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Food Safety and Spinach Demand: A Shock Correction Model

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, WI, July 26-28, 2009

Abstract

Conventional Error Correction Models estimate the adjustment rate to all components of econometric errors. In this paper we estimate the response to a specific large error and investigate if the adjustment rate to a particular disequilibrium shock was distinct. We examine demand for leafy green vegetables, accounting for the 2006 U.S. Food and Drug Administration announcement that consumers should not eat spinach as it was a possible cause of an ongoing multi-state foodborne illness outbreak due to *E-coli*. If consumers initially responded to the government warning as if risks were significant but gradually realized that risk levels were negligible, the adjustment back to pre-announcement behavior could be considered a correction. Here, we develop a model of consumer behavior where consumers correct both for past errors and for any errors in their reaction to the shock. This method provides estimates of the rates of adjustment to the government announcement.

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Introduction

Error Correction Models (ECMs) are a popular method for modeling economic phenomena when data are nonstationary (Enders, 2003). ECMs also serve as a practical, albeit non-theoretical tool for modeling the dynamic behavior of economic decision makers. A typical ECM consists of two components: a long-run equilibrium model constructed from data represented in levels and a short-run disequilibrium model represented in differences. The long-run model represents a standard economic relationship which may include parameter restrictions consistent with equilibrium economic theory. The short run disequilibrium component of the model models disequilibrium, there is no reason to impose restrictions derived from equilibrium theory.

A common goal of ECM modeling is to estimate the rate of adjustment from disequilibrium to equilibrium. In some situations, policy makers are keenly interested in how long it takes a market to recover from a shock. Is the rate nearly as fast as data are reported? Or, is the rate so slow that intervention might be thought a useful policy option?

Most rate estimates implicitly assume all factors embodied in the econometric error term influence the rate of adjustment to equilibrium equally. In this paper we investigate whether there are distinct rates of adjustment for distinct components of the econometric error. In particular, we investigate whether the adjustment rate to one particular disequilibrium shock at one particular point in time differs from the adjustment rate to all other shocks.

We investigate the 2006 foodborne illness outbreak linked to contaminated spinach with the aim of determining whether the consumer adjustment rate to the food safety shock was similar to the adjustment to others sources of disequilibrium. To explore whether we can identify distinct adjustment rates, we developed several variations of the standard ECM model. For our long-run component, we estimate a weekly model of leafy green vegetable consumption for the period Jan. 2004 through Dec. 2007. 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 multistate foodborne illness outbreak of the potentially deadly bacterium *Escherichia coli* O157:H7 (Calvin 2007). The next day the warning was expanded to include all fresh spinach. FDA had never before made such a sweeping statement about any U.S.-grown produce item. Stores and restaurants immediately removed spinach from their shelves and menus. Spinach harvesting and marketing ceased and there was no U.S. spinach on the market for five days.

Figure 1 shows weekly retail purchases of bagged spinach from 2004 to 2007. In recent years, most fresh spinach has been sold in bags rather than in traditional bunches. The timing of the FDA announcement is shown by the deep trough in weekly purchases. The data do not indicate that sales declined to zero as the five days of no sales were split across two marketing weeks. Consumer response to the government announcement was immediate. However, for several weeks afterward, there was considerable confusion as to the danger of eating spinach. After-the-fact calculations strongly suggest that consumers over-estimated the danger (appendix 1). Comparing the number of consumers who fell ill in the outbreak with the number of servings of spinach eaten during that period makes the risk appear negligible *ex post.* Thus, consumers may have corrected for their initial over-reaction to the announcement. Such a situation is ideal for modeling and testing whether consumers' adjustment rate to one particular shock was unique and different from adjustment to all other shocks.

This paper is organized as follows. In the next section we introduce the notion of a shock correction model, which serves as a generalization of the standard ECM. The first step is the development of an equilibrium model of demand for leafy green vegetables. The second step adds in the error correction to the two types of shocks: food safety shocks and all other shocks. In the following section we report estimated results which include variables to account for the outbreak of *E.coli* in spinach. Findings from some extensions of the model follow. Our conclusions note that the model admits a variety of interpretations. An appendix calculates health risks and shows they were negligible by the time the FDA announced that consumers should not eat spinach.

A Generalized Error and Shock Correction Model

Our generalized ECM is based on an equilibrium model (in levels) of retail demand for leafy green vegetables. The difference model measures two rates: the rate at which consumers corrected for past errors and the rate at which they corrected for the FDA announcement of *E.coli* contamination. We specified retail demand for six leafy green vegetables (bulk spinach, bagged spinach, romaine hearts, bulk iceberg lettuce, other bulk lettuce, and bagged salads without spinach) as a linear approximate almost ideal demand system (LA/AIDS) model. The *i*th equation in the system is written as:

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

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

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

Sin and Cos refer to standard harmonic variables representing an annual cycle. Consumption trend across years was represented by *t*. The restriction $\beta_{ij} = \beta_{ji}$ was imposed to insure symmetry. Homogeneity was imposed by the restriction $\sum_{j=1}^{6} \beta_{ij} = 0$. Adding up implied that for each j, $\sum_{i=1}^{6} \beta_{ij} = 0$, $\sum_{i=1}^{6} \alpha_i = 1$, and $\sum_{i=1}^{6} \lambda_i = 0$. The adding-up restrictions were used, along with symmetry and homogeneity restrictions to obtain the parameters of the dropped (romaine hearts) equation.

The term denoted by u_i is a vector of announcement shock shift terms which includes 29 0/1 dummy variables to represent the timing of the *E.coli* announcement. Individual variables are used to represent each of the first 20 weeks after the shock. For subsequent periods, there are eight dummy variables each of five weeks duration and a final dummy variable of eight weeks (covering 68 weeks through the end of the data set). The 29 dummy variables were selected so that the model could account for a changing consumer response in the immediate weeks following the announcement. The model allows for some changes in consumer reaction to the announcement beyond twenty weeks but is less flexible in that latter period. Collectively the dummy variables reveal whether consumption behavior returns to the pre-announcement pattern[1]

From estimated parameters on the dummy variables, one could construct a story about the rate of adjustment. If parameters are not significantly different from zero within the weeks following the shock then consumers quickly sorted through the conflicting media information about the safety of spinach and returned to their equilibrium consumption pattern.

There is, however, a more compact alternative to parsing the numerous dummy variable parameter estimates for a story about adjustment rates. Specifying such a model as an ECM—adding in the difference component—allows for adjustment back to equilibrium. A necessary condition for the model is that the risk from *E.coli* is negligible. That is, the product attributes of leafy greens (including safety) are unchanged through time. If consumers initially respond to a government warning as if risks were significant but gradually realize that risk levels are negligible, the adjustment back to pre-announcement behavior could be considered a correction.

ECMs can be estimated in two steps (Engle and Granger, 1987). The long-run equilibrium model is estimated first followed by a difference model that uses the lagged error of long-run model as an explanatory variable. This two-step method, which will be used in this paper, avoids many of the nonlinear estimation problems that can arise when estimating ECMS in single step.

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[1] The more flexible the model is in allowing for changing consumer response to the shock, the more likely that the shock correction term represents actual consumer behavior and less likely it represents corrections for modelers' misrepresentation of consumer behavior. For example, consider a model with just one 0/1 dummy variable. One dummy variable would be unlikely to adequately represent consumers' changing response to a food safety shock over several weeks. Therefore, use of this inadequate shock variable may require the modeler to later correct for it in a second step. However, if the changing consumer response to a shock were adequately captured, through numerous

Now consider a specification in which the second step difference disequilibrium component of the generalized ECM includes as explanatory variables *both* lagged error terms *and* the estimated lagged consumer response to a food safety shock. If consumers over-react to the shock then this expanded model will provide the analysts with a method to determine if consumers later compensate for any initial over-reaction to the food safety shock. This expanded model would provide for estimates of two distinct adjustment rates, one representing the standard ECM adjustment and the other representing the adjustment specific to consumer over- (or under-) reaction to the food safety shock.

Specifying this model as *both* a shock correction model and ECM obtains:

3)

$$\Delta S_{it} = \sum_{j=1}^{6} \pi_{ij} \Delta \ln(P_{jt}) + \theta_i \Delta \ln(E_t / PS_t) + a_{1i} \Delta \cos(2\pi t / 52) + a_{2i} \Delta \sin(2\pi t / 52) + \nu_i$$
$$- \psi_1 (S_{i,t-1} - (\alpha_i + \sum_{j=1}^{6} \beta_{ij} \ln(P_{j,t-1}) + \lambda_i \ln(E_{t-1} / PS_{t-1}) + \gamma_i \cos(2\pi t / 52) + \delta_i \sin(2\pi t / 52) + \nu_i t + \varepsilon_{i,t-1}))$$
$$- \psi_2 (S_{i,t-1} - (\alpha_i + \sum_{j=1}^{6} \beta_{ij} \ln(P_{j,t-1}) + \lambda_i \ln(E_{t-1} / PS_{t-1}) + \gamma_i \cos(2\pi t / 52) + \delta_i \sin(2\pi t / 52) + \nu_i t + u_{i,t-1})).$$

The model can be made more intuitive if it is rewritten in the Granger two-step form, consisting of equation 1 and the following disequilibrium component:

4)

$$\Delta S_{it} = \sum_{j=1}^{6} \pi_{ij} \Delta \ln(P_{jt}) + \theta_i \Delta \ln(E_t / PS_t) + a_{1i} \Delta \cos(2\pi t / 52) + a_{2i} (\Delta \sin(2\pi t / 52) + \nu_i - \psi_1 (u_{i,t-1}) - \psi_2 (e_{i,t-1})$$

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dummy variables, the modeler would not need to make secondary corrections. Instead any significant correction variable would represent consumer behavior itself.

where the terms $u_{i,t-1}$ and $e_{i,t-1}$ represent the lagged shock component and error components of the equilibrium model represented in equation 1. The parameters ψ_1, ψ_2 are related to the adjustment rates for the shock and error components of the model respectively. When the parameter ψ_1 equals zero, the model reduces to a standard ECM. If the parameter ψ_2 equals zero the model reduces to the shock correction model.

While the long run demand model is very similar to that estimated by Arnade, Calvin, and Kuchler (2008), the generalized ECM model is distinct from the earlier paper in several ways. First, the earlier paper used 5 dummy variables per equation to estimate consumer reaction to the *E.coli* outbreak. The dummy variables included 3 distinct types, allowing for varying rates of increase and decline after the announcement with the aim of bounding the pattern of adjustment and its speed. Alternatively, the ECM model dummy variables are 29 standard 0/1 dummy variables. Second, and most important, whereas the earlier paper estimated a standard long-run equilibrium LA/AIDS model, this paper expands that model by using Granger's two-step method to estimate an ECM. Thus this model allows for disequilibrium. Finally this paper expands the ECM framework to allow for distinct rates of adjustment to the *E.coli* outbreak. Thus, this model allows for the announcement to create a unique form of disequilibrium in the leafy green vegetable market.

Data and Estimation Results

Retail point-of-sale scanner data came from FreshLook Marketing. The data were aggregated into the six leafy green product categories. The database contains weekly sales by price lookup codes (PLU) for random-weight products such as bulk produce and universal product codes (UPC) for consumer packaged goods such as bagged salads. Information included weekly totals of expenditures; quantities purchased, and price (unit values) for each commodity. These were estimates of national-level, weekly grocery store sales for the period from 2004 through 2007—140 weeks before the spinach shock and 68 weeks afterwards (including the week of the outbreak announcement). Information Resources, Inc. (IRI) was FreshLook Marketing's data source on consumer packaged goods such as bagged salads.

Seemingly unrelated regression estimation methods were used in combination with Granger's two-step method to estimate several variations of the model represented in equation 3. All variations estimate the same first step long-run model (equation 1). In what can be considered the base model, the second step difference component of the model, was estimated as it is represented in equation 4. That is, both lagged shock (*u*) and lagged error (*e)* terms were included as linear explanatory variables.

Many other variations of the model are feasible and theory offers little guidance to choose among them. We tested other versions that included just one of the lagged terms. Also, we estimated a model that interacted a dummy variable on the lagged error term (e) to allow for a changing adjustment rate during the shock period. We imposed and tested the restriction that the two adjustment rates were equivalent. Other versions of the model used quadratic errors to allow for a changing speed of adjustment (Balcombe and Rapsomanikis (2008)). We also allowed for interaction between to two adjustment terms (ie. $\psi_1 u + \psi_2 e + \psi_3 u * e$) and interaction of quadratic terms. Each of these variations provides ways to measure possible changes in the adjustment rate.

Table 1 reports the estimated long-run model. The parameters estimates on the 29 dummy variables included in each share equation are not reported in table 1, but the pattern of dummy variable coefficient estimates is shown in figure 2. The parameters reveal that consumer response to the *E-coli* shock gradually declines towards zero.

Most price, expenditure, seasonal, and trend parameters have significant t-statistics in the long-run model. So do most dummy shock variables. The results indicate that the spinach shock shifted demand outward for other bulk lettuce, iceberg lettuce, and for bagged salads without spinach. The strongest effect seems to have occurred in the second and third week after the shock, but an outward shift in demand continued for these products, each of which could substitute for spinach, indicating a permanent effect. On the other hand, demand for bulk and bagged spinach demand shifted inward with the strongest effect occurring in the second and third weeks.

Tables 2 and 3 report the short-run disequilibrium component of the generalized ECM model. The disequilibrium model was estimated as a second step using SUR. The model was estimated with difference data and included differences in the seasonal and trend (a constant) variables. The model contains two lagged "errors," *e* and *u* of equation 4, and allows for adjustment rates to be distinct. Two estimates of the disequilibrium model are provided. One estimate was made using our entire data set (2004-2007) and one estimate was made over the period just prior to and after the spinach shock. In contrast to the long-run model, no economic restrictions were imposed on the disequilibrium model.

The long-run component of the model does not tell the complete story. The second stage difference models reported in tables 2 and 3 indicate that consumer reaction to the spinach shock is far more complex than revealed by the long-run model. There are several reasons one would suspect to find that the disequilibrium model is part of the story. First, given the existence of dummy shock variables and trend variables, the long-run model cannot identify a long-run equilibrium. By itself, the long-run model suggests an equilibrium along trend lines. Further, figure 1 shows a large drop in spinach purchases immediately after the announcement. The initial drop was not sustained. Thus, it is clear that not all of the consumer reaction to the shock represents a permanent shift in consumer behavior. The short run disequilibrium model provides some indication of the portion of the consumer reaction that might be transitory.

There are alternative ways of estimating the disequilibrium model, each with unique costs and benefits. Estimating over the entire period maintains all the information of inherent in the equilibrium model, but the econometric error, e, may be largely determined in the pre-announcement period. To focus on the post-announcement period, we also estimated the model over the entire post-shock period and three weeks prior. The additional three weeks prior to the announcement, where dummy variables were zero, were included so the dummy variables and the constant term would not be perfectly collinear.

Tables 2 (2004-2007) and 3 (post-shock period) tell qualitatively similar stories. Both reveal that most price and price index difference terms have significant t-statistics. However, the constant terms (representing the difference in trend) and most seasonal difference terms did not have significant t-statistics. At the one percent confidence level only the shock error term for bulk spinach in the post-shock estimation is significantly different from zero. At five percent confidence level all the econometric error terms are significant.[2]

Table 4 reports four parameter tests of the difference component of the model. Each test compared a restricted form of the model to the most general form of the difference model, which included both lagged model errors *e* and lagged shock response *u*. Likelihood -ratio tests were based on 5 degrees of freedom.[3] The first two tests computed likelihood ratio statistics for each type of error individually. Restricting the econometric error correction to zero significantly reduced the performance of the model, while similarly restricting the shock correction did not. The third test imposed equality between adjustment parameters. The significant statistic implied that the restriction reduced model performance and that parameter equality should be rejected. The fourth test split the econometric error into prior- and post-announcement periods. Rejection implied that the error correction did not differ between periods.

These tests provided some indication that in general consumers acted as if their original reaction to the announcement was not an error, but was a rational response to new information. However,

[2]However, t-statistics only represent how much confidence one has in the best estimate of a parameter. More appropriate is a specification test using a likelihood-ratio test.

[3]The test had 5 degrees of freedom, equal to the number of restrictions. That is, the dummy interaction term was represented once in each of 5 equations.

many slight variations of the model show that inclusion of shock correction errors do have a small but significant effect.

Estimated Adjustment Rates

Parameter estimates on errors the time over which adjustment to equilibrium occurs. For example, the length of time for adjusting to econometric errors is $-\psi_1^{-1}$. Table 5 reports the estimated time to adjustment to equilibrium. According to table consumer adjust to equilibrium in response to components of the standard economic error in approximately 2, 3, or 4 weeks. The longest adjustment occurs for bagged spinach. It takes consumers 8 and half weeks to adjust to equilibrium (equilibrium along a trend for this model). It takes a much longer time for consumers to adjust to their own over reaction (or under reaction) to announcement. For two commodities, salad without spinach and bagged spinach, consumers move *away* from equilibrium, perhaps indicating that the announcement created a permanent shift in the consumption of bagged products. Adjustment rates for shock reaction errors (the *u* term) tend to run into months. For example, it takes one year to consumers to adjust to their reaction to announcement for lettuce and a half year for bulk spinach, and 8 years and in an opposite direct for bagged spinach. This result makes sense for several reasons. Consumers may be unsure the true dangers represented by the *E.coli* outbreak and in particular, what it means for bagged products. And consumers, like anyone else may be reluctant to admit to a mistake.

It is quite interesting that consumers move appear to mover further away from the initial pre-shock equilibrium with the two bagged product and do so very slowly. It appears that consumers slowly come to believe their initial reaction to bagged products may have been too small and over time a new equilibrium level (trend line) of consumption for these products is established. This makes sense. Bagged products might first appear safe but upon reflection consumers come to realize that contents are not any more safe than non-bagged products.

Extensions

Balcombe and Rapsomanikis (2008) suggested using various specifications for estimating adjustment rates and suggested that by using quadratic lagged error terms in a ECM model one could estimate changing adjustment rates. Our model, in having two "error" terms, provides ample opportunity to expand on this idea. We estimated models with quadratic *e* terms, quadratic *u* terms, with cubic versions of both variables, and with interaction terms among both variables. The quadratic and cubic versions of the model produced significant t-statistics on many of these terms. Neither produced sensible estimates for the rate of adjustment. The model with interaction effects between the *e* and *u* lagged "error" terms did produce sensible estimates of adjustment rates but those rates did not appear to change much across time. Table 5 therefore reports one set of estimated adjustment rates from the error interaction model. The estimated adjustment rates change little for the error term from that for the more standard model but are much for the shock reaction term estimate adjustment is far slower, taking for example, ten years to adjust to the spinach shock. While allowing for changing rates of adjustment may be a good idea for some models, it did not provide credible insights for this model.

Conclusion

ECM arose primarily as econometric modeling tool without regard to any particular theory of dynamics. However, there are several ways for economists to interpret an ECM. One interpretation of the ECM modeling structure is that by incorporating long-run lagged errors into a model, analysts can account for the behavior of economic agents who "correct" for their errors. Another interpretation is that the analyst only corrects the model for typical sources of econometric errors. In reality both aspects of the correction play a role.

The above extension to the ECM model is open to several possible interpretations. If one views the shock component of a model as part of the error term, then this model breaks the error correction into two components with two different rates of adjustment. Alternatively, one could view the generalized ECM model as a way of reconciling the two interpretations of ECM models. A model specified as in equation 4 allows agents to "correct" for behavioral errors (the shock correction term) and, at the same time it allows the modeler to correct for the typical sources of econometric errors (the error correction term). In this paper we do not view either interpretation as more appropriate than the other.

In this paper we used a generalized version of the ECM to model consumers' reaction to the announcement of an outbreak of *E.coli* in spinach markets. The long-run equilibrium component of a leafy green vegetable model performed well and the series of shock-specific dummy variables provided evidence of a strong consumer reaction to the shock. Despite this performance, the addition of a disequilibrium component to the model also performed well. The performance of the latter component showed that there is much more to learn about consumer behavior beyond results of models of the long-run behavior of consumers. Not only were most variables in the disequilibrium model significant, adjustment rates indicated that it takes consumer several weeks to return to equilibrium behavior. And our model showed that it takes upwards to a year for consumers to correct from any over- or under-reaction specific to the *E.coli* announcement. In general, we found that consumers acted as their initial reaction to the shock was appropriate; their adjustment to changing news was rational and not a correction for an initial error.

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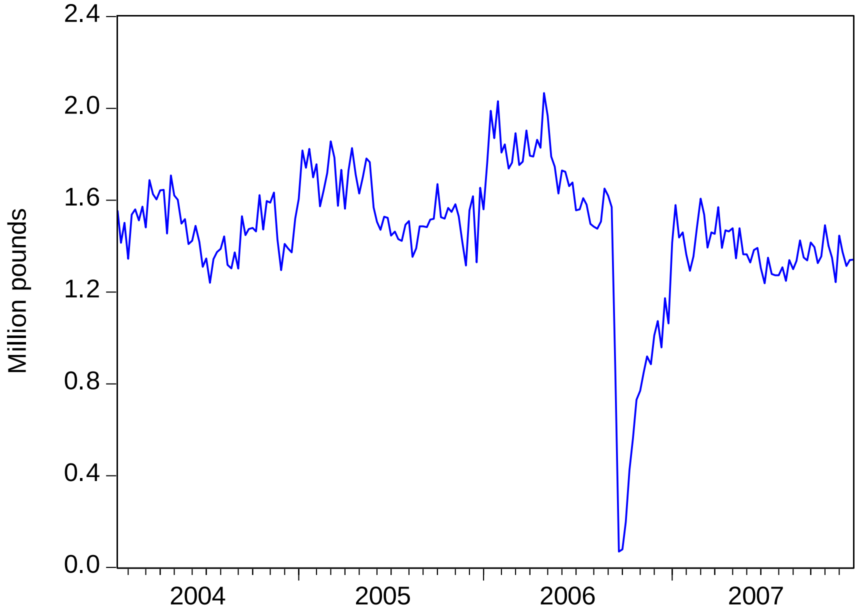
Figure 1. Weekly retail purchases of spinach in bags



Source: FreshLook Marketing

Figure 2. Bagged spinach shock variable estimates

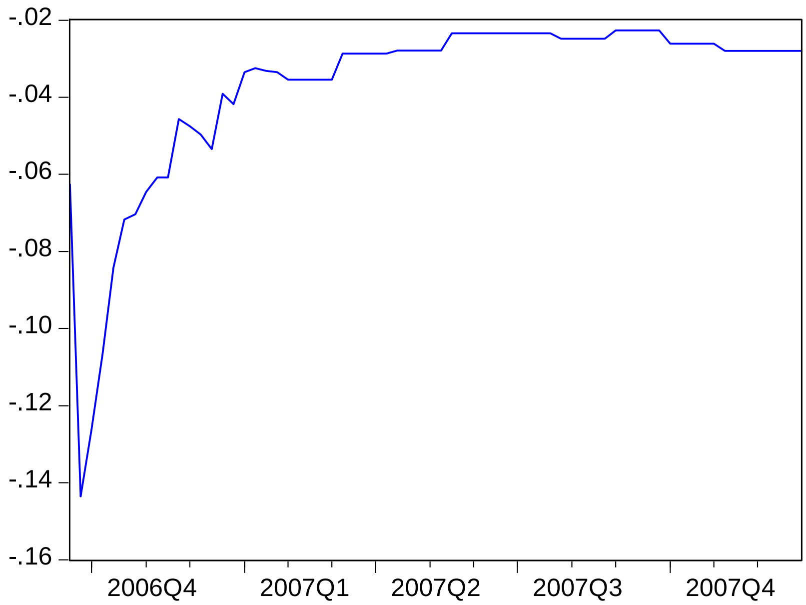


Table 1. Leafy greens demand model estimation results[1]

	Other bulk lettuce	Bulk spinach	Bagged spinach	Bulk iceberg lettuce	Salad without spinach
Variable	Coefficient estimate t-statistic				
Constant	0.49049	0.10319	0.55569	0.07450	-0.28525
	3.83	4.61	3.53	0.68	-1.12
Ln price other bulk lettuce	0.05597	-0.00135	-0.02367	0.01071	-0.04346
	12.16	-1.26	-4.71	2.62	-6.19
Ln price bulk spinach	-0.00135	0.00834	-0.00832	-0.00041	0.00119
	-1.26	4.17	-5.23	-0.29	0.63
Ln price bagged spinach	-0.02367	-0.00832	-0.02445	-0.00412	0.06635
	-4.71	-5.23	-2.12	-0.69	5.91
Ln price bulk iceberg	0.01071	-0.00041	-0.00412	0.04132	-0.04734
	2.62	-0.29	-0.69	6.67	-6.90
Ln price salad without spinach	-0.04346	0.00119	0.06635	-0.04734	0.01943
	-6.19	0.63	5.91	-6.90	1.17
Ln price romaine hearts	0.00180	0.00055	-0.00580	-0.00015	0.00383
	0.65	0.33	-1.35	-0.04	0.80
Ln leafy greens expenditures	-0.02011	-0.00447	-0.02352	0.00606	0.04228
	-2.72	-3.46	-2.59	0.96	2.85
Stone's price index	0.02011	0.00447	0.02352	-0.00606	-0.04228
	2.72	3.46	2.59	-0.96	-2.85
Sin	-0.00138	0.00022	0.00732	-0.00914	0.00736
	-2.50	2.27	10.61	-19.43	6.66
Cos	-0.00329	0.00044	0.00675	-0.00827	0.00456
	-4.99	3.61	8.17	-14.70	3.63
Trend	-0.00004	-0.00003	0.00014	-0.00008	-0.00006
	-4.88	3.61	10.51	-9.81	-3.27

1.Endogenous variables represent leafy green budget shares. Sin and Cos refer to trigonometric seasonal variables. Not reported are estimates for dummy variables. These include 20 weekly pulse dummy variables for the 20-week period following the announcement and eight five-week 0/1 dummy variables to indicate sequential periods.

Table 2. Short-run disequilibrium model (2004-2007)

	Other bulk lettuce	Bulk spinach	Bagged spinach	Bulk iceberg lettuce	Salad without spinach
Variable	Coefficient estimate t-statistic				
Constant	0.00003	-0.00004	0.00006	0.00001	-0.00014
	0.13	-0.99	0.28	0.07	-0.32
Δ *Ln* price other bulk lettuce	0.07602	0.00100	-0.01992	0.04274	-0.10451
	8.05	0.61	-2.15	6.06	-5.58
Δ *Ln* price bulk spinach	0.00894	-0.00080	-0.00790	-0.02362	0.02381
	1.35	-0.70	-1.21	-4.83	1.82
Δ *Ln* price bagged spinach	0.03566	-0.00748	-0.10837	0.05109	0.01448
	5.29	-6.37	-16.47	10.32	1.09
Δ *Ln* price bulk iceberg	0.00831	-0.00639	-0.11179	0.05384	0.03353
	1.12	-4.93	-15.30	9.89	2.29
Δ *Ln* price salad without spinach	0.09108	-0.01859	-0.39252	0.17200	0.06457
	4.81	-5.59	-21.09	12.15	1.73
Δ *Ln* price romaine hearts	0.01737	-0.00226	-0.03768	0.02820	-0.00778
	2.65	-1.98	-5.84	5.83	-0.60
Δ *Ln* leafy greens expenditures	-0.00227	-0.00036	0.00781	0.01380	-0.01513
	-0.49	-0.45	1.73	4.08	-1.66
Δ Stone's price index	-0.14295	0.03852	0.75965	-0.32432	-0.20535
	-4.79	7.34	25.77	-14.48	-3.48
Δ Sin	-0.00003	-0.00059	-0.00278	-0.00537	0.01168
	-0.01	-1.35	-1.11	-2.84	2.34
Δ Cos	0.00052	0.00004	-0.00196	-0.00466	0.00454
	0.21	0.09	-0.79	-2.50	0.91
Shock error	-0.01861	-0.04004	0.00226	-0.01400	0.01847
	-0.89	-1.43	0.37	-0.57	0.90
Econometric error	-0.25705	-0.44096	-0.11766	-0.26896	-0.21971
	-6.48	-7.24	-4.74	-6.35	-8.11

Table 3. Short-run disequilibrium model (post shock)

	Other bulk lettuce	Bulk spinach	Bagged spinach	Bulk iceberg lettuce	Salad without spinach
Variable	Coefficient estimate t-statistic				
Constant	0.0001	0.0000	0.0004	0.000	-0.001
	0.24	-0.54	0.69	0.48	-0.55
Δ *Ln* price other bulk lettuce	0.0808	-0.0002	-0.0081	0.057	-0.136
	4.11	-0.06	-0.37	4.24	-3.36
Δ *Ln* price bulk spinach	-0.0101	-0.0016	-0.0067	-0.028	0.048
	-0.93	-0.93	-0.56	-3.63	2.17
Δ *Ln* price bagged spinach	0.0433	-0.0098	-0.0813	0.045	-0.014
	3.76	-5.45	-6.46	5.83	-0.58
Δ *Ln* price bulk iceberg	0.0142	-0.0038	-0.1254	0.057	0.030
	1.13	-1.93	-8.92	6.59	1.17
Δ *Ln* price salad without spinach	0.1265	-0.0183	-0.4448	0.180	0.076
	4.12	-3.75	-13.01	8.17	1.21
Δ *Ln* price romaine hearts	0.0193	-0.0030	-0.0347	0.030	-0.019
	1.61	-1.60	-2.61	3.71	-0.77
Δ *Ln* leafy greens expenditures	-0.0117	0.0007	0.0083	0.016	-0.008
	-1.37	0.52	0.87	2.74	-0.47
Δ Stone's price index	-0.2155	0.0318	0.8087	-0.342	-0.148
	-4.43	4.12	14.84	-9.65	-1.48
Δ Sin	0.0010	-0.0010	-0.0021	-0.006	0.012
	0.21	-1.39	-0.40	-1.63	1.22
Δ Cos	0.0004	0.0002	-0.0014	-0.005	0.005
	0.08	0.26	-0.27	-1.52	0.49
Shock error	-0.0148	-0.0477	0.0100	-0.022	0.026
	-0.60	-1.64	1.05	-0.48	0.91
Econometric error	-0.3683	-0.5854	-0.1686	-0.469	-0.336
	-3.10	-3.36	-2.34	-4.88	-4.70

Table 4. Likelihood Ratio Tests of Various Model Specifications

Test description	Test	Test statistic	Degrees of freedom
No correction for econometric error	$\psi_1 = 0$	120	5
No correction for shock	$\psi_2 = 0$	4	5
Equal adjustment rates	$\psi_1 = \psi_2$	120 (significant at 1 percent)	5
Separate adjustments for econometric error	$\psi_1 = \alpha_0 + \alpha_1 D$ $D = \begin{Bmatrix} 0 \; prior\, to\, shock \\ 1 \; after\, shock \end{Bmatrix}$	6	5

Table 5. Estimated rates or time to adjust to equilibrium (weeks)

Model specification	Adjusting variable	Other bulk lettuce	Bulk spinach	Baged spinach	Bulk iceberg lettuce	Salad without spinach
		Model estimated over 2004-2007				
Includes econometric and shock correction errors	e	3.9	2.3	8.5	3.7	4.6
Includes only econometric correction	e	3.9	2.3	8.6	3.8	4.6
Includes shock and econometric error interaction	e	3.9	2.2	9.1	4.2	4.7
Includes econometric and shock correction errors	u	53.7	25.0	-443.1	71.4	-54.2
Includes only shock correction	u	76.3	26.6	-287.9	78.8	-53.1
Includes shock and econometric error interaction	u	526.0	256.0	-344.0	729.0	-555.0
		Model estimated over post-shock period				
Includes econometric and shock correction errors	u	67.8	21.0	-100.2	45.6	-38.3
Includes econometric and shock correction errors	e	2.7	1.7	5.9	2.1	3.0

Appendix 1. *E.coli* health risk was small and transitory

The observed reaction to the FDA announcement is best considered an error. *Ex post* examination of the risk posed by eating spinach suggests that if consumers had been aware of the magnitude of the risk, they would not have made significant changes in food choices; any changes would not have been permanent.

Eating spinach did pose a risk of *E.coli* infection for a few weeks, but the risk was nearly gone by the time it was made public and the risk diminished rapidly thereafter. If consumers judged spinach risk-free before the announcement, it was that same product afterward. No permanent changes in product attributes occurred.

Risk calculations

We want to characterize risk as the frequency of illness per risky serving. But a point estimate is not enough as the number of confirmed spinach-caused illnesses varied over time. Thus, there are a couple of ways to think about the risk from eating spinach.

One way to measure risk is to examine the bulk of illnesses relative to how much spinach was eaten that could have caused those bad outcomes. The first confirmed case in a person reporting fresh spinach consumption occurred on August 19, 2006 (CDC, September 26, 2006). Among ill persons who provided the date when their illnesses began, 82 percent occurred between August 19 and September 5. Between the first confirmed case and September 14, the day of the announcement, there were 165 cases with known dates of illness. This 26 day period implies a 27 day period in which consumers were eating risky spinach products (CDC timeline indicates a 3-4 day incubation period.) We can bound the risk with this information, comparing the number of illnesses with the number of risky spinach servings eaten. At the upper limit, if all spinach were eaten raw, there would have been 8 million servings over that time period (1/2 cup/serving = 30g/serving implies ~15 servings/pound, and we know that approximately 531,000 pounds of spinach or spinach containing products were sold in supermarkets each day prior to the announcement). If all spinach were cooked, the risk would have been limited to that from cross contamination as cooking deactivates the pathogen. However, the spinach in salad with spinach likely would not be cooked. If all non-salad spinach were cooked, potentially contaminated servings of salad with spinach would number 4.1 million. Risk of infection per serving then falls in the range 7.6×10^{-7} to 1.5×10^{-6}.

We can also focus on the peak time for illnesses (CDC identified that three-day period when 32 percent of illnesses occurred—August 30 to September 1, (CDC September 28)). The three days of illnesses imply four days of eating risky spinach. The four day period of risky meals implies the 60 illnesses were caused by 2.2×10^{7} to 3.2×10^{7} servings. The implied risk levels were 1.9×10^{-6} to 3.7×10^{-6}.

The average risk levels over the longer period are near conventional *de minimus* levels, one in a million. At the peak, risk levels were 2-3 per million servings. As spinach consumption data reflects only purchases from conventional grocery store sales, risks are overestimated despite the use of ranges. Data is not available for sales in big box stores and through food service.

Of course, consumers were not immediately aware of the magnitude of the risk they faced. Over the days following the announcement, they were informed that the risk was diminishing and was returning to normal. The trace back investigation narrowed to four implicated fields on four ranches. Those four fields were not being used to grow any fresh produce in mid-September, so the risky product was limited to spinach and bagged salad with spinach packed before the announcement. All spinach implicated in the outbreak was traced back to Natural Selection Foods LLC, which issued a recall, as did the firms it supplied (FDA). The risky product diminished also because spinach has a limited shelf life. In effect, the risk returned to its pre-announcement level. 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).