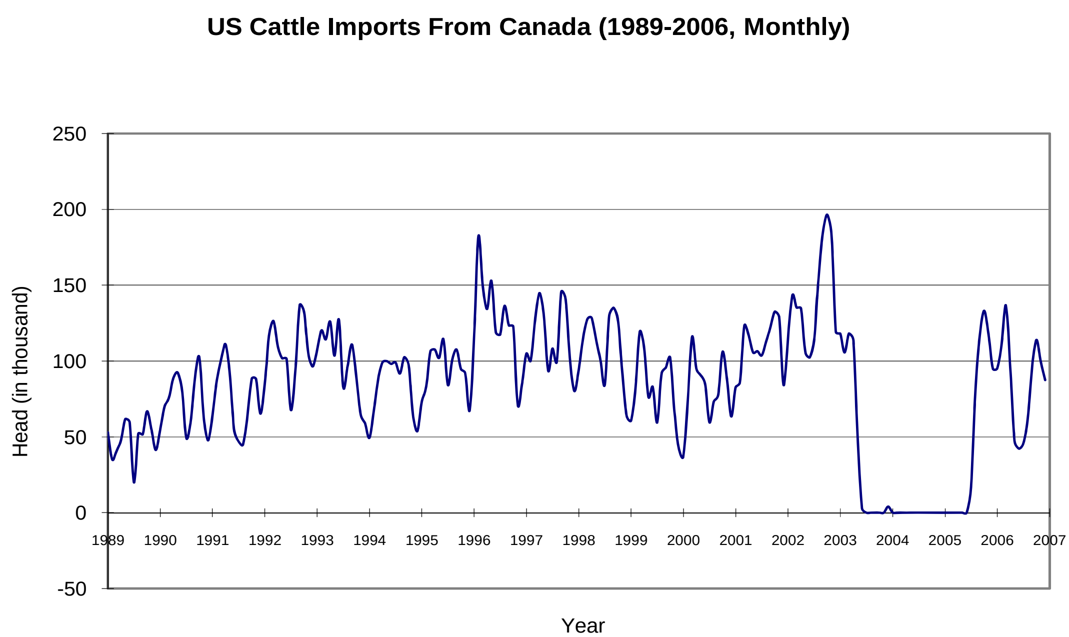


Figure 3.3 Partial Autocorrelations of Residuals from 3SLS Estimation

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                  Partial Autocorrelations of Residuals

Lag   Correlation   -1 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9 1

  1       0.51390    |                .  |**********         |
  2      -0.09363    |                .**|  .                |
  3      -0.05928    |                . *|  .                |
  4      -0.00936    |                .  |  .                |
  5      -0.04915    |                . *|  .                |
  6      -0.07569    |                .**|  .                |
  7      -0.06687    |                . *|  .                |
  8       0.02113    |                .  |  .                |
  9      -0.05292    |                . *|  .                |
 10       0.08885    |                .  |**.                |
 11       0.22628    |                .  |*****              |
 12       0.00311    |                .  |  .                |
 13      -0.13928    |                ***|  .                |
 14      -0.13305    |                ***|  .                |
 15       0.02567    |                .  |* .                |
 16      -0.00923    |                .  |  .                |
 17      -0.13409    |                ***|  .                |
 18      -0.02670    |                . *|  .                |
 19      -0.10274    |                .**|  .                |
 20       0.04187    |                .  |* .                |
 21       0.05393    |                .  |* .                |
 22      -0.07618    |                .**|  .                |
 23       0.13117    |                .  |***                |
 24       0.08003    |                .  |**.                |
```

Figure 3.4 Mexican Cattle Prices (Actual versus Forecast)

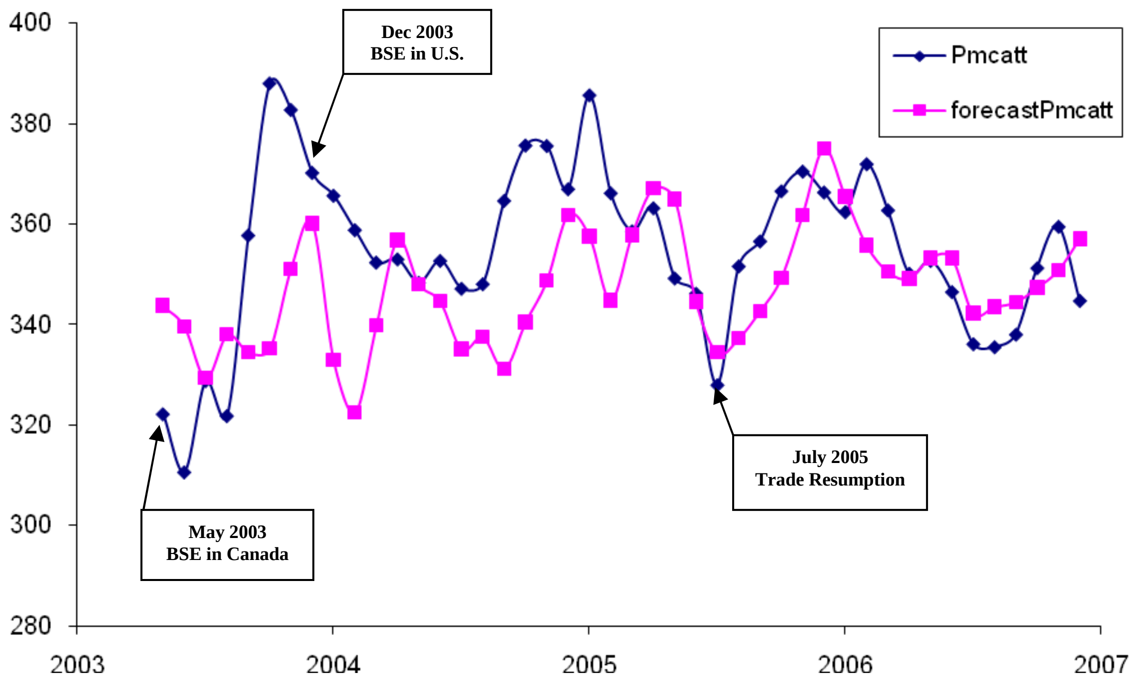
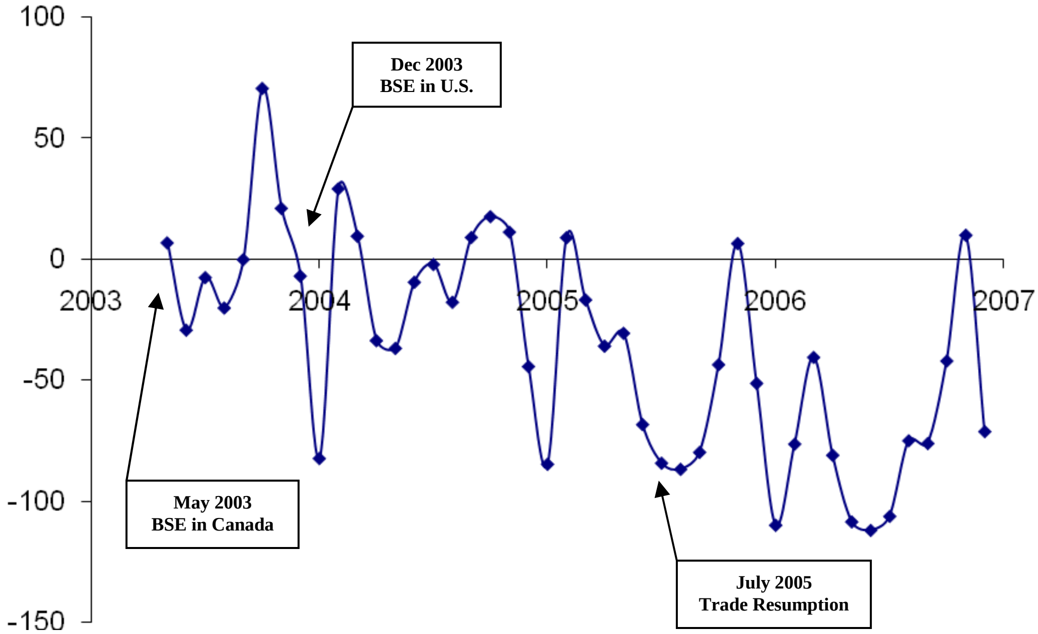


Figure 3.5 Abnormal Imports of Mexican Cattle (May 2003 – Dec 2006)



CHAPTER FOUR

WHAT IS THE "TARGET" QUALITY? CONSUMERS' WILLINGNESS TO PAY FOR ANJOU PEARS

Summary

Ethylene treatment has proven an effective way to shorten the conditioning time of Anjou pears and allows market availability of Anjou pears year round. However, the eating quality of pears may vary under different treatments. A sensory experiment and a consumer survey regarding their assessments of sensory characteristics, their purchasing habits, and demographics were conducted. A double-bounded dichotomous choice contingent valuation model is employed to estimate consumers' willingness to pay (WTP) for Anjou pears and the mean WTP for pears with each of the four treatments: 2 days, 4 days, 6 days with ethylene, and 7 days without ethylene. The model is estimated under four different scenarios and the results are compared. Analysis indicates that the treatment-induced eating quality significantly affects consumers' willingness to pay. The sensory characteristics *firmness*, *sweetness* and *juiciness*, as well as presence of children under 18 years old present in household, are influential factors in determining consumers' WTP. Mean WTP's for the four samples indicate that consumers like the pears with 6-day treatment the most and on average are willing to pay a premium of $0.25/lb compared to the market price.

Introduction

The Anjou pear is one of the most popular pear varieties in the United States. Ninety-eight percent of the Anjou pears in the U.S. are grown in the Pacific Northwest with a production of 12 million boxes (44 lb per box) each year (Chen, 2000). However, the feasibility of marketing immediately after harvest is challenging owing to Anjou pears' special conditioning and ripening requirements. To generate the normal ripening capacity for Anjou pears which are harvested at optimal commercial maturity,[11] the fruits have to be conditioned at 30ºF (-1ºC) for a chilling period of 60 days. The pears without sufficient chilling are termed as "under-chilled" fruit. As Anjou pears are harvested in September, consumers who purchase pears packed prior to November typically complain that the fruits do not soften sufficiently after one week of ripening at room temperature (Kupferman 1994). Thus, the requirement of the chilling period prevents the market availability of Anjou pears with a desirable eating quality during September and October each year.

Scientists have developed methods to shorten the conditioning time for Anjou pears. One way is an ethylene treatment. Chen et al. (1996) found that a 3-day conditioning treatment with ethylene is sufficient to induce normal ripening capacity of under-chilled Anjou pears. This allows year-round marketing of Anjou pears. However, many questions remain unanswered. For example, how do eating quality characteristics of pears vary as the time length of ethylene treatment increase or decrease? Is there a target eating quality of Anjou pears that consumers prefer the most? If such target quality exists, what is the optimal level of ethylene treatment that induces this target quality? What are consumers willing to pay for pears with these target levels

[11] The optimum commercial maturity for Anjou pears requires flesh firmness between 66.7N (15 lbs force) and 57.8N (13 lbs force), (Chen and Mellenthin 1981).

of sensory qualities? These questions call for an analysis of consumer preferences and the eating quality of Anjou pears under different ethylene treatments.

There have been many previous studies that investigate the relationship between food product attributes and consumer preferences. External attributes such as size, grade, cultivars, and reputation are found to be important influences on product price and demand (Tronstad et al. 1992, Carew 2000, Quagrainie et al. 2003). However, internal attributes or eating quality are more essential in determination of consumer preferences in repeated purchases (Kajikawa 1998, Brennan and Kuri 2002, Miller et al. 2005, McCluskey et al. 2007). Kajikawa (1998) argued that internal apple characteristics such as brix, brix/acid ratio, and juiciness have a significant effect on the prices of imported apples in Japan. McCluskey et al. (2007) found that firmness and soluble solids content significantly affect consumers' willingness to pay for Washington Gala apples. Miller et al. (2005) reported that consumers make the decision to purchase apples based on their experiences with internal attributes such as taste and flavor. Moreover, Brennan and Kuri (2002) found that once consumers develop a preference for a product based on sensory characteristics, it is unlikely that they will change.

The measurements of internal attributes, especially for fresh fruit, can be obtained in multiple ways: public information, scientific instruments, and sensory analysis. In a hedonic price analysis of the Japanese market for imported apples, Kajikawa (1998) used publicly available varietal sample averages for growing regions by season to represent the attributes of apples including brix, acid and juiciness. McCluskey et al. (2007) used scientific instruments that are currently available to the apple industry including destructive and non-destructive measurements to identify the objective eating quality of Washington apples, as well as the sensory analysis to obtain the subjective assessments from consumers. Sensory analysis is a method that can be used to quantify and understand consumer responses to food products. Foster (2004) argued that this approach helps researchers to understand and manipulate formulations in a predictable fashion helping clients to develop a successful product. This method has been applied to the economic studies in a wide range of products including wine, dairy, cigars, cheese, meat, citrus, and coffee (Combris et al. 1997; Maynard and Franklin 2003; Freccia et al. 2003; Grunert et al. 2004; Hobbs 2006; Poole et al. 2007; Donnet et al. 2008).

Sensory analysis has also been applied to pears. Predieri et al. (2002) conducted a sensory analysis to evaluate different indicators of preference for two varieties: Harrow Sweet and Williams Bartlett from the Emilia-Romagna region in Italy. They found that a longer shelf-life was positively correlated to perceived juiciness, sweetness, and aroma. Turner et al. (2005) conducted a sensory evaluation of multiple pear products including red and green Anjou, red and green Williams, Bosc, and Comice grown in the U.S. Pacific Northwest. They found that red and green Anjou pears were ranked lower than the other varieties. Their study is a content analysis of pear appearance rankings and overall liking scores, and no eating quality attributes are analyzed.

Willingness to pay (WTP) studies for pear quality attributes have also been performed in previous studies. Gamble et al. (2006) conducted a conjoint analysis to evaluate how consumers value appearance aspects on pears. Combris et al. (2007) conducted an experimental auction to measure the effect of information on the willingness-to-pay for Rocha pears. They found that having access to safety information and tasting the fruit reduced the premium individuals were willing to pay for a higher concentration of soluble solids.

This article utilizes sensory analysis and the contingent valuation (CV) method to evaluate consumers' WTP for Anjou pears with different levels of ethylene treatment. The objective of this study is to estimate a model that examines the relationship between sensory attributes and consumers' WTP for Anjou pears and to test whether the level of ethylene treatment plays an essential role in determining consumers' WTP. A sensory experiment and a consumer survey were conducted to obtain consumers' assessments on pears' eating quality as well as the socio-demographic characteristics, which both affect consumers' WTP for pears. A double-bounded dichotomous choice contingent valuation model is employed to estimate consumers' WTP for Anjou pears and the mean WTP for pears with each of the four levels of ethylene treatment: 2 days, 4 days, 6 days with ethylene, and 7 days without ethylene treatment. This study provides important information for pear producers regarding the most suited post-harvest conditioning procedure for Anjou pears, which induces the most desirable eating quality to fit consumers' preferences.

The remaining sections are organized as follows. The contingent valuation method is presented in the next section. This is followed by the description of the survey data and the discussion of results and implications. The conclusion is summarized in the final section.

Methodology

The CV approach is commonly used to elicit consumer's willingness to pay through a dichotomous choice, market-type questioning format. There are typically two types of bidding procedures used in dichotomous choice CV approaches: the single-bounded and double-bounded dichotomous choice. The double-bounded approach had been proven to be asymptotically more efficient than the single-bounded approach (Hanemann et al. 1999). The single-bounded approach involves only one bid amount by asking participants one dichotomous choice question. The binary responses of participants will be either "yes" or "no" reflecting whether they are willing to buy the product at the offered price. The double-bounded approach engages in two consecutive bids in which the second bid is contingent upon the response to the first bid. That is, a participant is first offered an initial bid and is asked whether he or she is willing to buy the product, if the answer is "yes", which means the individual is willing to pay the amount of the first bid, then a higher price will be presented to the individual as the second bid. If the answer to the first bid is "no", which means the individual is not willing to pay the amount of the initial bid, then she or she will be presented with a lower price as the second bid. Therefore, each individual gives two responses to the two successive bids. The four possible outcomes of responses in a double-bounded model will be: "no, no," " no, yes," "yes, no," and "yes, yes."

Since consumers' WTP is a latent variable which is not directly observable, the sequential questions serve to place upper and lower bounds on the true WTP in a way that consumers' WTP can be partitioned into four intervals based on the answers to the double-bounded bidding questions: (1) $(-\infty, B_D)$, the respondent's WTP is lower than the offered discounted price B_D when both bids are rejected ("no, no"); (2) $[B_D, B_I)$, the respondent's WTP is between the lower bid B_D and the initial bid B_I when the initial bid is rejected but the lower bid is accepted ("no, yes"); (3) $[B_I, B_P)$, the respondent's WTP is above the initial bid but lower than the higher bid B_P when the initial bid is accepted but the higher bid is rejected ("yes, no"); (4) $[B_P, +\infty)$, the respondent's WTP is higher than the premium price when both bids are accepted ("yes, yes").

Let WTP_i denotes individual i's WTP for the tasted pear. The discrete outcomes of the bidding process are:

(4.1) $$Y = \begin{cases} 1 & if \;\; WTP_i < B_D \\ 2 & if \;\; B_D \leq WTP_i < B_I \\ 3 & if \;\; B_I \leq WTP_i < B_P \\ 4 & if \;\; WTP_i \geq B_P \end{cases}$$

The WTP function (or bid function) for the specific type of pear for individual *i* is specified as:

(4.2) $$WTP_i = \alpha - \rho B_i + \lambda' z_i + \varepsilon_i, \quad \text{for } i = 1, \ldots, n$$

where B_i is the ultimate bid that individual *i* faces, z_i is a vector of explanatory variables associated with individual *i*, including the assessments of eating attributes and the demographics; the error term ε_i captures possibly unobservable factors and characteristics affecting the decision. α, ρ, and λ are the unknown parameters to be estimated. The distribution of the error term is assumed to follow a cumulative logistic distribution with mean zero and variance σ^2, i.e., $\varepsilon \sim G(0, \sigma^2)$. In the empirical implementation of the model, we define G(·) to have a standard logistic distribution having zero mean and standard deviation $\sigma = \pi / \sqrt{3}$.

The qualitative dependent variable in (1) can be expressed as the choice probability for individual *i*:

(4.3)

$$\Pr(Y_i = j) = \begin{cases} = \Pr(WTP < B_D) = G(\alpha - \rho B_D + \lambda' z_i) = \dfrac{e^{\alpha - \rho B_D + \lambda' z_i}}{1 + e^{\alpha - \rho B_D + \lambda' z_i}} \\ = \Pr(B_D \leq WTP < B_I) = G(\alpha - \rho B_I + \lambda' z_i) - G(\alpha - \rho B_D + \lambda' z_i) = \dfrac{e^{\alpha - \rho B_I + \lambda' z_i}}{1 + e^{\alpha - \rho B_I + \lambda' z_i}} - \dfrac{e^{\alpha - \rho B_D + \lambda' z_i}}{1 + e^{\alpha - \rho B_D + \lambda' z_i}} \\ = \Pr(B_I \leq WTP < B_P) = G(\alpha - \rho B_P + \lambda' z_i) - G(\alpha - \rho B_I + \lambda' z_i) = \dfrac{e^{\alpha - \rho B_P + \lambda' z_i}}{1 + e^{\alpha - \rho B_P + \lambda' z_i}} - \dfrac{e^{\alpha - \rho B_I + \lambda' z_i}}{1 + e^{\alpha - \rho B_I + \lambda' z_i}} \\ = \Pr(WTP \geq B_P) = 1 - G(\alpha - \rho B_P + \lambda' z_i) = 1 - \dfrac{e^{\alpha - \rho B_P + \lambda' z_i}}{1 + e^{\alpha - \rho B_P + \lambda' z_i}} \end{cases} \quad for \quad j = \begin{Bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{Bmatrix}$$

The log-likelihood function is:

$$(4.4)\quad L = \sum_i \begin{cases} I_{Y_i=1} \ln G(\alpha - \rho B_D + \lambda' z_i) \\ + I_{Y_i=2} \ln[G(\alpha - \rho B_I + \lambda' z_i) - G(\alpha - \rho B_D + \lambda' z_i)] \\ + I_{Y_i=3} \ln[G(\alpha - \rho B_P + \lambda' z_i) - G(\alpha - \rho B_I + \lambda' z_i)] \\ + I_{Y_i=4} \ln[1 - G(\alpha - \rho B_P + \lambda' z_i)] \end{cases}$$

where $I_{Y_i=j}$ is an indicator function for the event that individual i chooses the j^{th} alternative. Maximum likelihood method is the commonly used approach to estimate the model.

Mean WTP and Marginal Effects

There are two ways to compute the mean WTP in literature. An approach proposed by Hanemann (1989) is to re-estimate the likelihood function by restricting all the λ's to be zero and obtain the constrained $\tilde{\alpha}_j$ and $\tilde{\rho}_j$, the mean WTP for the j^{th} sample is then calculated as $\tilde{\alpha}_j / \tilde{\rho}_j$. An alternatively approach is based on a random utility framework, where consumers are willing to buy Anjou pears when the utility of purchasing the pears is at least as great as purchasing the other commodities (Kaneko and Chern, 2003). The mean WTP can be calculate as $(\alpha + \lambda' z_i) / \rho$. The latter approach is used in this study since consumers' demographic characteristics are considered playing a role in affecting their willingness to pay for Anjou pears.

The Marginal effect of an explanatory variable on WTP represents the impact of an incremental change in the variable on consumers' mean willingness to pay for Anjou pears. It can be calculated as the partial derivative of the mean WTP function with respect to the k^{th} explanatory variable: $\partial(WTP) / \partial z_k = \lambda_k / \rho$.

Data

The sample pears were commercially harvested from one orchard in mid-September and were placed into a warm room (72ºF) for 24 hours prior to storage in the cold (33ºF). Then they were moved to a conditioning room held at 65 ºF - 74 ºF for treatments with or without ethylene (2 days, 4 days, 6 days with ethylene and 7 days without ethylene). Following conditioning, all fruit were returned to cold storage (33ºF) to simulate transit. Before they were presented to consumer for evaluation, the fruit were ripened at room temperature (68ºF) for 3 days, just as what a consumer would usually do at home.

A consumer survey including the sensory experiment was conducted in Portland, Oregon, in October, 2008. Participants were recruited by phone and were offered a $25 incentive for their participation. In total, one hundred and twenty individuals participated in the survey. The participants were asked to taste the four samples of Anjou pears with different treatments, then they were asked to rate the attributes of tasted pears including overall liking, flavor, sweetness, juiciness, firmness, and texture, using a 9-point liking scale with 1 denoting “dislike extremely”, 5 “neither like nor dislike”, and 9 “like extremely.” The order of sample presentations was random by treatment, and the respondents were not informed about the treatment any sample received. The WTP questions were asked in conjunction with the taste experiment. The participants were also asked about their preferences and shopping habits, as well as demographic information. Summary statistics of the main socio-demographic variables are presented in Table 4.1. A comparison of the participants’ demographics with the 2000 U.S. Census for Portland, Oregon is presented in Table 4.2. Table 4.3 presents summary statistics of consumers’ ratings for the sensory characteristics of the sample pears with different numbers of days of ethylene treatment.

The majority of the survey respondents were Caucasian (91%) and female (78%). These proportions are higher than those for the whole population in Portland. The median age of the participants was in the range 35 to 44 years, which contains the median age of the population 35.2. Only 25% of the responded households had children under 18 years old. The level of education in our sample is higher than the general population. Thirty-one percent have 2-year college or technical degree, and 69% have a Bachelor's or higher degree. The median income was within the range $40,000 to $59,999, which was also the mode income range, containing the median household income $40,146.

Sixty-four percent of the respondents reported that they eat fresh pears every week when they are in season. The vast majority (90%) of the respondents prefer "locally grown" pears. Most people consider price as an important factor when purchasing pears with 60% "somewhat important" and 20% "extremely important." Appearance (lack of blemishes or marks) is also considered important by many consumers (69%). Twenty-four percent of the respondents answered that it is "extremely important" that the purchased pears are organic, and 46% reported it is "somewhat important." About 48% stated that they usually buy organic pears. These percentages for buying organic questions reveal a fact that a considerable proportion of respondents value organic as an important character of pear quality. This result is consistent with that of a national survey conducted by Seeds of Change, a producer of premium organic products, who finds that Portland is one of the top three cities where people have a better understanding and a higher preference for organic products, and thus earns its reputation as "Organic Einstein".

The WTP questions in this study were designed based on the double-bounded dichotomous choice format to elicit consumers' WTP for Anjou pears with different levels of ethylene treatment. After tasting one pear sample, the respondents were asked if they would be willing to purchase the pears at an initial price $1.49/lb. This initial price was selected based on the average of pear prices in the grocery stores during the first week of October in the Portland metro area, where the survey was conducted. Then a follow-up question was asked regarding whether they would like to pay a discounted or premium price depending on their response to the initial price. The discounted price was then set at one of the following levels: $1.39/lb, $1.29/lb, $1.19/lb, $1.09/lb, or $0.99/lb. Similarly, the premium price was set at one of the following levels: $1.59/lb, $1.69/lb, $1.79/lb, $1.89/lb, or $1.99/lb. Each discount/premium level was randomly used for one-fifth of the surveys, and the survey versions were randomly assigned to the respondents. The distribution of responses to the discount and premium bids offered is presented in Table 4.4.

In response to the questions about preferences for pear attributes, most respondents indicated that they most liked the pears with 6-day ethylene treatment, followed by the 4-day treatment, then the 2-day treatment pears, and liked least the pears without ethylene treatment. The average overall liking rating was 7.46 out of 9 for 6-day treatment pears, and only 4.26 for pears without ethylene treatment. The ratings reveal that the internal attributes or eating quality of the pears, such as flavor, sweetness, juiciness, and texture, improved significantly by increasing the number of days with ethylene treatment. Correspondingly, a majority of the respondents (76%) were willing to pay a premium for the 6-day treatment pears, and about half (46%) were glad to pay even above the premium price. Only half of the consumers were willing to pay a premium for the 4-day treatment pears, and the other half rejected buying the pears at the initial price $1.49/lb. For the 2-day treatment and no treatment samples, most of the respondents (79% and 77%, respectively) expressed that they would not buy the pears at the initial price, and over half of the respondents (49% and 58%, respectively) would not buy the pears if offered at the discounted price.

Model Specification

Due to multicollinearity among the variables representing the pear characteristics, sweetness, juiciness and firmness are chosen as the representative tasting factors in the empirical model, owing to their importance as internal attributes of fresh fruit according to previous studies (Kajikawa 1998, McCluskey et al 2007). Consumers' demographic variables age, gender, children, ethnicity, and income are also included. The model is estimated under four different scenarios: (1) data are grouped by treatment (2) pooled data; and (3) pooled data with three dummy variables indicating treatments; and (4) pooled data with inclusion of dummy variables and interaction terms of dummies and attributes.

The first two scenarios utilize the following model specification:

$$(4.5)\quad WTP_i = \alpha - \rho B_i + \lambda_1 Sweetness_i + \lambda_2 Juiciness_i + \lambda_3 firmness_i + \lambda_4 Children_i + \lambda_5 Age_i + \lambda_6 Gender_i + \lambda_7 Ethnicity_i + \lambda_8 Income_i + \varepsilon_i \,.$$

where $i = 1, \dots, n$ denotes the i^{th} individual; $j = 1, 2, 3, 4$ represents the j^{th} sample; B_i is the final bid that individual *i* was offered; *Sweetness, Juiciness*, and *Firmness* are individual *i*'s ratings for the pear attributes; *Children* is an variable indicates the presence of children under 18 years old in the household; *Age* indicates the age group to which the i^{th} respondent belonged; *Gender* indicates whether the respondent is male; *Ethnicity* indicates the individual is Caucasian; *Income* indicates the income level of the household, and the unknown parameters α, ρ, and λ*'s* are to be estimated.

The third scenario includes indicator variables for treatment received:

$$(4.6) \quad WTP_{ij} = \alpha_j - \rho_j B_{ij} + \lambda_{j1} Sweetness_{ij} + \lambda_{j2} Juiciness_{ij} + \lambda_{j3} firmness_{ij} + \lambda_{j4} Children_{ij}$$

$$+ \lambda_{j5} Age_{ij} + \lambda_{j6} Gender_{ij} + \lambda_{j7} Ethnicity_{ij} + \lambda_{j8} Income_{ij} + \lambda_9 D_2 + \lambda_{10} D_4 + \lambda_{11} D_6 + \varepsilon_i ,$$

Where D_2, D_4, D_6 are dummy variables indicating the tasted sample received 2 days, 4 days and 6 days ethylene treatment, respectively.

The last scenario includes both the indicator variables for treatment received and the interaction terms of indicators with attributes:

$$\begin{aligned} WTP_i = \alpha - \rho B_i &+ \lambda_1 Sweetness_i + \lambda_2 Juiciness_i + \lambda_3 firmness_i \\ &+ \lambda_4 Children_i + \lambda_5 Age_i + \lambda_6 Gender_i + \lambda_7 Ethnicity_j + \lambda_8 Income \\ &+ \lambda_9 (D_2 * Sweetness_i) + \lambda_{10} (D_4 * Sweetness_i) + \lambda_{11} (D_6 * Sweetness_i) \\ &+ \lambda_{12} (D_2 * Juiciness_i) + \lambda_{13} (D_4 * Juiciness_i) + \lambda_{14} (D_6 * Juiciness_i) \\ &+ \lambda_{15} (D_2 * Firmness_i) + \lambda_{16} (D_4 * Firmness_i) + \lambda_{17} (D_6 * Firmness_i) \\ &+ \lambda_{18} D_2 + \lambda_{19} D_4 + \lambda_{20} D_6 + \varepsilon_i \end{aligned} \quad (4.7)$$

The reason for considering alternative model specifications is to identify whether there exists a treatment effect other than the effects of the three treatment-induced pear attributes, and whether the effects of the pear attributes on consumers' WTP differ across samples.

Results and Implications

The models in (4.5)-(4.7) are estimated using the Maximum likelihood method with the GAUSS statistical package. The parameter estimates are presented in Tables 4.5 – 4.7. We first discuss the results of the data are grouped by treatment, which is presented in Table 4.5. As expected, the bid offered to the respondents has a negative relationship with the WTP level and is statistically significant for all the four samples. This means the pears are a normal good, and, *ceteris paribus*, consumers are less likely to buy a good that is more expensive. *Firmness* is significant for all treatments, but *Sweetness* and *Juiciness* are not significant for some samples. The possible reason could be that consumers' ratings for these characteristics may be similar within a certain sample, thus they do not play a significant role in explaining the WTP. Most of the demographics are not statistically significant for the four samples, except for *Children*, *Gender*, and *Income* in some cases. The presence of children under 18 years old in the household tends to increase the probability of buying 4-day and no-treatment pears. Women are less likely to buy the 2-day treatment pears compared to men. Respondents with higher incomes like the 2-day treatment pears less.

The parameter estimates under scenarios 2 and 3 are presented in Table 4.6. We first discuss scenarios 3 -- the model with variables indicating the three types of ethylene treatment effects: 2 days, 4 days, and 6 days. The three sensory variables *Sweetness*, *Juiciness* and *Firmness* are all positive and statistically significant. At the same time, the three treatment indicator variables are all insignificant, which suggests that it is the treatment-induced eating qualities that affect consumers' willingness to pay.

In the pooled model without the treatment indicator variables (scenario 2), the results are similar to the model with the treatment variables. The three sensory variables *Sweetness*, *Juiciness* and *Firmness* are all positive and statistically significant. The significance of these variables reveals that these sensory attributes are important when consumers make repeat purchase decisions. As is the previous estimations, most of the demographic variables are insignificant except for the *Children* variable, which has a positive and significant relationship with WTP.

The estimates under scenario 4 are presented in Table 4.7. Results indicate that the 6-day treatment and the interaction of 6-day treatment and sweetness attribute are statistically significant. The model is then re-estimated with the other insignificant dummies and interaction terms removed. The estimation results for the reduced model are also presented in Table 4.7. The results for the other explanatory variables are consistent with those under the other scenarios. The positive and significant coefficient of *D6* implies that consumers have a higher WTP for the 6-day sample for some reasons besides the three eating attributes. The negative and significant coefficient of *Sweetness**D6* indicates that for the 6-day sample, sweetness has less effect on WTP compared with the other three samples.

The marginal effects associated with explanatory variables are presented in Tables 4.8 – 4.10. The results are consistent across the models. *Firmness* has the largest marginal effect among the sensory variables, suggesting that it is a key factor that affects consumers' willingness to pay. Based on the pooled model without treatment indicators (scenario 2), consumers are willing to pay 5.7¢, 3.7¢ and 8.5¢ more respectively as the rating of *Sweetness*, *Juiciness* and *Firmness* increases by one. The respondents with children under 18 years old are on average willing to pay 9.6¢ more to buy Anjou pears than those without children. Under scenario 4, consumers are willing to pay 2.8¢ and 8.6¢ more respectively as the rating of *Juiciness* and *Firmness* increases by one. If *Sweetness* rating increases by 1, consumers are willing to pay 7.1¢ for the 2-day and 6-day samples, and 2.9¢ for the 6-day sample.

We now examine consumers' mean WTP for pears with different levels of ethylene treatment. Following Kaneko and Chern's approach, the mean WTP is calculated as the ratio $(\alpha + \lambda' z_i)/\rho$. The estimated mean WTP's for the Anjou pears with different levels of ethylene treatment are presented in Table 4.11. On average, consumers are willing to pay \$1.74/lb, \$1.53/lb, \$1.19/lb, and \$1.09/lb for the four types of pears with 6-day, 4-day, 2-day ethylene treatment, and 7-day without ethylene treatment, respectively. This result indicates that 6-day ethylene treatment is most desirable among the four to induce the “target” eating quality that consumers most prefer. The lower mean WTP’s for pears with less or no ethylene treatment imply that the pears without the conditioning procedure are not able to generate the desirable eating quality to fit consumers’ preferences. Compared to the average market price $1.49/lb, consumers are willing to pay a premium of $0.25 and $0.04 for the pears with 6-day and 4-day ethylene treatment, which means that the 4-day treatment pears are similar to the pears available on the market, and the 6-day treatment pears are superior to the pears on the market.

Conclusions

Firms want to supply what consumers want. In the case of Anjou pears, supplying pears with optimal sensory characteristics can be challenging because of the way the product ripens. The conditioning procedures prevented the market availability during September and October each year. Treatment with ethylene could solve this problem by shortening the conditioning time of Anjou pears. However, the eating quality of pears may vary as the treatment time differs. It is important for pear producers to gain information regarding the “best” strategy of conditioning with ethylene treatment, which generates the target qualities that are most preferred by consumers.

This article uses sensory analysis and contingent valuation to evaluate consumers’ WTP for pears with different levels of ethylene treatment. A taste experiment and a consumer survey were conducted to collect data on consumers’ assessments of pear characteristics and their demographics. A double-bounded dichotomous choice contingent valuation model is employed to estimate consumers’ WTP for Anjou pears and the mean WTP for pears with each of the four levels of ethylene treatment: 6 days, 4 days, 2 days with ethylene, and 7 days without ethylene.

The "treatment-induced" sensory characteristics significantly affect WTP. The sensory variables *Firmness*, *Sweetness* and *Juiciness* are significant factors explaining consumers' WTP. Respondents with children under 18 years old have a higher WTP. The mean WTP's for pears with the four types of treatments are $1.74/lb, $1.53/lb, $1.19/lb, and $1.09/lb, respectively; compare to the benchmark average price of $1.49/lb in Portland-area grocery stores at the time of the experiment. This implies that consumers most like the pears with 6-day treatment and on average are willing to pay a premium of $0.25/lb compared to the market price. The pears without ethylene treatment have the least desirable eating quality. That is, analysis indicates that the 6-day treatment tends to induce the most preferable eating quality of Anjou pears.

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Table 4.1 Summary Statistics for Demographic Variables

Variable	Description	Frequency
Age	Age group of the participants:	
	18-24	5.83%
	25-34	26.67%
	35-44	20.00%
	45-54	23.33%
	55-64	20.00%
	65+	4.17%
Gender	1 if male	21.67%
	0 if female	78.33%
children	1 if there are children under 18 years old in the household	25.00%
	0 otherwise	75.00%
Ethnicity	1 if white	90.83%
	0 otherwise	9.17%
Education	Education group of the participants:	
	1 = high School or technical degree	30.83%
	2 = four-year college degree	40.00%
	3 = advanced degree	29.17%
Income	Income group of the participant:	
	1 = <$40,000/year	26.67%
	2 = $40,000 - $ 59,999/year	26.67%
	3 = $60,000 - $ 79,999/year	16.67%
	4 = $80,000 - $ 119,999/year	20.83%
	5 = $120,000 /year or more	9.17%

Table 4.2 Comparison of Main Demographics Between the Participants and the Portland, Oregon Population

Socio-demographic Characteristic	Sample	Portland Population
% of Female	78.33%	50.60%
Median Age	35 - 44	35.2
% of White	90.83%	77.90%
% of Households with children under 18 years old	25.00%	18.60%
Median of Household Income	$40,000 - $59,999	$40,146

Table 4.3 Summary Statistics of Consumers' Ratings for Anjou Pears with Ethylene Treatment for Different Numbers of Days

Variable	2-day with ethylene		4-day with ethylene		6-day with ethylene		7-day without ethylene	
	Mean	**Std**	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**
Overall liking	4.44	1.96	6.31	1.73	7.46	1.60	4.26	2.35
Pear flavor	4.74	1.93	6.40	1.72	7.43	1.44	4.68	2.11
Sweetness	3.92	1.92	5.69	1.99	7.07	1.92	3.63	2.04
Juiciness	3.13	1.94	5.79	2.06	7.94	1.42	2.42	1.58
Firmness	4.90	2.04	6.36	1.94	6.92	1.79	4.22	2.45
Texture	4.11	2.06	5.99	2.01	7.22	1.59	4.04	2.28

*Scale: 1 – 9, with 9 denoting most preferred.

Table 4.4 Percentage of Respondents in Each WTP Category by Treatment Level

WTP category	Response	2-day with ethylene	4-day with ethylene	6-day with ethylene	7-day without ethylene
$(-\infty, B_D)$	"no, no"	48.70%	24.79%	6.90%	57.89%
$[B_D, B_I)$	"no, yes"	30.43%	22.22%	17.24%	19.30%
$[B_I, B_P)$	"yes, no"	14.78%	25.64%	29.31%	12.28%
$[B_P, +\infty)$	"yes, yes"	6.09%	27.35%	46.55%	10.53%

Table 4.5 WTP Estimation Results for Anjou Pears by Level of Ethylene Treatment (Scenario 1)

	2-day with ethylene		4-day with ethylene		6-day with ethylene		7-day without ethylene	
Variable	parameter	std	parameter	std	parameter	std	parameter	std
Intercept	4.671***	1.239	1.439	1.224	4.271***	1.53	3.408**	1.399
Bid	-5.976***	0.744	-5.714***	0.671	-5.606***	0.674	-5.157***	0.767
Sweetness	0.327**	0.143	0.299**	0.13	0.169	0.115	0.555***	0.148
Juiciness	0.16	0.132	0.275**	0.131	0.148	0.166	-0.055	0.185
Firmness	0.341***	0.115	0.687***	0.125	0.331***	0.12	0.535***	0.131
Children	0.199	0.475	0.817**	0.474	0.194	0.488	0.947*	0.533
Age	0.238	0.161	-0.056	0.154	-0.06	0.149	-0.268	0.211
Gender	-0.877*	0.487	0.374	0.449	-0.32	0.464	0.333	0.544
Ethnicity	-0.693	0.648	-0.555	0.679	0.907	0.631	-0.397	0.769
Income	-0.356**	0.162	0.027	0.158	0.08	0.159	-0.202	0.179

***, **, * denote significant levels of .01, .05, .1, respectively

Table 4.6 WTP Estimation Results for Anjou Pears, Pooled Data (Scenarios 2 and 3)

	Scenarios 2: Without treatment Indicator variable			Scenario3: With treatment Indicator variable		
Variable	**parameter**	**std**	**p-value**	**parameter**	**std**	**p-value**
Intercept	2.884***	0.585	0.000	3.068***	0.607	0.000
Bid	-5.305***	0.333	0.000	-5.330***	0.334	0.000
Sweetness	0.304***	0.063	0.000	0.307***	0.063	0.000
Juiciness	0.197***	0.053	0.000	0.158**	0.069	0.022
Firmness	0.453***	0.056	0.000	0.457***	0.057	0.000
Children	0.510**	0.239	0.033	0.512**	0.239	0.033
Age	-0.023	0.078	0.766	-0.025	0.078	0.746
Gender	-0.142	0.235	0.545	-0.142	0.235	0.546
Ethnicity	-0.176	0.326	0.589	-0.165	0.326	0.611
Income	-0.102	0.079	0.199	-0.101	0.080	0.206
D2	--	--	--	-0.244	0.288	0.396
D4	--	--	--	0.054	0.324	0.866
D6	--	--	--	0.213	0.401	0.596

***, **, * denote significant levels of .01, .05, .1, respectively

Table 4.7 WTP Estimation Results for Anjou Pears, Pooled Data (Scenario 4)

	Full model			Reduced model		
Variable	**parameter**	**std**	**p-value**	**parameter**	**std**	**p-value**
Intercept	2.430***	0.833	0.004	2.652***	0.611	0.000
Bid	-5.448***	0.342	0.000	-5.318***	0.333	0.000
Sweetness	0.600***	0.140	0.000	0.378***	0.073	0.000
Juiciness	-0.075	0.184	0.682	0.149**	0.063	0.018
Firmness	0.491***	0.109	0.000	0.457***	0.057	0.000
Children	0.500**	0.242	0.039	0.506**	0.239	0.035
Age	-0.010	0.080	0.899	-0.026	0.079	0.744
Gender	-0.117	0.238	0.623	-0.162	0.236	0.491
Ethnicity	-0.207	0.342	0.544	-0.150	0.329	0.647
Income	-0.102	0.080	0.201	-0.094	0.080	0.241
SW*D2	-0.350*	0.192	0.068	-	-	-
SW*D4	-0.287	0.184	0.120	-	-	-
SW*D6	-0.403**	0.178	0.023	-0.224**	0.113	0.048
JC*D2	0.229	0.222	0.301	-	-	-
JC*D4	0.321	0.221	0.146	-	-	-
JC*D6	0.208	0.248	0.402	-	-	-
FM*D2	-0.129	0.149	0.388	-	-	-
FM*D4	0.154	0.156	0.324	-	-	-
FM*D6	-0.130	0.160	0.414	-	-	-
D2	1.299	0.888	0.144	-	-	-
D4	-0.897	1.058	0.397	-	-	-
D6	2.629**	1.334	0.049	1.700**	0.799	0.033

***, **, * denote significant levels of .01, .05, .1 respectively

Table 4.8 Marginal Effects of Explanatory Variables by Level of Ethylene Treatment (Scenario 1)

	2-day with ethylene		4-day with ethylene		6-day with ethylene		7-day without ethylene	
Variable	**parameter**	**std**	**parameter**	**std**	**parameter**	**std**	**parameter**	**std**
Sweetness	0.055**	0.024	0.052**	0.023	0.030	0.020	0.108***	0.029
Juiciness	0.027	0.022	0.048**	0.022	0.026	0.030	-0.011	0.036
Firmness	0.057***	0.019	0.120***	0.020	0.059***	0.021	0.104***	0.025
Children	0.033	0.079	0.143*	0.082	0.035	0.087	0.184*	0.104
Age	0.040	0.027	-0.010	0.027	-0.011	0.027	-0.052	0.041
Gender	-0.147*	0.081	0.065	0.078	-0.057	0.082	0.065	0.105
Ethnicity	-0.116	0.108	-0.097	0.119	0.162	0.112	-0.077	0.149
Income	-0.060**	0.027	0.005	0.028	0.014	0.028	-0.039	0.035

***, **, * denote significant levels of .01, .05, .1, respectively.

Table 4.9 Marginal Effects of Explanatory Variables, Pooled Data (Scenarios 2 and 3)

	Scenario 2: Without treatment Indicator variable			Scenario 3: With treatment Indicator variable		
Variable	**parameter**	**std**	**p-value**	**parameter**	**std**	**p-value**
Sweetness	0.057***	0.012	0.000	0.058***	0.012	0.000
Juiciness	0.037***	0.010	0.000	0.030**	0.013	0.022
Firmness	0.085***	0.010	0.000	0.086***	0.010	0.000
Children	0.096**	0.045	0.033	0.096**	0.045	0.032
Age	-0.004	0.015	0.766	-0.005	0.015	0.746
Gender	-0.027	0.044	0.545	-0.027	0.044	0.546
Ethnicity	-0.033	0.061	0.590	-0.031	0.061	0.612
Income	-0.019	0.015	0.199	-0.019	0.015	0.205
D2day	--		--	-0.046	0.054	0.395
D4day	--		--	0.010	0.061	0.866
D6day	--		--	0.040	0.075	0.596

***, **, * denote significant levels of .01, .05, respectively.

Table 4.10 Marginal Effects of Explanatory Variables, Pooled Data (Scenario 4, reduced model)

Variable	Marginal Effect	Std	t-statistic	p-value
Sweetness	0.071***	0.014	5.188	0.000
Juiciness	0.028**	0.012	2.372	0.018
Firmness	0.086***	0.010	8.344	0.000
Children	0.095**	0.045	2.117	0.034
Age	-0.005	0.015	-0.327	0.744
Gender	-0.031	0.044	-0.689	0.491
Ethnicity	-0.028	0.062	-0.458	0.647
Income	-0.018	0.015	-1.175	0.240
SW*D6	-0.042**	0.021	-1.975	0.048
D6	0.320**	0.151	2.119	0.034

***, **, * denote significant levels of .01, .05, respectively.

Table 4.11 Estimation of Mean WTP for Anjou Pears with Different Levels of Ethylene Treatment

Variable	2-day with ethylene			4-day with ethylene		
	parameter	std	95% Confidence Interval for Mean WTP	parameter	std	95% Confidence Interval for Mean WTP
WTP	1.19***	0.036	(1.12, 1.26)	1.53***	0.033	(1.46, 1.59)

Variable	6-day with ethylene			7-day without ethylene		
	parameter	std	95% Confidence Interval for Mean WTP	parameter	std	95% Confidence Interval for Mean WTP
WTP	1.74***	0.034	(1.67, 1.81)	1.09***	0.053	(0.98, 1.19)

*, **, *** denote significant levels of .1, .05, .01, respectively.