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Potential Impacts of Foodborne Illness Incidences on Market Movements and Prices of Fresh Produce in the U.S.

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This study investigates the potential impacts of food safety outbreaks on domestic shipments, imports, and prices of the produce industry. Three case studies were analyzed to assess these potential impacts: the cantaloupe outbreak of March–April 2008, the spinach outbreak of September 2006, and the tomato outbreak of June–July 2008. Data-determined historical decompositions were conducted to provide a weekly picture of domestic shipment, import, and price fluctuation transmissions. The empirical analysis based on a vector autoregression (VAR) model showed differences in the results depending on the source of the outbreak (domestic vs. imported).

Key Words: directed acyclic graphs, food safety, fresh produce, historical decomposition, outbreaks

JEL Classification: Q13

Although it is not certain that imported food presents higher food safety risks, a proliferation in the number of recent incidents have led to questions regarding the safety of the U.S. food supply (Doyle, 2000). Aside from the safety of the products they produce, fresh fruit and vegetable growers face many challenges. These include water availability for irrigation, increased energy and chemical costs, pest control, increased competition from globally sourced products, and the availability and cost of labor. With these many challenges, questions arise as to how much producers can afford to spend to assure the safety of their product. Put differently, what is the cost of not effectively controlling product safety? The following three case examples provide insight into the answers to these questions.

Consumers react to the news of a food safety alert by immediately changing their buying patterns and reducing consumption of the affected products. Because the initial reports of an outbreak may be indecisive as to the scope and origin of the problem, consumption/product demand may be affected nationally and even internationally. This shorter-term impact may actually shut down market movement until the source of the outbreak becomes clear by product, by the specific pathogen, by the source of the pathogen, and even by the handler and farm on which the product was produced. This may take several days or weeks. The reduction in sales depends on the severity of the outbreak in terms of the number of people affected, number of deaths, regional scope, and the type of products and its

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origin. Even after the source is identified, there are potential longer-term impacts on consumption and the entire supply chain, including issues such as legal liability from the incident, which may occur over a period of several months or years after the outbreak. This article studies both the contemporaneous and lagged effects of foodborne illness in the fresh produce industry and the length of time required to return to normal levels and the associated producer costs of the outbreaks.

Three case studies are used to assess the potential impacts of outbreaks on product shipments and prices. Specifically, we analyzed the spinach outbreak of September 2006; the cantaloupe outbreak of March–April 2008; and the tomato outbreak of June–July 2008. The data used in this study are weekly domestic shipments and imports and average prices for domestic production and imports of spinach, cantaloupes, and tomatoes from the Agricultural Marketing Service of the U.S. Department of Agriculture for the periods around the outbreaks (U.S. Department of Agriculture, National Agricultural Statistical Service, 2007). The prices are average weekly prices for all shipments, including national production and imports. Prices are expressed in dollars per one-half cartons of cantaloupes (40 pounds), carton of tomatoes (25 pounds), and a carton of 24 bunches of spinach (20 pounds).

On September 13, 2006, the Food and Drug Administration (FDA) issued a warning of a multistate *Escherichia coli* O157:H7 outbreak associated with the consumption of bagged spinach (FDA, 2006). The first reports were confirmed by several states on bagged spinach having a “best if used by” date of August 30, 2006. By the time the outbreak was contained, 227 people had become ill across the U.S., 104 had been hospitalized, 31 had developed serious complications from hemolytic–uremic syndrome, and three had died. An all-clear lifting of the warning alert was issued by FDA, although by November 1, 2008, the sources of the contamination had been clearly identified and measures were being taken to assure that the incident was under control.

On March 22, 2008, the FDA issued a warning alert of *Salmonella* food poisoning associated with cantaloupes from Honduras. The alert spanned 16 states and several Canadian provinces. According to the FDA, since January 2008, cantaloupes imported from Honduras, Central America, left 50 people ill with *Salmonella* poisoning. An initial alert was issued on February 22, 2008, and illnesses were reported since January 19, 2008. Although no deaths were reported, 14 people required hospitalization (FDA, 2008a). In their warning, the FDA linked the outbreak to a single company in Honduras (FDA, 2008b).

On June 3, 2008, the FDA alerted consumers in New Mexico and Texas that a *Salmonella* outbreak appeared to be linked to consumption of certain types of raw red tomatoes and products containing raw red tomatoes. Although the official alert was on June 3, the Centers for Disease Control and Prevention (CDC) and FDA notifications indicated that reported cases in New Mexico extended back to April 16, 2008 (FDA, 2008c). From early in the period, the prime suspected sources were tomatoes grown in Florida and Mexico. Tomatoes from other domestic and imported sources were still being sold and considered safe. The warning alert was lifted on July 17, 2008, when it was determined that Jalapeño and Serrano peppers from Mexico were the source of the contamination (FDA, 2008d).

These outbreaks are not unique. According to the CDC, more than 76 million people are affected and 5,000 die as a result of food poisoning every year (Mead et al., 1999). The most common foodborne illnesses are *Campylobacter*, *Salmonella*, and *E. coli*. Over the past 12 years, 22 leafy green *E. coli* O157:H7 outbreaks have been identified. All 22 indicated a California source of the leafy greens. Since the mid-1990s, foodborne illness outbreaks have occurred that were linked to raspberries, green onions, peppers, sprouts, and strawberries. In part as a reaction to these events, increased efforts to enhance food safety have been undertaken by the government and associated industry groups. Efforts have focused on increased scrutiny of imported products and the improvement in domestic standards.

The main objective of this article is to study the contemporaneous and lagged effects of foodborne ill incidence on market movements and prices of fresh produce in the U.S. by using historical decomposition analysis of the dates around the neighborhood of the outbreaks. This article also evaluates whether these effects differ according to the source of the outbreak (domestic vs. imports) by analyzing three different case studies with a different source of the outbreak. Finally, the farm-level costs associated with these outbreaks are calculated.

Methodology

The working hypothesis is tested empirically using a time-series econometric model. Specifically, the model explores how information is communicated across the three variables, price, imports, and shipments, for each product in a neighborhood of the aforementioned food events. The empirical analysis is based on a vector autoregression (VAR) model in which directed acyclic graphs are used to sort out causal flows of price information in contemporaneous time. Let X_t denote a vector that includes the weekly prices, imports, and shipments of each vegetable product:

$$X_t = \begin{pmatrix} P_t \\ I_t \\ S_t \end{pmatrix} \tag{1}$$

where t is an index of time observed. Under fairly general conditions, the dynamic correlation structure between these variables can be summarized as a structural vector autoregression. The structural VAR representing a $N \times 1$ vector of variables X_t can be written as:

$$\Phi_0 X_t - \sum_{k=1}^{K} \Phi_i X_{t-k} = \varepsilon_t \tag{2}$$

Here contemporaneous and lagged values of observational measures on X at periods t-k, $k = 0, 1, \ldots, K$ are mapped into the white noise innovation term ε_t, where $Cov(\varepsilon_t) = \Omega$ and Φ_i, $i = 0, 1, \ldots, K$ are square autoregressive matrices of order 3. The innovations ε_t represent new information arising in each element of the X vector at time t. Under general conditions permitting matrix inversion, an equivalent form exists as:

$$\begin{aligned} X_t - \Phi_0^{-1}\Phi_1 X_{t-1} - \cdots - \Phi_0^{-1}\Phi_k X_{t-k} \\ = \Phi_0^{-1}\varepsilon_t. \end{aligned} \tag{3}$$

The reduced form (nonstructural) VAR is written in similar form as:

$$X_t - \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} = u_t; \tag{4}$$

where $\Pi_h = \Phi_0^{-1}\Phi_h$ for $k = 1, \ldots, K$ and $u_t = \Phi_0^{-1}\varepsilon_t$. The reduced form innovations (u_t) are "mongrel" or mixtures of structural innovations ε_t. It follows thus that $Cov(u_t) = \Sigma = \Phi_0^{-1}\Omega\left(\Phi_0^{-1}\right)$.

Although the reduced form VAR has been championed as "atheoretic," the key to modeling structural VARs is proper identification of the matrix Φ_0. Bernanke (1986) and Sims (1980) used prior theory to achieve such identification. More recent work follows that of Swanson and Granger (1997) to use the causal pattern exhibited by observed innovations $\hat{u}_t$ to identify Φ_0. This article uses the machine learning algorithms of Spirtes, Glymour, and Scheines (2000) as applied earlier in Bessler and Akleman (1998) and Hoover (2005) to achieve structural identification.

The dynamic response patterns summarized by a VAR are difficult to interpret (Sims, 1980; Swanson and Granger, 1997). The dynamic price relationships can be best summarized through the moving average representation (MAR). We can solve for the MAR of the estimated version of Equation (4) where the vector X_t is written as a function of the infinite sum of past innovations:

$$X_t = \sum_{i=0}^{\infty} \Theta_i u_{t-i} \tag{5}$$

where Θ_i is a 3×3 matrix of moving average parameters, which map historical innovations at lag i into the current position of the vector X.[1] Notice Θ_0 is generally not the identity matrix, because we use directed graph structures on the observed innovations from the reduced form VAR to translate nonstructural innovations to

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[1] Although one can actually derive the first n terms of Equation (4) analytically, we almost always allow the computer to do this following the zero-one simulation as described in Sims (1980).

structural innovations as suggested first by Swanson and Granger (1997).

A directed graph is a picture summarizing the causal patterns among a set of variables. Lines with arrowheads represent such flows. For instance, $X_1 \rightarrow X_2$ indicates that variable X_1 causes variable X_2. Observed innovations from an estimated form of Equation (4) are modeled as a directed acyclic graph for each produce commodity. An acyclic graph has no path (sequence of connected variables) that returns to a variable. The idea that enables detection of the direction of causal flow among a set of (observational) variables is the screening-off phenomena and the more formal representation as d-separation (Pearl, 2000). For three variables, X_1, X_2, and X_3, if variable X_1 is a common cause of X_2 and X_3 such that $X_2 \leftarrow X_1 \rightarrow X_3$, then the unconditional association between X_2 and X_3 will be nonzero, because both have a common cause in X_1 (this pattern is labeled a causal fork [Pearl, 2000]). If we measure association (by correlation), then X_2 and X_3 will have a correlation not equal to zero However, if we condition on X_1, the partial correlation between X_2 and X_3 (given knowledge of X_1) will be zero. A common cause (X_1) "screens-off" association between its effects (X_2 and X_3).

Consider variables X_4, X_5, and X_6 such that $X_4 \rightarrow X_5 \leftarrow X_6$. Here X_5 is a common effect of X_4 and X_6 (this pattern is labeled a causal inverted fork [Pearl, 2000]). X_4 and X_6 will have no association (zero correlation if we are constrained to linear association); however, if conditioned on X_5, the association between X_5 and X_6 is nonzero (the partial correlation between X_5 and X_6, given knowledge of X_5 is nonzero). Knowledge of the common effect does not "screen-off" association between its causes. Finally, for variables X_7, X_8, and X_9 forma causal chain, $X_7 \rightarrow X_8 \rightarrow X_9$, the unconditional association (correlation) between X_7 and X_9 will be nonzero, but the conditional association (correlation) between X_7 and X_9, given knowledge of X_8, will be zero. Here X_8 "screens-off" communication between X_7 and $X_{9.}$

Pearl (2000) and Spirtes, Glymour, and Scheines (2000) present algorithms (under the TETRAD project label) for inference on directed acyclic graphs from observational data. We use PC algorithm, which is embedded in the software TETRAD II and III (see the offering at www.phil.cmu.edu/projects/tetrad/ and Scheines et al., 1996). PC algorithm has been studied extensively in Monte Carlo simulations in Demiralp and Hoover (2003) and Spirtes, Glymour, and Scheines (2000). It may make mistakes of edge direction and edge inclusion or exclusion. Errors of edge direction (orientation) appear to be more likely than errors of inclusion or exclusion. Spirtes, Glymour, and Scheines recommend: "In order of the methods to converge to correct decisions with probability 1, the significance level used in making decisions should decrease as the sample size increases and the use of higher significance levels (e.g., 0.2 at sample sizes less than 100, and 0.1 at sample sizes between 100 and 300) may improve performance at small sample sizes" (Spirtes, Glymour and Scheines, 2000, p. 116).

Once the price innovations from the VAR estimation are orthoganized, the historical decomposition of the equivalent MAR representation, at particular time $t = T + k$, can be divided into two parts:

$$(6) \qquad X_{T+k} = \sum_{s=k}^{\infty} \Theta_s u_{T+k-s} + \sum_{s=0}^{k-1} \Theta_s u_{T+k-s}.$$

The first term in the right-hand side of Equation (6), called the "base projection," uses information available up to time period T. The second term contains information available from time period $T + 1$ until $T + k$, including the disease outbreaks. The difference between the actual price (X_{T+k}) and the base price projection $(\sum_{s=k}^{\infty} \Theta_s u_{T+k-s})$ is thus written as a linear function of innovations (new information) arising in the series between the period T and period $T + k(\sum_{s=0}^{k-1} \Theta_s u_{T+k-s})$. Historical decomposition allows one to study the behavior of each price series in the neighborhood of important historical events (disease outbreaks in our cases) and to infer how much each innovation contributes to the variation of X_{T+k}.

Results and Discussion

This article analyzed weekly observations on prices, imports, and shipments of U.S. cantaloupes, spinach, and tomatoes around the neighborhood of the disease outbreaks obtained from the Fruit and Vegetable Market News Portal (U.S. Department of Agriculture, Agricultural Marketing Service, 2005–2009). The data plots are offered to give the readers a sense of the seasonal pattern and consumer response in a neighborhood around each food illness outbreak event. Vertical lines are placed at dates of the outbreaks for each product (Figures 1–3). A VAR was fit with 1 lag of levels data; a constant and three quarterly seasonal dummy variables where Schwarz loss was used to select lag length.

Causal pattern on innovations from a vector autoregressions model fit to weekly observation on shipments (S), imports (I), and prices (P) for cantaloupes, spinach, and tomatoes is shown in Figure 4 from each separate VAR. Cantaloupe innovations are connected with information flows among domestic shipments, imports, and prices, but it is not certain which variables causes which. Spinach innovations are contemporaneously independent. Contemporaneous innovations in tomatoes are modeled as an inverted fork with imports innovations being caused by innovations in prices and domestic shipments. In contemporaneous time, tomato prices and domestic shipments appear to be unrelated. Based on the contemporaneous structures in Figure 4 and the estimated VARs for each series, historical decomposition of each price series is obtained.

Historical decompositions of each price series following Equation (6) are offered in Tables 1–3. The decomposition analysis around the neighborhood of the outbreaks starts before the warning of the food outbreak and continues for several weeks after the event to observe how information arising in each series, price, shipments, and imports affected price at each weekly observation. In Table 1, cantaloupe price is decomposed in a period around the neighborhood of the food outbreak. Recall

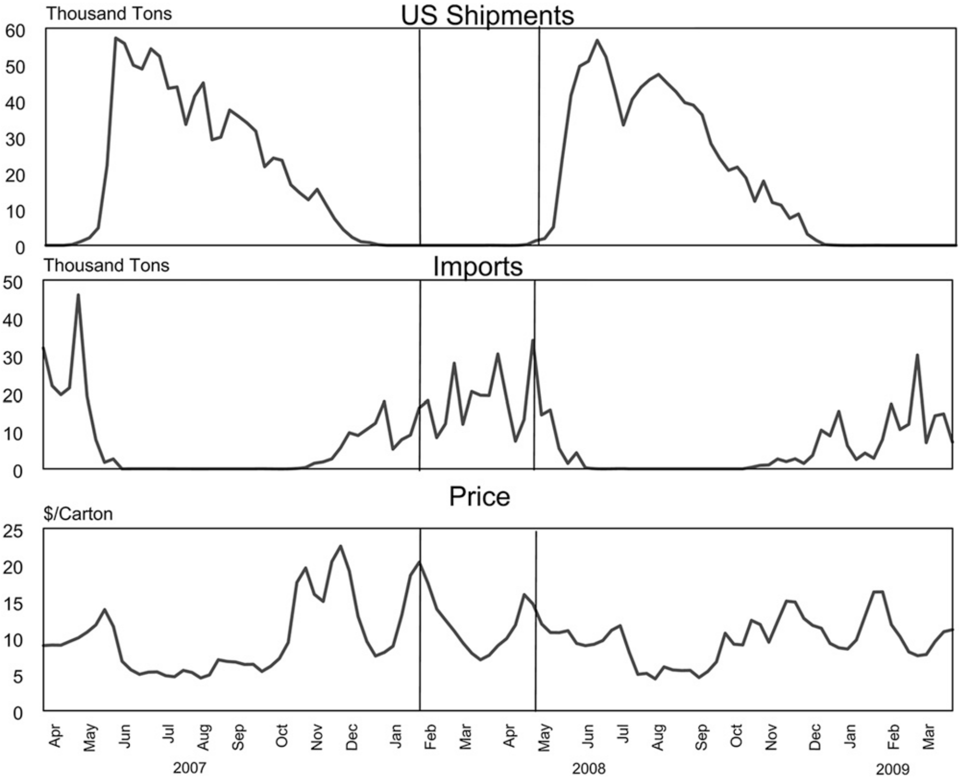


Figure 1. Time-Series Plots of Shipments, Imports, Prices of Cantaloupes—Weekly Data, March 31, 2007–March 28, 2009 (Note: Vertical Lines Are Placed at Dates of Interest, January 26, 2008 [beginning date of food scare] and April 26, 2008 [ending date on food scare])

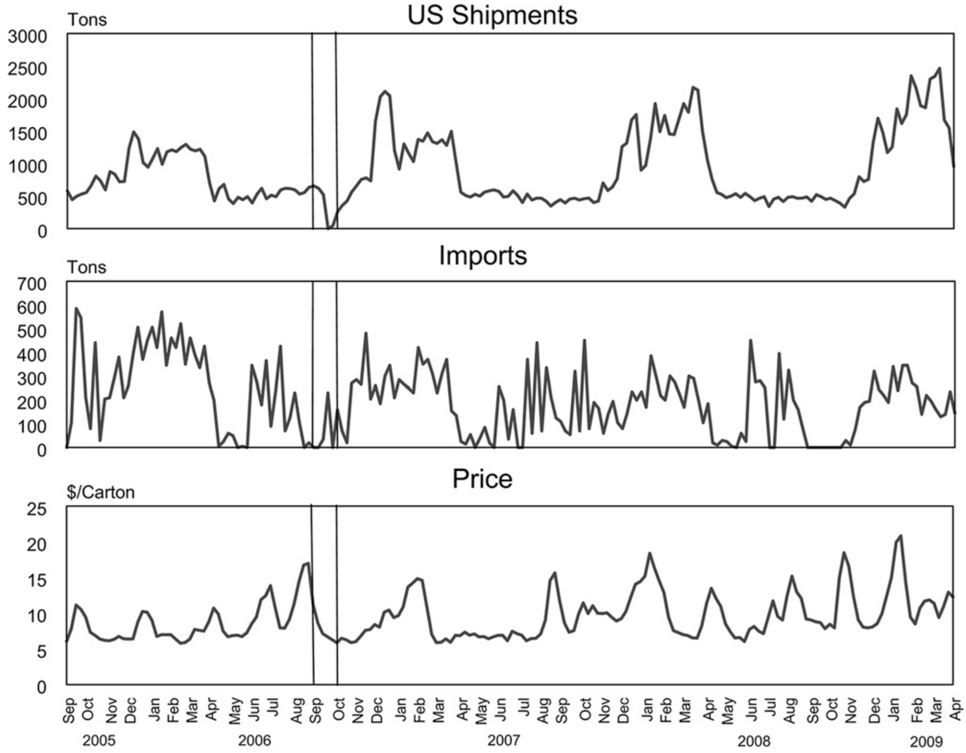


Figure 2. Time-Series Plots of Shipments, Imports, Prices of Spinach—Weekly Data, September 3, 2005–April 4, 2009 (Note: Vertical Lines Are Placed at Dates of Interest, September 8, 2006 [beginning date of food scare] and October 4, 2006 [ending date on food scare])

illnesses started on January 19, with an initial alert issued on February 22, and the official warning on March 22 that linked the outbreak to a single company in Honduras. Actual prices were higher than forecasted for the first 2 weeks followed by a slightly lower price than forecasted before the first alert was issued on February 22 (column 2). Most of the cantaloupes sold at the time of the outbreak were imported, because the domestic production season was just about to begin (U.S. Department of Agriculture, National Agricultural Statistical Service, 2007). There is an overall negative response in prices after the initial alert and official warning, arising mostly from prices and imports. Initially, most of the negative information arises in the market price itself, suggesting that a drop of consumer demand may be behind the fall off in prices after the initial outbreak alert. Interestingly, the model shows that after the official warning when the outbreak was associated with cantaloupes with a foreign source in a single company in Honduras, the negative effect was reduced and the information arising from imports dominated new price information (March 29–April 12). The depth of this cantaloupe outbreak event was the week of March 15, 2008, with the dominate pressure for the –$4.72 price difference decrease being accounted from the price innovation itself (–$3.42) and (–$1.20) from the import innovation.

Table 2 summarizes similar price, shipment, and import innovation responses after the September 2006 food event in spinach. For spinach, there was an overall negative response in price after the event. Actual prices were below forecasted prices with the knowledge before the food outbreak. Most of this negative information arises in the price market itself, suggesting that a drop in consumer demand may be behind the falloff in prices. Innovations in domestic shipments actually show very little negative influence on price. Interestingly, because the food outbreak

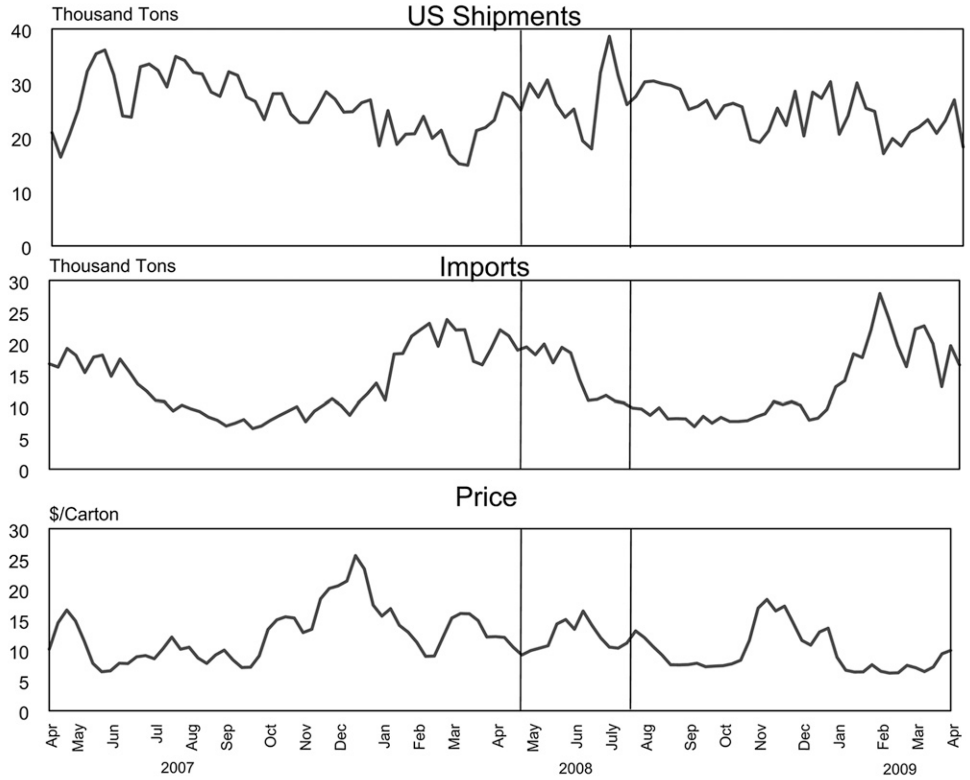
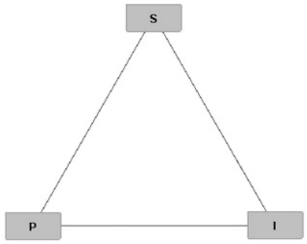


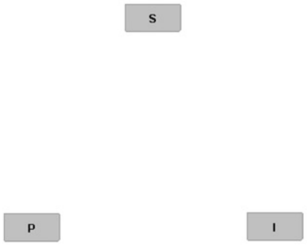
Figure 3. Time-Series Plots of Shipments, Imports, Prices of Tomatoes—Weekly Data, April 14, 2007–April 4, 2009 (Note: Vertical Lines Are Placed at Dates of Interest, April 16, 2008 [beginning date of food scare] and July 19, 2008 [ending date on food scare])

was associated with a domestic source, import information shows a positive but small effect on price information. The highest intensity of the spinach event was the week of September 9, 2006, with the dominate pressure for the –$4.29 price difference drop being accounted almost totally from the price innovation (–$4.33).

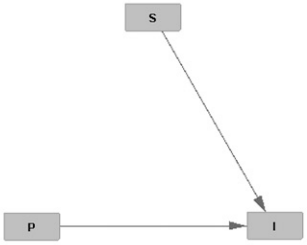
Table 3 offers price decompositions for tomatoes just before and after the outbreak event in tomatoes that found a foreign source in peppers. The first few weeks after the initial illnesses reported showed very small price effects (April 19–May 17) with both positive and negative effects, which may suggest consumers did not react strongly to the food outbreak. When the official warning was released on June 3, the main suspects of the contamination were Florida and Mexico, and a recall was imposed on tomatoes from FL; however, tomatoes from other domestic and imported sources were still considered safe and were being sold in the market. The model suggests that in that period (May 24–June 28), consumers did not react much to the food outbreak, and the reduction in supply from Florida and Mexico may have increased actual prices; hence, the results show actual prices being higher than forecasted prices during that period with the new price information arising coming from information in all domestic shipments, imports, and prices. The price effects were reduced after July 5, when the outbreak source started being linked to other sources (Jalapeño and Serrano peppers). The highest intensity of the tomato outbreak was in the week of June 14, 2008, a week after the original FDA warning of a potential illness outbreak in tomatoes, with the dominate pressure for the +$6.41 price difference increase being accounted for by domestic shipments, imports, and prices, the latter having the greatest price impact with +$4.25.



Cantaloupes



Spinach



Tomatoes

Figure 4. Causal Pattern on Innovations From a Vector Autoregressions Models Fit to Monthly Observations on Shipments (S), Imports (I), and Prices (P) for Cantaloupes, Spinach, and Tomatoes

Several studies have looked at the economic and consumer effects of a food outbreak, including Buzby (2001), Calvin, Avendano, and Schwentesius (2004), Onyango et al. (2008), and Worth (2000). When calculating the associated costs of a food safety outbreak to a particular industry, most of the literature focuses on the retail level. This article estimated the short-run farm level cost of the cantaloupe, spinach, and tomato outbreaks to its respective industries at the farm level. To estimate the short-term impacts of these food outbreaks to their industry, domestic shipments, imports, and prices were forecasted using only information known before the food outbreaks. The difference between forecasted variables and actual values is attributed to information arising from the outbreaks. The forecasting technique used to estimate domestic shipments, imports, and prices was a triple exponential smoothing. Triple exponential smoothing is a very popular scheme to produce a smoothed time-series and accounts trend and seasonality as well as overall smoothing of the data (Hyndman et al., 2008). In this study, it was estimated that the short-term farm level losses for U.S. spinach were over $8 million. Actual domestic shipments of spinach dropped 7,088 metric tons from the forecasted level before the spinach outbreak, whereas actual imports were 3,531 metric tons above the forecasted level. U.S. tomato farm losses were estimated at $25 million. Tomato imports levels were 96,900 metric tons or $97 million above the forecasted level, because imports from Canada offset the decrease in imports from Mexico. Finally, short-term farm-level cantaloupe losses were estimated at $5.8 million for the domestic market and $29.5 million for imports, because the contamination source was found to be foreign. Domestic shipments of cantaloupe were 9,843 metric tons below the forecasted levels before the cantaloupe incident, whereas actual imports decreased 36,508 metric tons from the forecasted level.

Summary and Conclusions

Although it is not certain that imported food presents higher food safety risks, a proliferation in the number of recent incidents have led to questions regarding the safety of the U.S. food supply (Doyle, 2000). Three case studies were analyzed to assess the potential impacts of food

Table 1. Historical Decomposition of Cantaloupe Price in a Neighborhood of the January 26, 2008, and April 26, 2008 Event

(1) Date	(2) Difference = Actual Price Minus Forecasted Price	(3) As a Result of Information Arising from Domestic Shipments	(4) As a Result of Information Arising from Imports	(5) As a Result of Information Arising from Price
January 26, 2008	3.47	0.00	0.00	3.47
February 1, 2008	2.19	0.14	–0.53	2.58
February 8, 2008	–0.11	0.17	–0.94	0.66
February 15, 2008	–0.75	0.12	0.04	–0.90
February 22, 2008	–1.66	0.21	0.15	–2.01
March 1, 2008	–2.88	0.24	–1.65	–1.47
March 8, 2008	–4.01	–0.05	–0.69	–3.27
March 15, 2008	–4.72	–0.10	–1.20	–3.42
March 22, 2008	–3.96	–0.28	–1.32	–2.37
March 29, 2008	–2.56	–0.45	–1.35	–0.76
April 5, 2008	–2.52	–0.61	–2.66	0.74
April 12, 2008	–0.53	–0.40	–1.69	1.56
April 19, 2008	4.06	0.11	0.22	3.73
April 26, 2008	3.18	0.85	0.63	1.70

Note: This table decomposes the difference between the actual price and the forecasted price at each date between January 26, 2008, and April 26, 2008. That difference at each date can be attributed to information arising in the domestic shipments variable, the imports variable, and the price variable. Accordingly, the column labeled (2) is decomposed at each date into the sum of columns (3), (4), and (5).

safety outbreaks on domestic shipments, imports, and prices of the produce industry: the cantaloupe outbreak of March–April 2008, the spinach outbreak of September 2006, and the tomato outbreak of June–July 2008.

Data-determined historical decompositions were conducted to provide a weekly picture of domestic shipment, import, and price fluctuation transmissions. The empirical analysis based on a VAR model showed differences in the results

Table 2. Historical Decomposition of Spinach Price in a Neighborhood of the September 9, 2006, and October 4, 2006 Event

(1) Date	(2) Difference = Actual Price Minus Forecasted Price	(3) As a Result of Information Arising from Domestic Shipments	(4) As a Result of Information Arising from Imports	(5) As a Result of Information Arising from Price
September 2, 2006	–4.12	0.00	0.00	–4.12
September 9, 2006	–4.29	–0.00	0.04	–4.33
September 16, 2006	–3.81	0.00	0.09	–3.88
September 23, 2006	–3.87	0.01	0.13	–4.02
September 30, 2006	–3.42	0.02	0.00	–3.44
October 7, 2006	–3.20	–0.26	0.01	–2.96
October 14, 2006	–2.49	–0.60	0.07	–1.96

Note: This table decomposes the difference between the actual price and the forecasted price at each date between September 2, 2006, and October 14, 2006. That difference at each date can be attributed to information arising in the domestic shipments variable, the imports variable, and the price variable. Accordingly, the column labeled (2) is decomposed at each date into the sum of columns (3), (4), and (5).

Table 3. Historical Decomposition of Tomato Price in a Neighborhood of the April 12, 2008, and July 19, 2008 Event

(1) Date	(2) Difference = Actual Price Minus Forecasted Price	(3) As a Result of Information Arising from Domestic Shipments	(4) As a Result of Information Arising from Imports	(5) As a Result of Information Arising from Price
April 12, 2008	1.76	–0.15	–0.91	2.82
April 19, 2008	0.26	–0.28	–0.74	1.27
April 26, 2008	–0.91	–0.12	0.03	–0.82
May 3, 2008	–0.09	–0.24	0.20	–0.05
May 10, 2008	0.35	–0.23	0.60	–0.02
May 17, 2008	0.78	–0.41	0.42	0.77
May 24, 2008	4.34	–0.28	0.94	3.68
May 31, 2008	5.06	0.28	0.44	4.34
June 7, 2008	3.44	0.58	0.32	2.54
June 14, 2008	6.41	1.22	0.94	4.25
June 21, 2008	4.06	2.19	1.20	0.67
June 28, 2008	1.99	1.75	0.76	–0.52
July 5, 2008	0.72	0.27	0.43	0.02
July 12, 2008	–0.01	–0.66	0.00	0.65
July 19, 2008	0.34	–0.59	–0.56	1.50

Note: This table decomposes the difference between the Actual Price and the Forecasted Price at each date, between April 12, 2008, and July 19, 2008. That difference at each date can be attributed to information arising in the domestic shipments variable, the imports variable, and the price variable. Accordingly, the column labeled (2) is decomposed at each date into the sum of columns (3), (4), and (5).

depending on the source of the outbreak (domestic vs. imported). Cantaloupe innovations are connected with information flows among domestic shipments, imports, and prices, but it is not certain which variables causes which. Spinach innovations are contemporaneously independent. Contemporaneous innovations in tomatoes are modeled as an inverted fork with import innovations being caused by innovations in prices and domestic shipments. Historical decomposition of each price series showed similar results for cantaloupes and tomatoes (both had original warnings linked to a potential foreign source) with actual prices being higher than forecasted prices with information arising before the outbreaks. In spinach, there was an overall negative response in price with actual prices below forecasted prices. Most of this negative information on spinach arises in the price information itself, suggesting that a drop in consumer demand might be behind the fall in spinach prices.

The short-term farm-level impacts of the cantaloupe, spinach, and tomato food outbreaks to their industry was estimated by forecasting domestic shipments, imports, and prices using only information known before the food outbreaks. The difference between forecasted variables and actual values is attributed to information arising from the outbreaks. It was estimated that the short-term farm level losses for U.S. spinach were over $8 million. Domestic shipments of spinach dropped 7,088 metric tons. U.S. tomato farm losses were estimated at $25 million. Finally, short-term farm-level cantaloupe losses were estimated at $5.8 million for the domestic market and $29.5 million for imports, because the contamination source was found to be foreign.

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References

Bernanke, B.S. “Alternative Explanations of the Money–Income Correlation.” *Carnegie-Rochester Conference Series on Public Policy* 25(1986): 49–99.

Bessler, D.A., and D.G. Akleman. “Farm Prices, Retail Prices, and Directed Graphs: Results for Pork and Beef.” *American Journal of Agricultural Economics* 80,5(1998):1145–50.

Buzby, J.C. 2001. “Effects of Food-Safety Perceptions on Food Demand and Global Trade.” Changing Structure of Global Food Consumption and Trade. Economic Research Service, United States Department of Agriculture WRS-01-1. Washington, DC.

Calvin, L., B. Avendano, and R. Schwentesius. 2004. “The Economics of Food Safety: The Case of Green Onions and Hepatitis A Outbreaks.” U.S. Department of Agriculture. VGS-305-01. December 2004. Washington, DC.

Demiralp, S. and Hoover, KD. “Searching for the Causal Structure of a Vector Autoregression.” *Oxford Bulletin of Economics and Statistics* 65(2003):745–67.

Doyle, M.P. “Food Safety Issues Arising at Food Production in a Global Market.” *Journal of Agribusiness* 18,1(2000):129–33.

Food and Drug Administration. (October 6, 2006). FDA Statement on Foodborne *E. coli* O157:H7 Outbreak. Internet site: www.fda.gov/bbs/topics/NEWS/2006/NEW01486.html (Accessed December 2, 2009).

———. (March 21, 2008a). Archived Updates on the FDA Investigation in Honduras. Internet site: www.fda.gov/oc/opacom/hottopics/cantaloupearchive.html (Accessed January 5, 2010).

———. (March 22, 2008b). FDA Warns of *Salmonella* Risk with Cantaloupes from Agropecuaria Montelibano. Internet site: www.fda.gov/bbs/topics/NEWS/2008/NEW01808.html (Accessed January 5, 2010).

———. (June 3, 2008c). FDA Warns Consumers in New Mexico and Texas Not to Eat Certain Types of Raw Red Tomatoes. Internet site: www.fda.gov/bbs/topics/NEWS/2008/NEW01843.html (Accessed January 5, 2010).

———. (July 17, 2008d). FDA Lifts Warning About Eating Certain Types of Tomatoes. Internet site: www.fda.gov/bbs/topics/NEWS/2008/NEW01862.html (Accessed January 5, 2010).

Hoover, K.D. “Automatic Inference of the Contemporaneous Causal Order of a System of Equations.” *Econometric Theory* 21(2005):69–77.

Hyndman, R.J., A.B. Koehler, J.K. Ord, and R.D. Snyder. *Forecasting with Exponential Smoothing: The State Space Approach.* Springer. XII, 2008, 360 pp.

Mead, P.S., L. Slutsker, V. Dietz, L.F. McCaig, J.S. Bresee, C. Shapiro, P.M. Griffin, and R.V. Tauxe. “Food-Related Illness and Death in the United States.” *Emerging Infectious Diseases* 5,5(1999):607–25.

Onyango, B., D. Miljkovic, W. Hallman, W. Nganje, S. Condry, and C. Cuite. “Food Recalls and Food Safety Perceptions: The September 2006 Spinach Recall Case.” *Journal of Agribusiness* 26,1(2008):77–98.

Pearl, J. *Causality: Models, Reasoning and Inference*. New York: Cambridge University Press, 2000.

Scheines, R., P. Spirtes, C. Glymour, C. Meek, and T. Richardson. 1996. “Tetrad III Tools for Causal Modeling: User’s Manual.” Internet site: www.phil.cmu.edu/projects/tetrad/tet3/master.htm.

Sims, C. “Macroeconomics and Reality.” *Econometrica* 48(1980):1–48.

Spirtes, P., C. Glymour, and R. Scheines. *Causation, Prediction and Search*. Cambridge, MA: MIT, 2000.

Swanson, N.R., and C. Granger. “Impulse Response Functions Based on a Causal Approach to Residual Orthogonalization in Vector Autoregressions.” *Journal of the American Statistical Association* 92(1997):357–67.

U.S. Department of Agriculture, Agricultural Marketing Service. *Fruit and Vegetable Market News Portal.* Price and Shipment Information. 2005–2009.

U.S.Department of Agriculture, National Agricultural Statistical Service. 2007. *Vegetable Usual Planting and Harvesting Dates.* Agriculture Handbook Number 507, May 2007. Washington, DC.

Worth, T.W. 2000. “The Cost of an Outbreak in the Fresh Strawberry Market.” The Economics of HACCP: New Studies of Costs and Benefits. L.J. Unnevehr, ed. St. Paul, MN: Eagan Press. Chapter 12.