Food Safety and Spinach Demand: A Generalized Error Correction Model

Carlos Arnade, Fred Kuchler, and Linda Calvin

We estimate an error correction model representing demand for leafy green vegetables but generalize the structure to allow for adjustment to one conspicuous shock. We investigate whether the adjustment rate to the U.S. Food and Drug Administration's (FDA) 2006 warning that fresh spinach was contaminated with deadly bacteria was distinct from the overall adjustment rate. Our model allows consumers to correct both for past errors and for any errors in their reaction to the shock. This method yields an estimate of the adjustment rate to the policy shock and points to an improved estimate of the duration of policy impacts.

Key Words: error correction model, adjustment rates, AIDS demand model, retail food demand

This paper uses an Error Correction Model (ECM) to determine whether consumers' adjustment to a warning from the federal government that a food was unsafe differed from the way in which consumers adjusted to more typical sources of disequilibrium. In general, policy makers are keenly interested in how long it takes a market to recover from any shock. Is the adjustment rate, or return to equilibrium, nearly as fast as data are reported? Or, is the rate so slow that intervention might be thought a useful policy option? Policy makers may be specifically interested in adjustments to food safety shocks, as these shocks are sometimes so big that they dwarf the impacts of all other events.

ECMs are a popular method for modeling economic phenomena when data are nonstationary and for modeling cointegrated relationships (Duffy 2003, Edgerton et al. 1996, Enders 2003, Karagiannis and Mergos 2002, and Nzuma and Sarker 2010). But ECMs have several practical uses even when economic data are stationary. For example, they can be used as an atheoretical tool for modeling a wide variety of dynamic economic behaviors (Friesen 1992, Friesen, Capalbo, and Denny 1992).

Regardless of whether data are stationary or nonstationary, ECMs are often used to estimate the rate of adjustment from disequilibrium to equilibrium, a critical goal in itself (Balcombe and Rapsomanikis 2008). A typical ECM consists of two components: an equilibrium model constructed from data represented in levels, obeying equilibrium constraints, and a disequilibrium model represented in differences. The interaction between these two model components allows economists to estimate the adjustment rate to equilibrium. Adjustment rate estimates derived from ECMs have been based on the implicit assumption that all factors embodied in the econometric error term equally influence the rate of adjustment to equilibrium (Duffy 2003, Edgerton et al. 1996, Enders 2003, Karagiannis and Mergos 2002, and Nzuma and Sarker 2010).

This analysis departs from the standard ECM by generalizing the model to investigate: (1) whether the adjustment rate changes before and after a major shock, and (2) whether there are distinct rates of adjustment for various components of the econometric error. In the second case, the ECM investigates whether the adjustment rate to one conspicuous disequilibrium shock that occurred at a well-known point in time differs from the adjustment rate to all other shocks. This requires us to break the ECM error term into component parts

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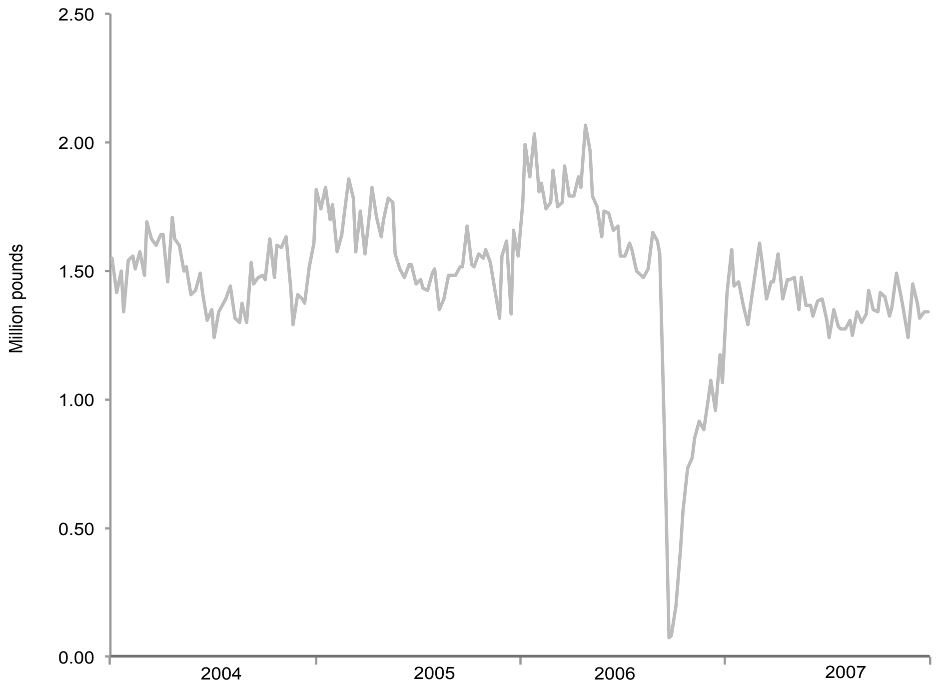


Source: FreshLook Marketing.

Figure 1. Weekly Retail Purchases of Bagged Spinach

and test whether distinct adjustment rates exist for each component. In effect, this analysis investigates whether analysts can expand the structure of the typical ECM to measure adjustment rates to the unusual events that drive policy making.

This is a forensic economics question. If, for example, the public sector chooses to make some subsector of the agricultural economy financially whole after an adverse event, analysts would need to know how long it took for the market to recover and what path it took to recovery. It is possible that the rate at which adjustments were made to the relatively small ex ante events might not offer much guidance.

The particular shock under investigation is the U.S. Food and Drug Administration's (FDA) 2006 announcement warning consumers not to eat bagged spinach because of an outbreak caused by the potentially deadly bacterium *Escherichia coli* O157:H7 linked to spinach. This analysis investigates whether the consumer adjustment rate to the food safety shock was similar to the adjustment to other sources of disequilibrium. We estimate a weekly model of leafy green vegetable consumption for the period January 2004 through December 2007. The estimation period contains the date (September 14, 2006) on which the FDA announced that consumers should not eat bagged spinach.[1] The event had a uniquely large impact on the spinach market. Stores and restaurants immediately removed spinach from their shelves and menus. For five days, spinach harvesting and marketing ceased. Even after the FDA allowed spinach to return to the market, sales lagged.

Figure 1 shows the weekly retail purchases of bagged spinach. The timing of the FDA announcement is shown by the deep trough in week-

[1] 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).

ly purchases.[2] Consumer response to the government announcement was immediate. With the benefit of hindsight, a comparison of the number of consumers who fell ill in the outbreak with the number of servings of spinach eaten during that period indicates that the risk was negligible by the time the FDA made its announcement (see the Appendix for risk calculations). Thus, it appears that consumers initially overestimated the danger (justifiably, as public health authorities repeatedly said consumers should avoid spinach) and afterward may have corrected for their initial overreaction to the announcement. Such a situation is ideal for testing whether consumers' adjustment rate to one particular shock was unique and different from adjustments to all other shocks.

The logic of this paper is as follows. The next section introduces an equilibrium model of retail demand for leafy green vegetables. This model includes dummy variables to allow the *E. coli* announcement to operate as a demand shock, temporarily or permanently altering consumer demands. A standard ECM is based on this demand model. The next section presents two ECM models that demonstrate a variety of ways to decompose the error correction. First, a 0/1 dummy variable can be used to test for changing adjustment rates before and after the demand shock—decomposing the error across time. A changing adjustment rate provides circumstantial evidence that consumers' reaction to large market distortions may differ from more common distortions. Second, the adjustment process can be split into two parts to test if consumers later offset their initial reaction to the *E. coli* announcement—decomposing the error by source.

After introducing the models, the following sections describe data and report estimation results from the generalized ECM. Findings from some extensions of the model follow. Conclusions note that while the model admits a variety of interpretations, we find consumers' behavior was well specified by the demand model. The demand model tracks adjustment back to equilibrium. Estimated rates of adjustment differed before and after the announcement. However, the adjustment rates differed because the announcement itself was unusual, not a typical shock. The error decomposition revealed that consumers did not make adjustments along the return to equilibrium. That is, consumers did not treat their adjustment to the shock as an error requiring any adjustment. The Appendix calculates health risks and shows they were negligible by the time the FDA announced that consumers should not eat spinach.

A Generalized Error Correction Model

The Equilibrium Model

This section discusses the specification of the equilibrium model from which various ECMs were derived. A modified linear approximation to an almost ideal demand system (LA/AIDS) model represents equilibrium retail demand for six leafy green vegetables (bulk spinach, bagged spinach, romaine hearts, bulk iceberg lettuce, other bulk lettuce, and bagged salads without spinach). The ith equation in the system is written as:

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

S_i are the expenditure shares for the six products, $\ln(P_j)$ are the natural logarithm of prices, and E/PS is total expenditures on leafy green vegetables (E) deflated by the price index for the same products. The price index is the Stone's price index,

$$(2)\qquad PS = \sum\nolimits_{j=1}^{6} S_j \ln(P_j).$$

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

$$\sum\nolimits_{j=1}^{6} \beta_{ij} = 0\,.$$

Adding up implied that for each j,

[2] The data do not indicate that sales declined to zero, since the five-day period of no sales was split across two marketing weeks.

$$\sum_{i=1}^{6} \beta_{ij} = 0.$$

Also implied are

$$\sum_{i=1}^{6} \alpha_i = 1 \text{ and } \sum_{i=1}^{6} \lambda_i = 0.$$

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 u_i represents the impact of the food safety shock announcement on retail demand. Theory does not offer much guidance on the form we should expect consumers' reactions to take. Consumers might flee from spinach, temporarily or permanently. They might substitute other leafy green vegetables, beyond the impact of relative prices, again temporarily or permanently (the shock itself can induce substitution). Or they might revise their ideas about the safety of all leafy greens and the announcement could create shock complements (as opposed to complementarity in prices). Empirically, u_i takes the form of a set of 0/1 dummy variables that change from 0 to 1 at different post-announcement times (discussed in detail below).

In some cases, a relatively small set of dummy variables included within the demand system could adequately account for the form of consumers' adjustment and provide a story about the rate of adjustment. For example, if parameters are not significantly different from zero within a few weeks following the shock, then one could conclude that consumers quickly sorted through the conflicting media information about the safety of spinach and returned to their equilibrium consumption pattern. But such a procedure is only adequate in the case of a rapid and complete consumer adjustment.

Where it is not so certain that consumers quickly reestablished their equilibrium consumption pattern, one could include a very large number of dummy variables to represent consumers' response to the announcement. Where analysts are uncertain about the length of time to adjust, dummy variables could be so numerous that there would have to be a unique variable for each and every post-announcement time period. The number of included dummy variables could be extended indefinitely, in hopes of eventually finding that at some point, consumer response to the shock completely dissipates.

In contrast, an ECM is more compact for modeling the adjustment back to the initial equilibrium than parsing a long string of dummy variable parameter estimates. The ECM approach allows a richer set of hypotheses about the way in which consumers adjust. Here, we assume that consumers initially responded to the government warning as if risks were significant. The ECM allows us to model their behavior as if they gradually realized that risk levels were negligible. Hence, the adjustment back to pre-announcement behavior could be considered a correction.

ECM Model 1—Generalized to Decompose the Error across Time

ECMs can be estimated using the Engle-Granger two-step method (Engle and Granger 1987). The error of the equilibrium model [equation (1) is the first step] is lagged and used as an explanatory variable in the second step, which is based on the equilibrium model but written in differences. This method avoids many of the nonlinear estimation problems that can arise when estimating ECMs in a single step.

Specifying an ECM with a dummy interaction variable on the error correction term obtains:

$$
\begin{aligned}
(3)\quad \Delta S_{it} = {} & \sum_{j=1}^{6} \pi_{ij} \Delta \ln(P_{jt}) + \theta_i \Delta \ln(E_t / PS_t) \\
& + a_{1i} \Delta \cos(2\pi t / 52) + a_{2i} \Delta \sin(2\pi t / 52) \\
& + \nu_i + \omega_{it} - \psi_{1i}[S_{i,t-1} - (\alpha_i + \sum_{j=1}^{6} \beta_{ij} \ln(P_{j,t-1}) \\
& + \lambda_i \ln(E_{t-1} / PS_{t-1}) + \gamma_i \cos(2\pi t / 52) \\
& + \delta_i \sin(2\pi t / 52) + \nu_i t + u_{i,t-1}](1 + \varphi_i D).
\end{aligned}
$$

In equation (3), the difference terms represent disequilibrium. The level terms represent the equilibrium component of the model. In contrast to the equilibrium model, no economic restrictions are imposed on the disequilibrium model. The term ω_{it} represents the equation error. The term in brackets represents the lagged error from the equilibrium model. The dummy interaction term, D, is used to determine if the adjustment rate changed following the *E. coli* announcement. That is, the coefficient ψ_1 measures the adjustment rate before the shock, and the term $\psi_1(1+\varphi)$ measures the adjustment rate after the shock.[3] If φ were equal to 0 this would be the standard ECM. The model can be made more intuitive if it is rewritten in the Engle-Granger two-step form, consisting of equation (1) and the following disequilibrium component:

$$(4) \quad \Delta S_{it} = \sum_{j=1}^{6} \pi_{ij} \Delta \ln(P_{jt}) + \theta_i \Delta \ln(E_t/PS_t)$$

$$+ a_{1i} \Delta \cos(2\pi t/52) + a_{2i} \Delta \sin(2\pi t/52)$$

$$+ \nu_i - \psi_{1i}(e_{i,t-1}) - \psi_{1i}\varphi_i(D^* e_{i,t-1}) + \omega_{it}$$

where the term $e_{i,t-1}$ represents the error term of the equilibrium model in equation (1). The term $D^* e_{i,t-1}$ is an interaction of a dummy variable and the lag error term. By setting the parameter φ equal to zero, and determining if that significantly changes the performance of the model, the analyst can infer whether the adjustment rate was significantly different after the announcement.

ECM Model 2—Generalized to Decompose the Error Term by Source

The second goal is to determine if eventually consumers treat their initial reaction to the *E. coli* announcement as an error that they later correct. Consider a specification in which the second step difference disequilibrium component of an ECM includes as explanatory variables *both* lagged error terms and the estimated lagged consumer response to a food safety shock, $\hat{u}_i$. This model provides the analyst with a method to determine if consumers later compensate for any initial overreaction to the food safety shock. It also allows for estimation of two distinct adjustment rates, one representing the standard ECM adjustment and the other representing the adjustment specific to consumer overreaction (or underreaction) to the food safety shock. This second model can be written as:

$$(5) \quad \Delta S_{it} = \sum_{j=1}^{6} \pi_{ij} \Delta \ln(P_{jt}) + \theta_i \Delta \ln(E_t/PS_t)$$

$$+ a_{1i} \Delta \cos(2\pi\, t/52) + a_{2i} \Delta \sin(2\pi\, t/52)$$

$$+ \nu_i - \psi_{1i}(e_{i,t-1}) - \psi_{2i}(\hat{u}_{i,t-1})$$

where $e_{i,t-1}$ represents the lagged error term of the long-run equilibrium model, $\hat{u}_{i,t-1}$ represents the lagged estimate of the consumer reaction to the shock, and ψ_2 represents the adjustment rate on the $\hat{u}_{i,t-1}$ term. If consumers overreacted (or underreacted), they may later correct for this reaction when returning to equilibrium.

In short, the model above allows for the adjustment process to equilibrium to have two components: i) adjustments from the model error term, and ii) adjustments arising from consumers' own reaction to the *E. coli* announcement. When ψ_2 equals zero, the model in equation (5) reduces to a standard ECM. If the parameter ψ_1 equals zero, the model in equation (5) represents a situation where consumers only correct for their past over- or underreaction to the initial shock.

Data and Estimation Results

The analysis uses retail point-of-sale scanner data from FreshLook Marketing (FreshLook Marketing Group, Hoffman Estates, IL). 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 after the shock (including the week of the announcement itself). Information

[3] 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 that it represents a correction for the modeler's 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 dummy variables, the modeler would not need to make secondary corrections. Instead, any significant error correction response would represent consumer behavior itself.

Resources, Inc. (IRI; now SymphonyIRI Group, Chicago, IL) was FreshLook Marketing's data source on consumer packaged goods such as bagged salads.

As with most models of consumption, analysts can never be certain that the data reflect final demand. A reduction in observed demand, due to a shock, or any other variable, may indicate that consumers reduced their demand for an available commodity, or instead, simply that stores reduced availability. Estimated demand will appear to fall if either food stores reduced availability or consumers chose not to purchase an available item. While it would be useful to distinguish between these two effects, as with most studies, available data is inadequate for the task.[4]

The term denoted by u_i is a vector of announcement shock shift terms or[5]

$$(6) \quad u_i = \sum_{i=1}^{20} A1_i D1_{it} + \sum_{j=1}^{8} A2_j D2_{jt} + A3D3.$$

Thus u_i includes 29 0/1 dummy variables to represent adjustment to 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 our 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 20 weeks but is less flexible in that latter period. Collectively, the dummy variables reveal whether consumption behavior returns to the pre-announcement pattern by the last observation.

Seemingly unrelated regression estimation methods were used in combination with the Engle-Granger two-step method to estimate several variations of the model represented in equation (4). All variations estimate the same first step long-run model [equation (1)]. Table 1 reports the estimated equilibrium model [equation (1)].[6] The parameter estimates for the 29 dummy variables included in each share equation are reported in Table 2. Most price, expenditure, seasonal, and trend parameters have significant t-statistics in the equilibrium model. Most of the t-statistics on dummy variables estimates are significant. Demand for bulk and bagged spinach shifted inward, with the strongest effect occurring in the second and third weeks. 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 longer-run effect.

Figure 2 shows the pattern of dummy variable coefficient estimates for bagged spinach and bulk iceberg lettuce. The parameter estimates for bagged spinach reveal that the consumer response to the *E. coli* announcement gradually declined towards zero. The opposing pattern of estimates for iceberg lettuce shows that the two goods are shock substitutes. Yet there still appears to be a slight impact after 68 weeks, with a slight movement away from zero in the final three weeks. It appears that it may have taken more than 68 weeks for bagged spinach to completely recover from the announcement. Increases in the demand for iceberg lettuce may have taken a similar amount of time to dissipate.

Results for Model 1—Decomposing Errors across Time

Table 3 provides parameter estimates of Model 1 [equation (4)]. The model included differences in the seasonal and trend (a constant) variables. The dummy adjustment rate variable has significant t-statistics in three out of five equations. Furthermore, the first log likelihood-ratio test in Table 5

[4] A study to solve this common problem would be both useful and interesting but would be a major project by itself. It is beyond the scope of this paper.

[5] The 0/1 dummy variables are defined as follows:

$$D1_{it} = \begin{Bmatrix} 1 \text{ if } t = 139 + i, i = 1, 2, \ldots, 20 \\ 0, \text{ otherwise} \end{Bmatrix}$$

$$D2_{jt} = \begin{Bmatrix} 1 \text{ if } t \in [160 + 8(j-1), 167 + 8(j-1)], j = 1,2,3,4,5 \\ 0, \text{ otherwise} \end{Bmatrix}$$

$$D3_t = \begin{Bmatrix} 1 \text{ if } t \geq 200 \\ 0, \text{ otherwise} \end{Bmatrix}.$$

[6] The equilibrium component of the demand model is similar to that estimated by Arnade, Calvin, and Kuchler (2009). That paper did not attempt to model disequilibrium. Instead, it used a more parsimonious method to estimate consumer reaction to the *E. coli* announcement, one less suited to becoming a component of an ECM.

Table 1. The Equilibrium Leafy Green Vegetable Demand Model[1]

	Endogenous Variables: Budget Shares				
	Other Bulk Lettuce	Bulk Spinach	Bagged Spinach	Bulk Iceberg Lettuce	Salad without Spinach
Explanatory Variables	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 lettuce	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] Estimated coefficients are on the top line, and the *t*-statistics for the coefficients are on the following line.

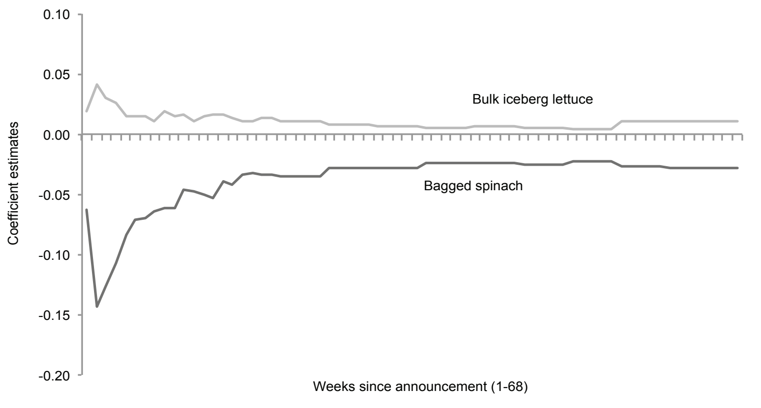
(see below) shows that the model performed significantly better when this variable was included in the model.

Estimated adjustment rates from Model 1, which includes a dummy variable on the error adjustment term, reveal that during the period without (with) a shock, it took bulk lettuce 14 (6) weeks to reach equilibrium, bulk spinach 2 (12.8) weeks, and iceberg lettuce 10.5 (2.5) weeks. For bagged spinach and salads without spinach it took 2.5 weeks and 4 weeks, respectively, to reach equilibrium *when there was a shock*. However, both of these markets moved away from equilibrium when there was no shock. This latter phenomenon may reflect the extraordinarily rapid growth in consumption of these two goods, which may have kept the markets out of equilibrium (Arnade, Calvin, and Kuchler 2009).

Table 2. Estimated Dummy Variable Coefficients from the Equilibrium Model[1]

	Other Bulk Lettuce		Bulk Spinach		Bagged Spinach		Iceberg Lettuce		Salad without Spinach	
Var.	Coeff.	*t*-Stat.	Coeff.	*t*-Stat.	Coeff.	*t*-Stat.	Coeff.	*t*-Stat.	Coeff.	*t*-Stat.
1-week dummy for week:										
1	0.0145	3.91	-0.0025	-3.82	-0.0626	-13.54	0.0185	5.84	0.0229	3.09
2	0.0446	11.35	-0.0112	-8.74	-0.1436	-26.87	0.0409	11.69	0.0464	5.81
3	0.0395	9.82	-0.0095	-6.88	-0.1262	-22.28	0.0300	8.25	0.0440	5.36
4	0.0294	7.62	-0.0059	-5.96	-0.1066	-20.66	0.0261	7.69	0.0407	5.20
5	0.0241	6.25	-0.0047	-5.34	-0.0842	-17.22	0.0143	4.32	0.0386	4.98
6	0.0228	5.96	-0.0036	-4.46	-0.0717	-14.81	0.0146	4.43	0.0248	3.22
7	0.0203	5.37	-0.0035	-4.76	-0.0703	-14.93	0.0142	4.42	0.0282	3.74
8	0.0165	4.43	-0.0024	-3.35	-0.0645	-13.84	0.0106	3.33	0.0289	3.86
9	0.0151	4.07	-0.0020	-2.94	-0.0608	-13.09	0.0184	5.79	0.0221	2.97
10	0.0144	3.85	-0.0023	-3.51	-0.0608	-12.96	0.0155	4.85	0.0254	3.38
11	0.0241	6.29	-0.0019	-2.87	-0.0457	-9.51	0.0165	5.02	0.0002	0.02
12	0.0146	3.89	-0.0014	-1.98	-0.0475	-10.06	0.0114	3.54	0.0146	1.94
13	0.0128	3.39	-0.0023	-3.45	-0.0497	-10.53	0.0146	4.51	0.0163	2.15
14	0.0151	3.91	-0.0019	-2.80	-0.0535	-11.08	0.0161	4.86	0.0144	1.86
15	0.0281	7.52	-0.0008	-1.27	-0.0391	-8.38	0.0158	4.96	-0.0158	-2.11
16	0.0191	5.00	-0.0023	-3.42	-0.0418	-8.75	0.0139	4.25	0.0010	0.14
17	0.0119	3.14	-0.0008	-1.22	-0.0335	-7.07	0.0103	3.18	0.0038	0.50
18	0.0074	1.97	-0.0012	-1.74	-0.0325	-6.84	0.0106	3.29	0.0100	1.32
19	0.0069	1.85	-0.0010	-1.50	-0.0332	-7.09	0.0129	4.04	0.0087	1.15
20	0.0050	1.31	-0.0017	-2.46	-0.0335	-7.01	0.0133	4.07	0.0102	1.34
5-week dummy for weeks:										
21-25	0.0027	1.35	-0.0013	-3.43	-0.0354	-14.29	0.0113	6.60	0.0161	4.04
26-30	0.0043	2.26	-0.0003	-0.94	-0.0287	-11.99	0.0082	4.97	0.0168	4.38
31-35	0.0029	1.52	-0.0003	-0.90	-0.0279	-11.58	0.0062	3.74	0.0190	4.94
36-40	0.0030	1.53	0.0000	0.06	-0.0234	-9.66	0.0055	3.31	0.0156	4.05
41-45	0.0031	1.58	0.0002	0.57	-0.0234	-9.57	0.0067	3.98	0.0155	4.01
46-50	0.0037	1.86	0.0001	0.39	-0.0248	-10.01	0.0052	3.07	0.0170	4.32
51-55	0.0015	0.77	0.0007	1.84	-0.0227	-9.27	0.0042	2.49	0.0178	4.56
56-60	-0.0002	-0.10	0.0010	2.48	-0.0261	-10.13	0.0108	5.86	0.0170	4.18
8-week dummy for weeks:										
61-68	0.0054	2.80	0.0010	2.69	-0.0280	-11.66	0.0113	6.66	0.0109	2.85

[1] Each dummy variable represents a week, or group of weeks, following the *E. coli* announcement. Week 1 is the week of the announcement.



[1]Data presented by week (week 1 is the week of the announcement).

Figure 2. Bagged Spinach and Bulk Iceberg Lettuce Coefficient Estimates on Shock Dummy Variables[1]

Results for Model 2—Decomposing Errors by Source

The second ECM model [equation (5)] tests whether adjustment to equilibrium could be broken into two components with distinct adjustment rates to different sources of error. Here both the lagged shock response (u) and lagged error (e) terms were included as linear explanatory variables, each with distinct parameters representing possible distinct adjustment rates. Analysis determines whether the u term belongs in the model and tests whether adjustment rates were different than those associated with the typical econometric error (e).

Table 4 reports model results. 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 5 percent confidence level, all adjustment rate parameters on the lagged error terms are significant.[7]

Table 5 reports several key tests of different parameter restrictions relating to the adjustment rate. The tests relate to the main hypothesis put forth in this paper. 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.[8]

This first test is a systems likelihood-ratio test to determine whether the dummy adjustment rate variable belongs in Model 1. The significance of the χ^2 statistic (Table 5, row 1) clearly indicates that the hypothesis should be rejected; that is, that the dummy variable belongs in the model and that adjustment rates were different following the *E. coli* announcement. The second and third tests reported in this table are likelihood-ratio statistics for each type of error individually in Model 2. Restricting the econometric error correction to zero (i.e., $\psi_1 e = 0$) significantly reduced the performance of the model, while similarly restricting the shock correction (i.e., $\psi_2 u = 0$) did not. The fourth test imposed equality between adjustment parameters ($\psi_1=\psi_2$). The significant statistic

[7] 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.

[8] 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.

Table 3. The Estimated Model 1—Decomposing Errors across Time

	Endogenous Variables: First Differenced Budget Shares				
	Other Bulk Lettuce	Bulk Spinach	Bagged Spinach	Bulk Iceberg Lettuce	Salad without Spinach
Explanatory Variables	Coefficient Estimate *t*-Statistic				
Constant[1]	-0.00003	-0.00003	0.00002	-0.00003	-0.00002
	-0.12	-0.71	0.11	-0.22	-0.04
Δ Ln price other bulk lettuce	0.0744	0.0008	-0.0200	0.0472	-0.1093
	7.58	0.50	-2.11	6.62	-5.64
Δ Ln price bulk spinach	0.0084	-0.0009	-0.0062	-0.0246	0.0240
	1.22	-0.74	-0.93	-4.97	1.77
Δ Ln price bagged spinach	0.0390	-0.0075	-0.1086	0.0515	0.097
	5.54	-6.36	-16.20	10.26	.71
Δ Ln price bulk iceberg lettuce	0.0089	-0.0067	-0.1127	0.0537	0.0341
	1.16	-5.16	-15.16	9.79	2.24
Δ Ln price salad without spinach	0.0970	-0.0193	-0.3973	0.1781	0.0556
	4.94	-5.86	-21.03	12.57	1.44
Δ Ln price romaine hearts	0.0176	-0.0024	-0.0373	0.0295	-0.0090
	2.57	-2.08	-5.66	6.04	-0.67
Δ Ln leafy greens expenditures	-0.0009	-0.0003	0.0085	0.0143	-0.0192
	-0.19	-0.33	1.85	4.17	-2.04
Δ Stone's price index	-0.1433	0.0396	0.7677	-0.3324	-0.2043
	-4.62	7.62	25.67	-14.81	-3.34
Δ Sin	-0.0003	-0.0005	-0.0033	-0.0056	0.0123
	-0.10	-1.24	-1.31	-3.01	2.37
Δ Cos	0.0003	0.0001	-0.0021	-0.0049	0.0051
	0.10	0.32	-0.83	-2.64	0.99
Econometric Error	-0.0710	-0.3849	0.0189	-0.0949	0.0139
	-1.97	-5.98	0.85	-2.12	0.68
Econometric Error* Dummy	-0.1581	-0.0776	-0.2434	-0.3997	-0.2491
	-1.17	-0.38	-3.26	-3.80	-3.06

[1] The constant represents the difference in the trend variable of the long-run model.

implied that the restriction reduced model performance and that parameter equality of the two adjustment rates should be rejected.

Overall, these tests indicate that the adjustment rate to equilibrium was significantly different after the shock. However, tests with Model 2 indicate that consumers acted as if their original reaction to the announcement was not an error but a rational response to new information. That is, leaving out lagged u terms as a correction factor did not significantly reduce model performance. However, many slight variations of the model

Table 4. The Estimated Model 2—Decomposing Errors across Source

	Explanatory Variables: First Differenced Budget Shares				
	Other Bulk Lettuce	Bulk Spinach	Bagged Spinach	Bulk Iceberg Lettuce	Salad without Spinach
Explanatory Variables	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 lettuce	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

show that the inclusion of shock correction errors does have a small but significant effect.

The results for Models 1 and 2 reported in Tables 3 and 4 indicate that consumer reaction to the spinach shock was more complex than was revealed by a typical long-run model. There are several reasons one would expect to find that the disequilibrium model is important. First, inclusion of dummy shock variables and trend variables insure that the long-run model cannot identify a long-run equilibrium. By itself, the estimated model suggests equilibrium along trend lines. Further, Figure 1 shows a large drop in spinach purchases immediately after the announcement, which was not sustained. Thus, it is clear that not all of the consumer reaction to the announcement 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.

The estimated length of time it takes for consumers to adjust to equilibrium can be derived from the estimated parameters ψ_1 and ψ_2. The adjustment rate, or length of time for adjusting to

Table 5. Likelihood-Ratio Tests of Various Model Specifications

Test Description	Test[1]	Test Statistic	Degrees of Freedom
Different adjustment rate	$\varphi^* D^* \varepsilon_1 = 0^*$	24[2]	5
No correction for econometric error	$\psi_1 = 0$	120[2]	5
No correction for shock reaction term	$\psi_2 = 0$	4	5
Equal adjustment rates	$\psi_1 = \psi_2$	120[2]	5

[1] ψ_1 represents the coefficient on the lagged error of the long-run model, φ^* represents the coefficient on the interaction of the lagged error and the shock dummy variable. ψ_2 represents the coefficient on u_i, which, in turn, represents the sum of dummy variables times estimated coefficients, or the initial consumer reaction to the shock.
[2] Significant at the 1 percent level.

Table 6. Model 2: Estimated Time to Adjust to Equilibrium (weeks)

Model Specification	Adjusting Variable	Other Bulk Lettuce	Bulk Spinach	Bagged Spinach	Bulk Iceberg Lettuce	Salad without Spinach
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

long-run model errors is $-\psi_1^{-1}$ (Asche and Salvanes 1996).[9]

Table 6 reports estimates of the time to adjust to equilibrium derived from Model 2. This table reveals that the estimated time to adjust to equilibrium is shorter when a second adjustment factor is included in the model. In contrast to Model 1, Model 2 reveals that it took consumers approximately 2-4 weeks to adjust to equilibrium. The longest adjustment occurred for bagged spinach. It took consumers 8.5 weeks to adjust to equilibrium (equilibrium along a trend for this model).

It took a much longer time for consumers to adjust to their own overreaction (or underreaction) to the announcement. However, this second set of adjustment rates must be viewed cautiously, since tests indicated that correction parameters on lagged u were not significant in most equations. And, for salad without spinach and bagged spinach, consumers moved *away* from equilibrium,

[9] If $\psi_1 = 1$, consumers snap back to equilibrium within one period. If $\psi_1 = 0.1$, it takes 10 weeks for consumers to reach equilibrium after a disruption.

perhaps indicating that the announcement created a permanent shift in the consumption of bagged products. Adjustment rates for shock reaction errors (the u term) tended to run into months. For example, it took one year for consumers to adjust to their reaction to the *E. coli* announcement for lettuce and half a year for bulk spinach. Parameter estimates indicated it would take 8 years, and in an opposite direction, for bagged spinach to adjust. This result makes sense for several reasons. Consumers may be unsure of the true dangers represented by the *E. coli* outbreak and in particular, what it means for bagged products. And consumers may be reluctant to rationally admit to their own mistakes.

It is quite interesting that consumers appeared to move further away from the initial pre-shock equilibrium with the two bagged products and did so very slowly. It appears that consumers slowly came 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 was established. Bagged products might have first appeared to be safe, but upon reflection consumers might have come to realize that the contents were not any safer than non-bagged products.

Extensions

We tested whether either adjustment term belongs in the model ($\psi_j = 0$, $j = 1, 2$) and whether adjustment rates were equivalent ($\psi_1 = \psi_2$). There are more ways to characterize adjustments and adjustment rates; Balcombe and Rapsomanikis (2008) suggested various specifications for estimating adjustment rates, along with the associated specification tests. This analysis employed their suggestion of using quadratic lagged error terms in an ECM model to estimate a changing adjustment rate. Our model, in having two error terms, provides ample opportunity to expand on this idea. While many variations of the model are feasible, theory offers little guidance to choose among them. In any case, we allowed for interaction between two adjustment terms (i.e., $\psi_1 e + \psi_2 u + \psi_3 u * e$) and interaction of quadratic terms. We even estimated a version of the model that included cubic lagged error variables. Each of these variations provides ways to measure possible changes in the adjustment rate.

The quadratic and cubic versions of the model produced significant t-statistics on many of these terms. However, 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 6 therefore reports one set of estimated adjustment rates from the error interaction model. The estimated adjustment rates changed little for the error term (e_i) but are far slower for the shock reaction term (u_i), taking, for example, 10 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.

Conclusions

This analysis extended the standard ECM in two ways. The first model used a dummy variable, representing the period following the *E. coli* announcement, to test if adjustment rates changed. The second model decomposed the post-announcement adjustment process into two components and allowed them to have different rates of adjustment. The decomposition allowed for testing if consumers later corrected for their initial reaction to the *E. coli* announcement.

To apply our test we estimated a generalized ECM to represent consumers' reaction to the announcement of an outbreak of *E. coli* caused by contaminated spinach. The equilibrium component of the 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 additional disequilibrium component of the ECM model also performed well, indicating that a simple equilibrium model does not fully explain consumer behavior.

The performance of the latter component showed that there is much more to learn about consumer behavior beyond results of models representing the equilibrium behavior of consumers. Not only were most variables in the disequilibrium model significant, adjustment rates indicated that it takes consumers several weeks to return to equilibrium behavior. And our model shows clearly that adjustment rates were distinctly different for three out of five commodities in the period following the *E. coli* announcement.

In general, we found that consumers reacted differently to a food safety shock than they did to more typical surprises and that consumers did not appear to overreact to the *E. coli* announcement. Parameters on the shock correction terms were largely insignificant. That is, we found that consumers acted as if their initial reaction to the shock was appropriate; their adjustment to changing news was measured and predictable and not a correction for an initial error.

This one example should provide policy makers with some evidence that the public is not likely to overreact to a direct and widely broadcast announcement of a food safety event. That consumer behavior appears measured in the face of an emotionally charged issue should provide the government with few misgivings toward informing the public as quickly and directly as possible when food safety has been compromised. Hesitation about setting off a consumer "panic" or creating an overreaction appears to be unjustified—at least in this one instance.

We also found that it takes a long time for markets to complete the reaction to a shock and return to equilibrium and that the impact on green leafy vegetables varied by commodity. This is also important for policy makers to consider. Food safety announcements about a particular food product are likely to have a long-run effect, and that effect will influence consumer demand for other food products.

The idea introduced in this paper can be applied to testing the impact of any crisis, structural break, or transitory policy change. It could be applied to other economic models and be used to test the impact of a transitory government stimulus on the behavior of consumers, or even the behavior of investors and producers.

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Appendix. *E. coli* Health Risk Was Small and Transitory

The information the FDA has is always insufficient. For *E. coli*, it usually takes 2-3 weeks between the onset of illness and confirmation that the illness was part of an outbreak (Centers for

Disease Control and Prevention 2006c). That is, when the FDA issued its September 14, 2006 statement that bagged spinach was unsafe, it had to be operating without benefit of illness counts in the preceding two weeks. In effect, the agency knew that illnesses had occurred, but it could not know whether the number of illnesses its investigators saw was the peak of a transitory event—a problem that had already disappeared—or was instead widespread with increasing numbers of illnesses, a problem that the agency might be able to mitigate. Ex post illness counts (Centers for Disease Control and Prevention 2006a) revealed that most of the illnesses occurred before the FDA made its announcement.

Even at the peak, the risk consumers faced was relatively small, at least from a federal regulatory perspective. One way to measure risk is to examine the number of illnesses relative to how much spinach was eaten that could have caused those bad outcomes. The CDC identified the three-day period when 32 percent of illnesses occurred—August 30 to September 1 (Centers for Disease Control and Prevention 2006b). With a three to four day incubation period, meals that could have caused illnesses were consumed over as much as four days (Centers for Disease Control and Prevention 2006c). Prior to the announcement (2004–2006), 531,000 thousand pounds of spinach and spinach-containing foods were purchased from supermarkets each day (average). At ½ cup per serving, that implies approximately 8 million servings per day, or 1.9×10^{-6} illnesses per serving. Alternatively, if all non-salad spinach were cooked, potentially contaminated servings of salad with spinach would number 4.1 million. Illnesses per serving would then be approximately 3.6×10^{-6}.

Peak risks so estimated are above conventional de minimus levels, one in a million. However, these calculations overestimate risks. Our spinach consumption data reflects only purchases from conventional grocery store sales, as data are not available for sales in big box stores and through food service.

The FDA's announcement likely prevented some illnesses, but at the announcement date, daily illness counts point to the risk of illness from spinach being an order of magnitude smaller than at the peak. Prevented illnesses were likely few because the amount of contaminated spinach was limited. The initial 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 2006). The risky product diminished also because spinach has a limited shelf life.

In effect, the risk returned to its preannouncement level. On September 29, the FDA reported that "spinach on the shelves is as safe as it was before this event" (Shin 2006). 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. If consumers judged spinach risk-free before the announcement, it was that same product afterward. No permanent changes in product attributes occurred.