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# Market Response to a Food Safety Shock:
# The 2006 Foodborne Illness Outbreak of *E. coli* O157:H7 Linked to Spinach

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**By**

**Carlos Arnade, Linda Calvin, and Fred Kuchler[1]**

## Introduction

On September 14, 2006, the U.S. Food and Drug Administration (FDA) announced that consumers should not eat bagged spinach. Epidemiological evidence pointed to bagged spinach as a possible cause of an ongoing multi-state foodborne illness outbreak of the potentially deadly bacterium *Escherichia coli* O157:H7 (FDA 2006). The next day the announcement was widened to include all fresh spinach. FDA had never before made such a sweeping warning about any U.S.-grown produce item. The immediate result of the announcement was that there was no U.S. spinach on the market for 5 days. Even after FDA lifted its warning, consumers did not rush back to their previous consumption patterns. Spinach sales only gradually increased.

This paper investigates consumers' response to the announcement to not eat spinach. Some aspects of their response are obvious: amid massive publicity and a temporary closure of the U.S. fresh spinach market, all fresh spinach sales declined. The announcement raised consumer assessments of health risks from consuming spinach, but theory does not point to a unique long-run response to such announcements. The magnitude and duration of consumers' response depend on how consumers revised their risk perceptions in the face of some clear-cut and some ambiguous safety information.

[1] The authors are with USDA's Economic Research Service. The views expressed herein are those of the authors, who do not necessarily reflect official USDA policy.

Further, it is conceivable that problems in spinach affected demand for other closely related leafy green products such as bulk lettuce, bagged salads without spinach, and other vegetables in general. For closely related goods such as lettuce, theory does not indicate the direction of consumer response to a food safety issue related to spinach. Consumers might turn from spinach to other leafy green vegetables. A product that experiences such a reaction we define as a shock substitute. Although other leafy greens were not implicated in the outbreak, identical packaging and brand names, along with contiguous shelving in grocery stores could lead consumers to conclude that the similar-looking products are equally risky. In addition, the adverse publicity regarding spinach brought out the fact that leafy greens had been associated with 19 previous outbreaks linked to *E. coli* O157:H7 contamination since 1996 (Calvin 2007). Consumers might reason that closely related products are produced under similar growing and packing conditions, and consumption of these products could fall along with spinach. A product that experiences such a reaction we define as a shock complement.

The analysis in this paper is based on an Almost Ideal Demand System (AIDS) model of six closely related leafy green products. This model accounts for prices, expenditures, ongoing trends in consumption patterns, both across years and seasonal patterns within years, as well as the outbreak shock. This type of model separates the effect of prices and trends from the impact of the FDA announcement shock. The analysis uses retail scanner data.

Much of the research estimating impacts of food safety information on food demand examines demand for meat (see Piggott and Marsh, 2004, for a summary of this literature). For example, Kuchler and Tegene (2006) examined retail markets for beef products and showed that the 2003 government announcements of finding cattle infected with bovine spongiform encephalopathy (BSE) increased consumers' awareness of BSE but did not affect beef purchases beyond a brief period. In this case, the government assured consumers that the meat supply was safe. Comparatively few studies focus on food safety problems in produce markets. Richards and Patterson (1999) investigated the impact of positive and negative news on the recovery of the strawberry market after food safety problems, with the aim of finding optimal defensive expenditures that a grower organization might employ to manage negative publicity.

**Background**

FDA's announcement was unique in several ways. Typically by the time an outbreak associated with fresh produce is detected and the contaminated item is identified, the outbreak is over and the product in question has long since been consumed or discarded. As a result, there is usually no benefit to warning consumers about consumption of contaminated fresh fruit and vegetables, and such warnings are rare. In contrast, this warning occurred while the event appeared to be ongoing and, in effect, served as a daily conversation between FDA and the public that carried on for more than two weeks. In addition, most previous outbreaks had been related to one firm and one product—not a warning about an entire industry.

The initial warnings covered all spinach grown in the United States. The geographic coverage was gradually reduced as FDA narrowed its focus to particular areas. On September 19, FDA announced that all the contaminated spinach came from California and that consumers could resume purchasing spinach grown in other areas. Three days later, FDA announced that spinach implicated in the outbreak was grown in a maximum of three California counties, and spinach grown outside those counties could be consumed. At that time of the year, however, most spinach production came from those 3 counties.

In the end, government detective work did not uncover the exact mechanism by which spinach became contaminated.[2] On September 29, sixteen days after FDA became involved, Dr. David Acheson, Chief Medical Officer for the FDA's Center for Food Safety and Applied Nutrition, said that "spinach on the shelves is as safe as it was before this event" (Shin 2006). The leafy green industry may have preferred a stronger endorsement of their product. It is not clear what message consumers took away from the statement.

*Market response*

Spinach is a small part of the leafy green industry which for the purpose of this analysis consists of spinach and various lettuces—iceberg, romaine, leaf, frisee, arugula, and others. In 2005, the year before the outbreak, spinach and products containing spinach accounted for 9 percent of the sales of leafy greens (table 1). At retail, fresh spinach is generally sold in three forms: bulk spinach; spinach in bags, including bags of spinach and spinach mixed with other salad greens; and spring mix which can be sold either in bags or in bulk. Traditionally, spring mix contained baby spinach among other baby lettuces and greens. The largest share of the leafy green group

[2] It is not unusual for FDA to be unable to pinpoint the exact source of contamination. Even in the spinach outbreak when the Centers for Disease Control and Prevention and FDA identified the outbreak, commodity, and location of the fields very rapidly, FDA did not arrive at the fields until a month after the spinach had been harvested. At that point there was not much to see.

in 2005 was bagged salad without spinach (47 percent share), followed by bulk iceberg lettuce (24 percent share).

Between 2004 and 2005, quantities purchased of all the bagged categories were increasing while sales of all the bulk leafy greens were either stagnant or declining. The products that were growing the most rapidly from 2004 to 2005 were the newest in the market place—romaine hearts (13 percent), spinach in bags (7 percent), and bagged spring mix (6 percent). In the first 8 months of 2006, the same trends prevailed as in same time period of the previous year except that salad without spinach declined 6 percent.

After the FDA announcement, sales experienced large changes. In the last four months of 2006, sales of spinach in bags fell 49 percent over the same time in the previous year. Bulk spinach fell 44 percent. Bagged spring mix fell 14 percent (after a 22 percent growth in the first 8 months of the year) and bulk spring mix fell 15 percent. Although spinach products are a small part of the market they appear to have had an important impact on purchases of other leafy greens. Looking at the last four months of the year, all other types of bulk leafy greens, except bulk iceberg lettuce, increased in sales. The salads without spinach category continued its previous decline.

While consumers were reassessing their willingness to buy spinach and other leafy greens, the leafy green industry and the retail and foodservice sectors were also reacting. Many growers plowed under fields of spinach in the face of low demand. With the expectation of continued low demand, many growers stopped planting new fields of spinach or cut back anticipated plantings. Many growers instead planted more romaine and other lettuces. Recipes for some salads are flexible. The leafy green industry was anxious to continue offering spring mix, its most rapidly growing product; so many marketers took spinach out of the mix temporarily or permanently. In addition, if a spinach salad containing other lettuces was not selling well, marketers might cut back production of that product and divert the other lettuces to salads without spinach or the bulk lettuce market. Some retailers and foodservice buyers cut back on orders due to lower consumer demand and some decided not to offer certain products for a period. For example, Costco did not sell spinach again until January 2007, four months after the outbreak was announced (Schmit 2007).

**Data**

The model uses national-level, weekly point-of-sale retail scanner data for the period 2004-2007—two and a half years before the spinach shock and one and a half years after.[3] Retail scanner data came from IRI and FreshLook Marketing. Data include 208 weekly totals of expenditures, quantities purchased, and prices (unit values). IRI was FreshLook Marketing's source of data on consumer packaged goods such as bagged salads. The database contains weekly sales by price lookup codes (PLU) for random weight products such as bulk perishable produce and universal product codes (UPC) for consumer packaged goods. The data are from U.S. grocery stores with sales above $2 million per store per year. The data do not include sales from mass merchandisers such as Wal-Mart and Costco, farmer's markets, or natural food stores. The database is built on records from approximately 15,000 stores which provides 65 percent

[3] Retail data are available, but foodservice data are not. This is a limitation to the analysis. Most fresh spinach goes through retail channels (Lucier, Allshouse, and Lin 2004). For lettuce the foodservice market is very important for hamburgers, sandwiches, and salads.

census actual cash value coverage for all supermarkets. Data are weighted to represent a U.S. total using standard industry projection methods.

**Demand Model**

The demand model is a linear approximation of an AIDS model, consisting of a system of equations. The primary objectives of the model were to determine the influence of the spinach shock on demand for several related leafy green products, evaluate how long the effect of the shock influenced consumer demand, and obtain a better understanding of cross-product reactions to the shock. Estimating a system of equations rather than a single equation allows for the analysis of the size and direction of cross-product responses. While there have been studies which analyze consumer response to a food safety shock in one product, there have been few studies which evaluate cross-product responses. Further, a system of equations allows for the identification of shock complements and substitutes as well as price complements and substitutes.

The six leafy green products included in the model were spinach in bags, bulk spinach, salads without spinach, bulk iceberg lettuce, other bulk lettuces, and romaine hearts. The spinach in bags category includes: bagged spinach intended as salad; bagged salads with spinach, including bagged spring mix; and spinach in bags that may have been intended for microwaving but could be consumed as a salad. Bulk spinach includes bulk spinach and bulk spring mix. Other bulk lettuce is everything except iceberg; it includes romaine, leaf lettuce, bibb, Boston/butter, frisee, hydroponic, and mache, among others. These newer components of the lettuce market are considered separately from iceberg lettuce because they might be more likely substitutes for spinach than iceberg lettuce. Romaine hearts, which are value-added romaine and often sold in bags, are considered separately from bulk romaine. Even when aggregated, many of these categories still represent very small shares of total leafy green consumption. The model allows for estimation of all but one of the 6 commodity categories; in this case the romaine hearts equation was omitted.[4]

In the AIDS model, the log of prices and log of expenditures on all leafy green products were key explanatory variables. Following conventional practice, the model included Stone's price index, to represent higher-order components of the AIDS model, thus insuring the model remained linear in parameters. In addition, the model included a linear trend and assumed a sinusoidal waveform for seasonal cycles in quantities purchased to control for ongoing changes in demand (Arnade and Pick 1998). As the form of the announcement impacts on demand are not known *a priori*, the model employs a set of shock variables that allow the data to reveal both permanent impacts and a wide variety of transitory effects. The shock variables are described in more detail below.

Each share equation in the estimated AIDS system is modeled as:

$$S_i = \alpha_i + \sum_{j=1}^{6} \beta_{ij} \ln(P_j) + \lambda_i \ln(E/PS) + \gamma_i \cos(2\pi t/52) + \delta_i \sin(2\pi t/52) + v_i t + u_i + \varepsilon_i$$

[4] In theory, parameter estimates of an AIDS model are invariant to which equation is dropped. In practice this is rarely the case. Adding-up restrictions can be used to obtain estimates of these parameters. However, it is doubtful that adding up holds for trend, seasonal and shock variables. Thus the main impact of choosing to drop romaine hearts is that we do not directly analyze the shock effect for this vegetable product. However we did estimate a system which included romaine hearts but dropped another variable. This information will be provided upon request.

$S_i$ are expenditure shares for the five products. The variables ln$P_j$ are log prices and *E/PS* is total expenditures on green leafy vegetables deflated by the price index of green leafy vegetables. The price deflator is Stone's price index,

$$PS = \sum_{j=1}^{6} S_i \ln(P_j),$$

which serves as an approximation to the higher-order components of the AIDS demand system. The trigonometric variables represent annual cycles which are discussed below. Consumption trend across years is represented by *t*. The variable $u_i$ represents the set of announcement shock terms which are discussed below.

The restriction $\beta_{ij} = \beta_{ji}$ is imposed to insure symmetry. Homogeneity is imposed by the restriction $\sum_{j=1}^{6} \beta_{ij} = 0$. Adding up implies for each j $\sum_{i=1}^{6} \beta_{ij} = 0$, $\sum_{i=1}^{6} \alpha_i = 0$, and $\sum_{i=1}^{6} \lambda_i = 0$.

The adding-up restrictions can be used, along with symmetry and homogeneity restrictions to obtain the parameters of the dropped equation.

*Shock Variables*

There are numerous methods which could be used to evaluate the influence of the *E. coli* O157:H7 foodborne illness outbreak on demand. This model employs 5 shock variables. The most basic variable is a standard dummy variable, zero prior to the announcement and one afterward. This type of dummy variable in each expenditure share equation allows us to identify a permanent shift in demand. If this variable alone were significant among the shock variables, it would mean that demand shifts in response to the spinach outbreak were permanent. The signs on these dummy variables can play a role in determining whether a product is a shock substitute or complement.

If the demand shift were not permanent, but transitory, variables indicating a temporary pattern of changing demand might be statistically significant while the simple dummy variable was not. But temporary shifts admit a wide variety of possible patterns. The model included 4 dummy variables to allow for the possibility that impacts were transitory. Two immediate onset/decay variables were used to capture the possibility that the shock onset was immediate followed by decay. One such variable allowed for rapid decay while the other decayed slowly.[5] Including these variables could show the demand for, say, spinach shifting inward immediately but gradually rising to its original position. These variables were zero before the announcement, one at the time of the announcement, and decayed to zero afterward. The combination of coefficients of these two terms (one decaying rapidly, one decaying slowly) determines the length of time it takes demand to shift back to its original position. As with the dummy variable, the signs on these coefficients help determine if each product is a shock substitute or shock complement.

The last 2 shock variables, immediate onset/gradual increase and decay, allowed for the possibility that the demand shift might not begin to decay immediately. The variables allowed for the demand response to gradually increase after the immediate shock before beginning to decay.[6] The two variables were initially zero, followed by a 1 at the date of the announcement.

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[5] Decay variables were constructed as $1-(1+e^{-rt})^{-1}$ and normalized to 1.0 at the announcement, where r=.95 for rapid decay and r=.01 for slow decay. The function embeds an exponential decay within a logit to remain within the unit interval. The rapid decay function fell to 0.001 by week number 9. The slow decay was still at 68 percent of the initial value at the end of the data series.

[6] Variables were constructed as $(1+e^{-rz})^{-1}\ with\ z=.9t-.1t^2$ and normalized to 1.0 at the announcement, where r=.95 for the rapid decay and r=.25 for the slow decay. The rapid decay increased to 1.277 in weeks four and five

The variables rise in the weeks following a shock and then fall, decaying to zero. If either or both of these variables were significant and other impact variables not, then following a shock the demand curve would gradually shift, perhaps as information about the health shock spreads, before gradually shifting back to the pre-announcement demand. As with the immediate onset/ decay dummy variables, estimates from the immediate onset/gradual increase and decay variables can be combined to determine a particular direction and speed of consumer response to the spinach health shock.

*Seasonal cycles*

Purchases of leafy greens display seasonal patterns. For example bulk iceberg lettuce sales are generally higher during the summer. Seasonal cycles in demand are modeled as following a 52-week pattern each year: a cosine wave. The seasonal component of consumption can be expressed as $R\cos(2\pi/52 \cdot t - \phi)$, where R is the amplitude, 2π/52 converts the weekly frequency into radians, $t$ is a time variable ($t$ = 0, 1, 2, . . .), and φ is the phase angle—the time in angular measure of the maximum. The general cosine function can be rewritten as $\gamma\cos(2\pi/52 \cdot t) + \delta\sin(2\pi/52 \cdot t)$ where $\gamma = R\cos\phi$ and $\delta = R\sin\phi$, a form amenable to estimation. Varying the relative sizes of coefficients on the sine and cosine functions makes it possible to model a sinusoidal waveform with any phase and amplitude.

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before descending. By week 14, the variable was less than 0.01. The slow decay increased to 1.132 at weeks four and five before descending, and was less than 0.01 at week 20.

**Results**

Table 2 shows the results of the model, estimated with iterative SUR. The t-statistics for most coefficients indicate a fairly high level of confidence in their estimated values. The own-price coefficient is negative for bagged spinach. Others are positive and significant except for salad without spinach. Stone's price index is positive and significant for bulk lettuce, bulk spinach, and spinach in bags. It is negative and significant for salad without spinach.

Table 3 shows price and expenditure elasticities. These elasticities are estimated using model (iii) of Green and Alston (1990) using share data at the means. All the price elasticities are the expected sign. Demand is quite responsive to price.

The trigonometric terms are highly significant for all commodities except bulk spinach. The trend over time is significant for each equation with other bulk lettuce, bulk spinach, and bulk iceberg lettuce all declining. Estimated coefficients indicate that only spinach in bags has experienced a positive trend effect. Salad without spinach is also declining, which is a relatively new phenomenon for this product.

The five shocks in each equation show that about half have significant t-statistics. While such a general model allows for significant flexibility in modeling consumer response to the spinach shock, it runs the risk of over-parameterizing these events. Analysis of the t-statistics alone is not sufficient to properly assess which of these terms belong in the model. We tested the shock terms jointly in all equations. Then we tested these terms equation-by-equation. To apply these tests we used the general unrestricted model with all the shock variables as the maintained model. We then estimated a restricted version of the model where the coefficients on the shock term of interest were set equal to zero. A standard likelihood ratio test, which produces a $\chi^2$ statistic, and which is asymptotically equivalent to the Wald test, was used to determine if the restriction significantly reduced model performance.

Table 4 reports the result of the tests of the shock terms. The first three tests reported in the table refer to joint tests, where each type of shock variable was tested jointly in all five estimated equations. For example, in the first row, when setting all the dummy variables to 0, the $\chi^2$ statistic (100.06) is significant, indicating removing the dummy variables from the model would significantly reduce model fit. The two shocks that decay immediately are tested together (hence 10 degrees of freedom). The shocks that gradually increase and then eventually decay are treated similarly. All the joint tests are significant indicating all the shock variables should be included.

We also tested the shock terms equation by equation. That is, we estimated the system of equations including all shock terms and then re-estimated with the coefficients of one of the 3 shock variable types set equal to zero in equation one. This is repeated for all the shock variables equation by equation. Since there is no particular sequence by which these equation by equation test should be carried out, each of these restrictions were tested against the maintained model.[7] Looking at the equations separately shows that dropping a shock variable would lead to a decline in 12 out of 15 cases. As a result of these tests, we use the model with all 5 shock variables in each equation.

[7] Test results will be provided upon request.

This finding that all the shock variables are significant points to an advantage and a disadvantage of the model. It is clear that the test used cannot determine if the influence of the spinach shock: 1) permanently shifts demand, 2) shifts demand immediately and allows it to gradually shift back, or 3) shifts demand immediately and gradually increases before gradually shifting back. All coefficients relating to all types of shifts are critical to the performance of the model. However it is also clear that the model is flexible enough to incorporate all of these consumer reactions to the spinach shock, reactions which may accurately reflect the mixed (and perhaps muddied) nature of consumer response to food safety shocks.

Since the tests revealed each shock term to be significant, evaluating the coefficients on any of these terms alone would not reveal the true nature of direct consumer response to the spinach. To reveal the impact of the shock on each product category requires a comparison of simulated model estimates with and without the spinach shock. Doing this also provides a visual check on model performance.

Figures 1-5 indicate which products are shock substitutes and which are shock complements. Other bulk lettuce, bulk iceberg, and salads without spinach are substitutes: when demand for spinach fell (both bulk and in bags), demand for these products increased. Recall that sales data appeared to show bulk iceberg lettuce as a shock complement (table 1). After accounting for other factors such as changes in prices and expenditures, it is shown to be a shock substitute. For most products, if the impact of a shock is permanent, that impact is quite small. Most of the impact lies in the week immediately after the shock.

Table 5 shows the difference between predicted results with and without a food safety shock as well as the difference between between actual and predicted sales without a shock. The magnitude and duration of the impact varies by commodity. For example, comparing predicted sales with and without a shock for bulk spinach, the first week after the outbreak had the largest divergence: sales were 26 percent below where the model predicted they would be in the absence of an outbreak. At week 26, predicted sales were still 2 percent below where they were predicted to be without the shock. Bagged spinach also displays large differences. The difference between predicted with and without a shock was biggest during the third week, down 59 percent. But after 26 weeks predicted sales were still 16 percent below the predicted level. Recall that bagged spinach was growing at a rapid rate prior to the outbreak while bulk spinach was declining so the predicted level of sales without a shock is increasing. Even in the last four weeks of 2007 (weeks 65-68), predicted sales with an outbreak were down 10 percent from predicted sales without an outbreak.

The shock substitutes—bulk spinach, bulk iceberg, and salads without spinach—increased in sales after the outbreak. Bulk lettuce had the largest difference between predicted sales with and without a shock with a 27 percent gap in the fourth week, followed by bulk iceberg with a 20 percent gap in the first week, and salads without spinach with a 6 percent gap in the second week. By week 26, all three were still above their predicted levels but only in the 3-7 percent range.

**Conclusions**

This paper provides a reasonable model of demand for the 6 leafy green product categories which allowed for standard economic relationships to hold, as well as incorporating trend, and seasonal factors on demand for leafy vegetables. With a solid model of demand, it was possible to isolate and thus identify the effect of the spinach shock on demand for leafy greens. Had our model not performed well, one would be left guessing as to what in the changing data in the weeks after the spinach shock could be directly attributed to the shock.

By estimating a system of equations we were able to identify what products were shock complements and shock substitutes, something we have not seen before. By creating several shock variables our flexible model made it possible to assess a muddied consumer response to the *E. coli* O157:H7 foodborne illness outbreak linked to spinach. Particularly, we were able to evaluate consumer response in the weeks following the shock and demonstrate that this consumer response was *changing* over time**.** And we were able to use standard statistical procedures to provide degrees of confidence to verify this conclusion.

However we were *not* able to determine the exact nature of this response since most of our shock variables were shown to be significant and were all included in the model. Most important we were not able to say, with our analysis, that consumer response was only transitory or only permanent.

We did not evaluate the indirect effects on consumers, via the effect of the shock on prices and expenditures. We also did not include the shock impact on a broader category of vegetable products nor did we access how different regions of the country responded, and with what weekly lags, to the outbreak. These issues remain to be addressed in following papers.

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**Table 1--Leafy green retail market shares and changes in sales**

| Commodity | Share of leafy green sales 2005 | Change in sales quantity | | | |
|---|---|---|---|---|---|
| | | 2004-05 | 2005-06 (Jan-Aug) | 2005-06 (Sep-Dec) | 2005-2007 |
| | | *percent* | | | |
| Romaine hearts | 7 | 13 | 10 | 10 | 7 |
| Spinach in bags 1/ | 5 | 7 | 8 | -49 | -13 |
| Bagged spring mix | 2 | 6 | 22 | -14 | 13 |
| Salad without spinach | 47 | 1 | -6 | -8 | -9 |
| Bulk romaine | 6 | 0 | 0 | 14 | -3 |
| Bulk iceberg lettuce | 24 | -3 | -6 | -4 | -11 |
| Bulk leaf and other bulk lettuce | 7 | -4 | -5 | 7 | -5 |
| Bulk spring mix | 1 | -4 | -7 | -15 | -14 |
| Bulk spinach 2/ | 1 | -9 | -2 | -44 | -21 |
| All leafy greens | NA | 1 | -3 | -6 | -7 |
| All other vegetables | NA | 3 | 0 | -1 | 3 |

NA=not applicable.
1/ Does not include bagged spring mix. 2/ Does not include bulk spring mix.

*Source* : IRI and FreshLook

**Table 2-- AIDS model with spinach shock variables**

| Variable | Other bulk lettuce | | Bulk spinach | | Spinach in bags | | Iceberg lettuce | | Salad without spinach | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Coeff | T-Stat | Coeff | T-Stat | Coeff | T-Stat | Coeff | T-Stat | Coeff | T-Stat |
| constant | 0.418 | 3.29 | 0.097 | 4.13 | 0.626 | 2.98 | 0.123 | 1.07 | -0.344 | -1.43 |
| ln price of other bulk lettuce | 0.049 | 10.81 | 0.002 | 1.68 | -0.001 | -0.22 | 0.006 | 1.45 | -0.053 | -7.87 |
| ln price of bulk spinach | 0.002 | 1.68 | 0.004 | 3.12 | -0.013 | -7.83 | 0.000 | 0.37 | 0.006 | 3.56 |
| ln price of spinach in bags | -0.001 | -0.22 | -0.013 | -7.83 | -0.076 | -5.71 | -0.004 | -0.68 | 0.094 | 7.58 |
| ln price of bulk iceberg lettuce | 0.006 | 1.45 | 0.000 | 0.37 | -0.004 | -0.68 | 0.047 | 8.54 | -0.051 | -7.92 |
| ln price of salad without spinach | -0.053 | -7.87 | 0.006 | 3.56 | 0.094 | 7.58 | -0.051 | -7.92 | 0.006 | 0.37 |
| ln price of romaine hearts | -0.002 | -0.71 | 0.001 | 0.70 | 0.000 | 0.07 | 0.002 | 0.58 | -0.002 | -0.50 |
| ln expenditures | -0.017 | -2.37 | -0.004 | -2.80 | -0.024 | -2.03 | 0.003 | 0.50 | 0.044 | 3.16 |
| Stone index | 0.017 | 2.37 | 0.004 | 2.80 | 0.024 | 2.03 | -0.003 | -0.50 | -0.044 | -3.16 |
| cos seasonal variable | -0.001 | -2.36 | 0.000 | 1.23 | 0.007 | 7.19 | -0.009 | -17.92 | 0.008 | 7.51 |
| sin seasonal variable | -0.002 | -2.49 | 0.000 | 0.79 | 0.003 | 2.87 | -0.007 | -11.86 | 0.005 | 3.94 |
| Trend | -2E-05 | -2.51 | 0.000 | -17.19 | 1E-04 | 5.3 | -0.0001 | -8.30 | -4E-05 | -2.08 |
| Shock variables: | | | | | | | | | | |
| Permanent | -0.016 | -2.12 | 0.011 | 7.65 | 0.021 | 1.67 | -0.0003 | -0.04 | 0.016 | 1.13 |
| Immediate | | | | | | | | | | |
| Rapid decay | 0.001 | 0.25 | -0.001 | -1.48 | -0.009 | -1.29 | 0.010 | 2.55 | -0.001 | -0.12 |
| Slow decay | 0.024 | 2.68 | -0.013 | -7.65 | -0.058 | -3.91 | 0.010 | 1.20 | -0.002 | -0.09 |
| Immediate with gradual increase | | | | | | | | | | |
| Rapid decay | 0.018 | 3.31 | 0.001 | 0.79 | -0.014 | -1.56 | 0.007 | 1.54 | -0.013 | -1.28 |
| Slow decay | -0.004 | -0.78 | -0.002 | -2.14 | -0.026 | -3.42 | 0.001 | 0.23 | 0.027 | 3.10 |

**Table 3--Price and expenditure elasticities and average market share**

| Commodity | Other bulk lettuce | Bulk spinach | Spinach in bags | Bulk iceberg lettuce | Salad without spinach | Romaine hearts |
|---|---|---|---|---|---|---|
| | | | *Price elasticities* 1/ | | | |
| Other bulk lettuce | **-0.44** | 0.12 | 0.01 | 0.04 | -0.11 | 0.01 |
| Bulk spinach | 0.02 | **-0.80** | -0.08 | 0.00 | 0.01 | 0.02 |
| Spinach in bags | 0.02 | -0.69 | **-1.48** | -0.03 | 0.16 | 0.01 |
| Bulk iceberg lettuce | 0.09 | 0.06 | 0.00 | **-0.65** | -0.11 | -0.02 |
| Salad without spinach | -0.50 | 0.47 | 0.68 | -0.39 | **-0.99** | -0.05 |
| Romaine hearts | -0.01 | 0.07 | 0.01 | 0.01 | -0.01 | **-0.98** |
| | | | *Expenditure elasticities* 1/ | | | |
| | 0.80 | 0.78 | 0.85 | 1.03 | 1.08 | 0.98 |
| | | | *Average share* | | | |
| | 0.09 | 0.02 | 0.16 | 0.14 | 0.54 | 0.06 |

1/ Price and expenditure elasticities calculated using formula 3 of Green and Alston using the means of the share data.

**Table 4--Testing shock variables**

| Equation | Shock variable(s) to test | $\chi^2$ | Degrees of freedom | Significance level |
|---|---|---|---|---|
| All 5 | Permanent | 100.06 | 5 | 0.01 |
| All 5 | Immediate onset/decay | 96.78 | 10 | 0.01 |
| All 5 | Immediate onset/gradual increase and decay | 135.98 | 10 | 0.01 |
| Other bulk lettuce | Permanent | 4.78 | 1 | 0.05 |
| Bulk spinach | Permanent | 55.68 | 1 | 0.01 |
| Spinach in bags | Permanent | 2.92 | 1 | 0.10 |
| Bulk iceberg lettuce | Permanent | 0.01 | 1 | Not |
| Salads without spinach | Permanent | 1.34 | 1 | Not |
| Other bulk lettuce | Immediate onset/decay 1/ | 7.78 | 2 | 0.10 |
| Bulk spinach | Immediate onset/decay | 59.68 | 2 | 0.01 |
| Spinach in bags | Immediate onset/decay | 18.06 | 2 | 0.01 |
| Bulk iceberg lettuce | Immediate onset/decay | 8.88 | 2 | 0.05 |
| Salads without spinach | Immediate onset/decay | 0.02 | 2 | Not |
| Other bulk lettuce | Immediate onset/gradual increase and decay 1/ | 36.84 | 2 | 0.01 |
| Bulk spinach | Immediate onset/gradual increase and decay | 9.56 | 2 | 0.01 |
| Spinach in bags | Immediate onset/gradual increase and decay | 99.80 | 2 | 0.01 |
| Bulk iceberg lettuce | Immediate onset/gradual increase and decay | 16.36 | 2 | 0.01 |
| Salads without spinach | Immediate onset/gradual increase and decay | 20.84 | 2 | 0.01 |

1/ Here the rapid and slow variables are tested jointly for significance.

**Figure 1—Impact of spinach shock on other bulk lettuce sales.**

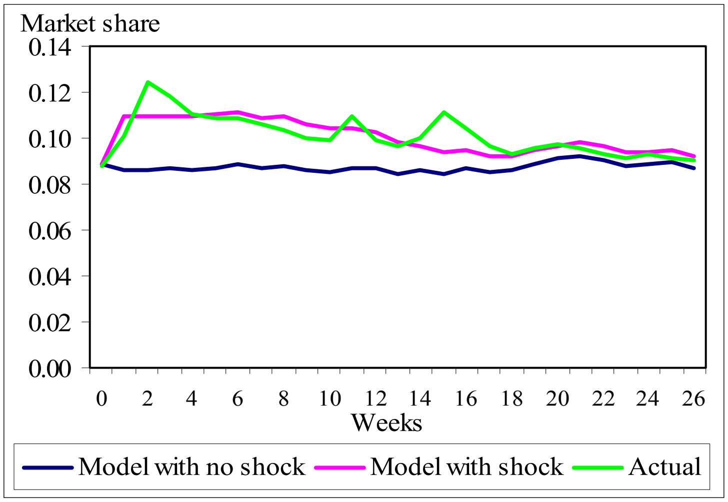

**Figure 2—Impact of spinach shock on bulk spinach sales.**

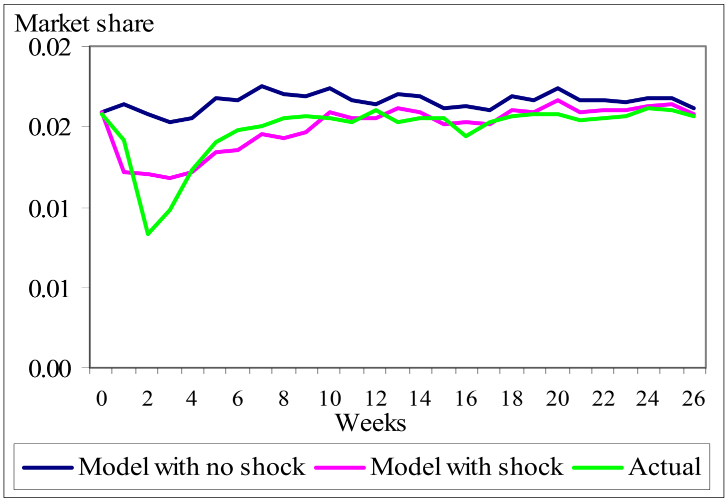

**Figure 3—Impact of spinach shock on spinach in bags sales.**

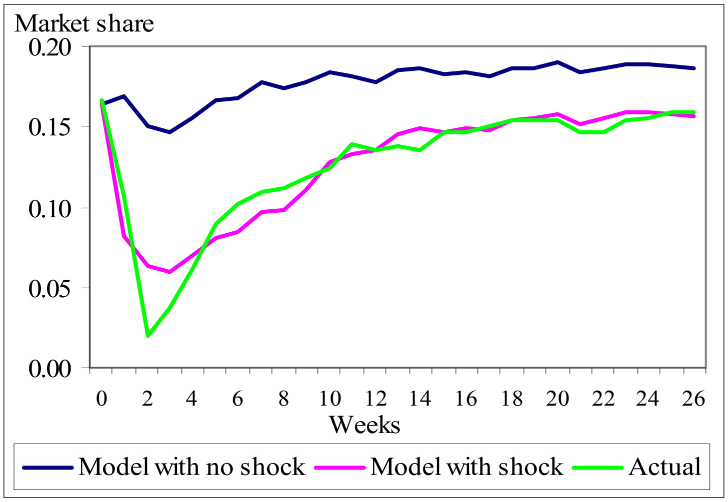

**Figure 4—Impact of spinach shock on bulk iceberg sales.**

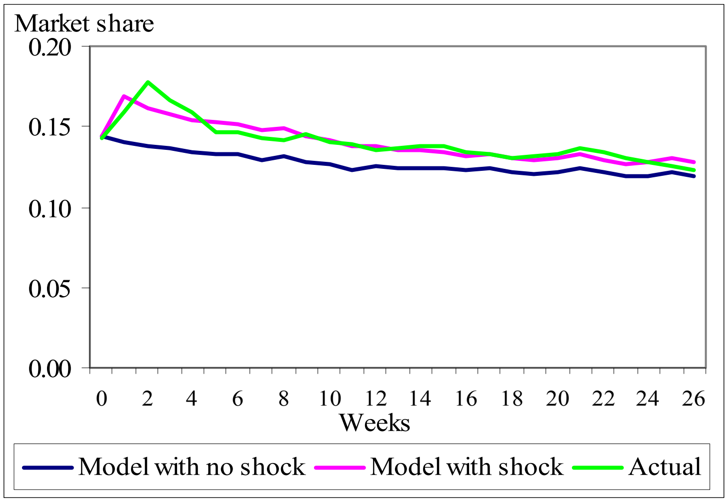

**Figure 5—Impact of spinach shock on salads without spinach sales.**

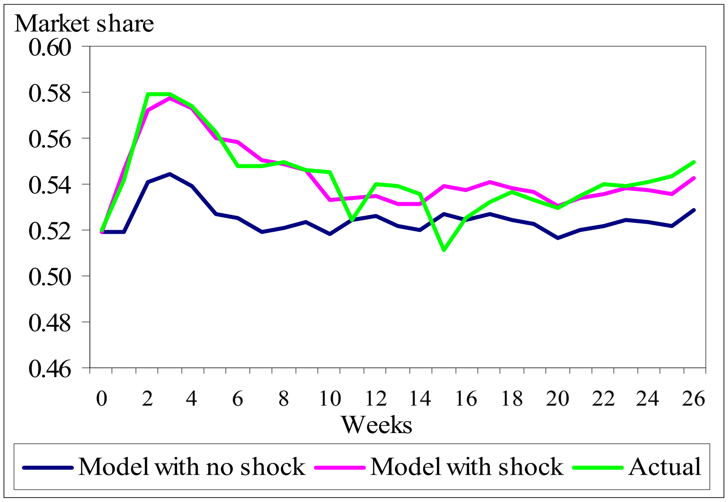

**Table 5-- Difference in leafy green sales at various time periods**

| Commodity | Type of difference | Difference in sales | | | |
|---|---|---|---|---|---|
| | | Predicted with shock vs predicted without shock | | Actual vs predicted without shock | |
| | | Week 1/ | Percent | Week | Percent |
| Bulk spinach | | | | | |
| | Maximum difference | 1 | -26 | 2 | -48 |
| | Difference at week 26 | 26 | -2 | 26 | -3 |
| Spinach in bags | | | | | |
| | Maximum difference | 3 | -59 | 2 | -87 |
| | Difference at week 26 | 26 | -16 | 26 | -15 |
| Other bulk lettuce | | | | | |
| | Maximum difference | 4 | 27 | 2 | 45 |
| | Difference at week 26 | 26 | 6 | 26 | 4 |
| Bulk iceberg lettuce | | | | | |
| | Maximum difference | 1 | 20 | 2 | 29 |
| | Difference at week 26 | 26 | 7 | 26 | 3 |
| Salad without spinach | | | | | |
| | Maximum difference | 5 | 6 | 2 | 7 |
| | Difference at week 26 | 26 | 3 | 26 | 4 |

1/ The outbreak announcement was made on Thursday of the Monday through Sunday sales week which is week 1.