LONG-RUN EFFECTS FROM CONSUMER REACTION TO THE SPREAD OF FOODBORNE PATHOGENS: THE CASE OF E. COLI CONTAMINATION OF BEEF AT JACK IN THE BOX RESTAURANTS

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Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009

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May 11, 2009

Abstract

Using news coverage of food safety as an indicator of public attention to food pathogen issues in meat products, we found the 1993 *E. coli* O157:H7 contamination of hamburgers likely permanently changed consumers' perception of beef safety. A food consumption model with rational habit persistence is developed to examine whether consumers make forward-looking consumption decisions accounting for expectations of future food safety. We document clear evidence of forward-looking consumption behavior, which suggests that government regulations implemented subsequent to the 1993 event to protect consumers from ignorance or cognitive defects may be ineffective.

JEL Classification: D12, D18

Key words: food safety, habit persistence, linear rational expectations model

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*This research has benefited from discussions with Jeffrey Furher, Nick Piggott, Paolo Zagaglia and seminar participants at North Carolina State University and Research Triangle Institute. All errors are our own.

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1 Introduction

> *. . . American housewives and cooks normally are not ignorant or stupid and their methods of preparing and cooking of food do not ordinarily result in salmonellosis.* Argument made by the U.S. Department of Agriculture (USDA) and agreed by a majority of the Judges that the official USDA inspection labels on meat products containing salmonellae and other pathogens did not constitute misbranding [American Public Health Association v. Butz, 511 F.2d 331 (D.C. Cir. 1974)].

Several recent highly publicized food safety outbreaks involving spinach, tomato, jalapeno pepper, and peanut butter have led to calls for new regulatory actions to improve the nation's food safety system. A flurry of bills aimed at strengthening the safety of the food supply and protecting consumers from consumer ignorance or negligence of safe food handling practices are introduced. Central to the debate over whether or not more government regulations of food safety are needed is the incentive provided by the private market for producing safe foods. This incentive comes from the costs imposed upon firms responsible for providing unsafe foods. The potential costs include those due to tort liability, increased regulatory oversight, and loss of demand as consumers stay away from foods perceived as unsafe.

Prior empirical research has documented that markets react significantly to news of food recalls or safety scandals. Carter and Smith (2006), for example, find large and persistent declines in corn prices after news broke out that the U.S. food-corn supply was contaminated by an unapproved genetically modified variety. A number of papers report significant (in statistical or economic sense or both) shareholder losses and reduction in consumer demand for food products found to be unsafe. In one such paper, Schlenker and Villas-Boas (2009) found transitory drops in U.S. cattle futures prices and grocery shoppers temporarily turning away from beef products following the first discovery of the Mad Cow disease in the United

States.

Notwithstanding the documented financial incentives for firms to produce safe foods, some argue that these costs incurred in private markets are small relative to the social costs of foodborne illness. Consumers, for instance, may be ill-informed about the risks associated with food pathogens, do not take enough safety precautions, and insufficiently reduce consumption of potentially unsafe foods such that there is not enough incentive in the private market for supply of safe foods. If this is indeed the case, greater government regulatory oversight may be desired in order to create a socially optimal level of food safety. Because of its preponderance in informing the policy debate, we examine whether or not consumers are ignorant in processing available food safety information.

This paper contributes to the literature on the economics of food safety by extending the rational habit persistence model of Becker and Murphy (1988) to include food safety information and explains how information about food quality, as imbedded in media coverage of food safety events, can affect consumer demand when consumers are viewed as rational in the sense that they account for the effects of food quality information on consumption capital. Consumption capital is viewed as either deteriorating or expanding depending on whether the information is negative or positive about food quality. In the context of the rational habit model, the consumer has an incentive to account for increased risk to future exposure to the food pathogen (through changes in future expected marginal utilities of consumption) in addition to current exposure to the pathogen (through changes in current marginal utility). The greater the expectation that future marginal utilities will be affected, the greater the likelihood the consumer will reduce consumption of the good now and, in the extreme case, avoid consumption of the good completely.

We applied the habit model to meat consumption in the United States covering the rather volatile period from the early 1990s to the early 2000s when information about both *E. coli* O157:H7 and bovine spongiform encephalopathy (BSE) contamination was in the forefront of the news. We used indexes of media coverage to signal information about meat food safety (both bad and good) and found over our sample period that the single most important food safety event that accounted for significant change in the media index was *E. coli* O157:H7 contamination in the fast food chain Jack in the Box in late 1992 and early 1993. This finding allowed us to further explore whether consumer response was rational or not to this shock and also whether the food safety shock was transitory or permanent. The econometric results indicate that habit persistence is present in meat consumption. Our simulation results reveal that the observed consumption data are more congruent to data simulated assuming consumers form rational expectations about future food safety than to data simulated under the assumption that consumers form static food safety expectations or are myopic in processing currently available food safety information. We estimated that the 1993 outbreak may have reduced per capita beef consumption by about 0.54 pound per year and, based on our calculations using the 2005 retail beef price, may have costed the beef industry $0.66 billion annually in lost sale. The finding of consumer rationality suggests that more government regulations intended to protect consumers from ignorance or cognitive defects may not be needed.

The remainder of the paper proceeds as follows. Section 2 describes the evolution of public awareness of food safety issues. Section 3 sets up the theoretical model and layouts the empirical specification of the rational habit model. Section 4 presents the econometric results and conducts simulation exercises. Section 5 discusses the policy implications and concludes the paper.

2 E. coli O157:H7 in the News

Food safety is an important public health issue. The Centers for Disease Control and Prevention estimates that 76 million people get sick and 5,000 die each year from foodborne illness in the United States. The single most important food safety outbreak in the past several decades in the United States is perhaps the *E. coli* O157:H7 contamination of hamburgers sold in the fast food chain Jack in the Box. Between December 1992 and February 1993, hundreds of people in the western U.S. states were hospitalized with symptoms of severe food poisoning. By the time the outbreak was over, four children had died. The cause was traced to undercooked beef patties contaminated with *E. coli* O157:H7 sold in Jack in the Box restaurants. Foodmaker Co., parent company of the fast food chain, lost nearly 40% of its stock market value in the week after the chain was implicated (Martin 1993). Individual and class-action settlements followed in the next several years and totaled over $50 million, resulting in the largest payments ever involving foodborne illness.

The 1993 incidence was tragic because young lives were lost. It came as a shock to some people because this time it was hamburger, one of the greatest American food icons, that was contaminated. The 1993 incidence was also historic in that it helped to push through important regulatory changes to government inspection of animal slaughter and meat processing. The most sweeping change was the implementation of the Pathogen Reduction and Hazard Analysis and Critical Control Points (PR/HACCP) programs at all meat production facilities. The PR/HACCP was established as an effective approach to enact good production, sanitation, and manufacturing practices that produce safe foods. With respect to *E. coli* O157:H7, PR/HACCP helps identify fecal matter in beef and ways to remove it prior to manufacture and sale.

As the USDA stepped up regulatory reforms of its meat inspection system, the 1993 outbreak also raised public awareness of food safety. To provide insights into evolution of public attention to food safety over time, we followed Piggott and Marsh (2004) and others to construct food safety information indices using counts of newspaper articles on meat food safety. We focused on four U.S. newspapers: Christian Science Monitor, New York Times, Wall Street Journal, and Washington Post. The reason for using these four papers is that other papers were not available over the entire 1979Q1–2005Q4 period in LexisNexis

Academic, which was the search engine used to identify relevant articles. We identified full-text articles and abstracts containing the following keywords used in Piggott and Marsh (2004): *food safety* or *contamination* or *product recall* or *outbreak* or *Salmonella* or *Listeria* or *E. coli* or *trichinae* or *Staphylococcus* or *foodborne*. Based on this pool of articles, the search was narrowed down to individual meats. The keywords *beef* or *hamburger* or *meat*, *pork* or *ham* or *meat*, and *poultry* or *chicken* or *turkey* or *meat* were used to find articles related to beef, pork, and poultry food safety, respectively. Every article was then read to determine its pertinence to food safety with irrelevant ones dropped from the information base.

Figure 1 plots counts of newspaper articles on food safety issues related to beef, pork, and poultry over the 1979Q1-2005Q4 period. A striking feature of the plot is the sudden increase in food safety news for beef and pork starting in 1993Q1, the increase appears to have persisted over the remaining sample period. To formally test whether public attention to food safety was permanently changed by the Jack in the Box incidence, Bai and Perron's (BP hereafter, 1998, 2003a) test of multiple unknown break points was performed on each index series to determine the number and dates of possible structural breaks. The BP test is desirable because, besides the Jack in the Box *E. coli* O157:H7 contamination, a number of other incidences may have resulted in persistent changes in media coverage of food safety as well. These incidences include the March 20, 1996, British government's announcement of a probable link between BSE and Variant Creutzfeldt-Jakob disease (vCJD), and the discovery of the first case of BSE in the United States between late 2003 and early 2004.

To perform the BP test, we regressed each food safety index on an intercept and tested for structural breaks in the intercept. Table 1 presents the sequential test results, where l is the number of break points. The test results indicate one break point in 1992Q4 for the beef safety index, two break points in 1992Q4 and 2000Q2 for pork, and one break point in 1997Q2 for poultry. These results point to the 1993 *E. coli* contamination as the single event that permanently changed the level of public attention to beef safety. The quarterly average number of beef safety articles increased from 4 during the pre-1993 period to 29 after the Jack in the Box outbreak. Table 2 reports the intercept estimates for the subsamples. Table 3 provides the 95 percent confidence intervals for the estimated break dates. Interestingly, the break date for the beef safety index is precisely pinpointed at 1992Q4.

3 A Rational Habit Persistence Model with Food Safety

3.1 Theoretical Model

It is useful, following Becker and Murphy (1988), to think of the consumer as rational and possessing a utility function with constant tastes. Suppose that at any moment in time, the consumer derives utility from the level of consumption of the final commodity (g), representing nourishment and "tastes" derived from food (Stigler and Becker 1977), and all other goods (Y) whose price is normalized to one. Nourishment and food tastes (g) are produced from three inputs: the raw food quantity (C), its quality (k), and cumulative consumption (S) summarizing the experience and knowledge from past cooking and dining experiences. At any point in time, the utility function is

$$U\left(t\right)=U\left(Y\left(t\right),g\left(t\right)\right), \tag{1}$$

where $g\left(t\right)=g\left(C\left(t\right),S\left(t\right),k\left(t\right)\right)$ is the household food production function. The utility function is assumed to be a monotonically increasing, strictly concave function in each of its arguments. The food production function is assumed to be a monotonically increasing, strictly concave function in C and S. The variable k is assumed to be an indicator of food contamination outbreaks, a higher value of which indicates more severe contamination incidences so that the perceived quality of C is lower.

Substituting the production function into the utility function gives the derived instantaneous utility function

$$U(t) = U(Y(t), C(t), S(t), k(t)), \tag{2}$$

where $U_Y = \frac{\partial U}{\partial Y} > 0$, $U_C = \frac{\partial U}{\partial C} > 0$, $U_S = \frac{\partial U}{\partial S} > 0$, $U_k = \frac{\partial U}{\partial k} < 0$, $U_{CS} = \frac{\partial^2 U}{\partial C \partial S} > 0$, $U_{Ck} = \frac{\partial^2 U}{\partial C \partial k} < 0$, and $U_{Sk} = \frac{\partial^2 U}{\partial S \partial k} \leq 0$. The quality indicator k is neither chosen nor priced but exogenous to the household. In this case, the outbreak can be considered as a public good that is a quality characteristic of the privately consumed good (Bockstael and McConnell 1993; Piggott and Marsh 2004).

Define the consumption capital stock to be an exponentially weighted sum of past levels of consumption $S(t) = \int_0^t e^{-\delta(t-\tau)} C(\tau)\, d\tau$ with δ being the rate of capital depreciation. Differentiating this with respect to t results in the equation of motion for the capital stock

$$\dot{S}(t) = C(t) - \delta S(t), \tag{3}$$

Assuming the interest rate and rate of time preferences are the same, the consumer maximizes her lifetime utility function

$$U(0) = \int_0^\infty e^{-rt} U(Y(t), C(t), S(t), k(t))\, dt, \tag{4}$$

subject to the equation (3) for the flow of consumption capital stock and the budget constraint

$$\int_0^\infty e^{-rt} (Y(t) + P(t) C(t))\, dt \leq W(0), \tag{5}$$

where r is the rate of interest, $P(t)$ is the price of C in period t, and $W(0)$ is lifetime wealth discounted to period 0.

The optimal paths of $Y(t)$ and $C(t)$ are determined by the following equations:

$$U_Y(t) = \mu \tag{6}$$

$$U_C(t) = \mu P(t) - \int_t^{\infty} e^{-(r+\delta)(\tau-t)} U_S(\tau)\, d\tau. \tag{7}$$

The first equation defines μ as the marginal utility of the discounted lifetime wealth. It can be shown that, at least under perfect foresight, μ is a constant, exactly what a rational consumer strives to achieve during the life cycle. The second term on the right-hand side of equation (7) is the shadow price of the capital stock. It shows how much future utility will be affected from changes in future stocks induced by a one-unit change in $C(t)$. The sum of the two terms on the right-hand side of equation (7) is the total price or shadow cost, π_C, of consuming an additional unit of the good. With habit formation, the marginal utility of S is positive, so the second component of π_C is negative, implying that marginal utility of $C(t)$ in the current period will be less than the money value of the good.

Both current marginal utility and the shadow price of consumption capital depend on the quality variable. Assume that there is a food safety event such as *E. coli* O157:H7 contamination, which potentially causes the consumer to believe that the quality of both current and future food will be lower. At any given price level, a change in quality from k to k' would cause both current and perceived future marginal utilities to change. Let the shadow price of the capital stock after the *E. coli* O157:H7 contamination be

$$\int_t^{\infty} e^{-(r+\delta)(\tau-t)} U_S(Y(\tau), C(\tau), S(\tau), k'(\tau))\, d\tau. \tag{8}$$

This value of the shadow price of the capital stock will be less than the original value of the capital stock,

$$\int_t^\infty e^{-(r+\delta)(\tau-t)} U_S\left(Y\left(\tau\right), C\left(\tau\right), S\left(\tau\right), k\left(\tau\right)\right) d\tau, \tag{9}$$

at each point in time. This means that for a given price level, the shadow cost of consumption, π_C, will increase, and the consumer will be induced to reduce consumption even more compared with the myopic case where future effects on marginal utility are ignored.[1]

The size of the long-run effect compared to the short-run effect, and length of time required to achieve equilibrium, depends crucially on how the consumer perceives the *E. coli* O157:H7 contamination to affect future beef that is sold. If the risk is expected to persist into the future, then the total reduction in consumption will be much larger than if the event was expected to occur only once and then disappear.

3.2 Empirical Model

In moving from the theoretical to empirical framework, we specify that the instantaneous utility function is a quadratic utility function of beef, pork, and poultry and is expressed in discrete time as follows

$$U_t = \sum_{i=1}^{3} \alpha_{it} C_{it} + \frac{1}{2} \sum_{i=1}^{3} \sum_{j=1}^{3} \beta_{ij} C_{it} C_{jt} + \sum_{i=1}^{3} \gamma_i C_{it} S_{it} \tag{10}$$

where C_{1t}, C_{2t}, and C_{3t} are quantities of beef, pork, and poultry consumed in period t, respectively; β_{ij} and γ_i are parameters to be estimated. To incorporate food safety into the utility function, α_{it} is specified as a linear function of a constant, a trend term and current and lagged food safety media indices for food i that are used to capture public attention to safety issues in the ith food. The habit stock S_{it}, in its most general form, is specified as

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[1] Even when $U_{Sk} = 0$, the shadow price of the capital stock will still be lower after the contamination outbreak due to a reduction in $C\left(t\right)$ and the assumption $U_{CS} > 0$.

$$S_{it} = \rho_i S_{it-1} + (1-\rho_i) C_{it-1} = \sum_{k=1}^{\infty} \rho_i^{k-1} (1-\rho_i) C_{it-k}, \tag{11}$$

where ρ_i measures memory of the habit stock for good i. For $0 < \rho_i \leq 1$, a larger value of ρ_i indicates the higher importance of consumption in the more distant past in affecting current utility. The lifetime utility function is

$$U = U_t + \beta U_{t+1} + \beta^2 U_{t+2} + \ldots, \tag{12}$$

where β is the time preference discount factor. The marginal effect of a small change in consumption of the ith meat in period t on lifetime utility is

$$\frac{\partial U}{\partial C_{it}} = \frac{\partial U_t}{\partial C_{it}} + \beta \frac{\partial U_{t+1}}{\partial S_{it+1}} \frac{\partial S_{it+1}}{\partial C_{it}} + \beta^2 \frac{\partial U_{t+2}}{\partial S_{it+2}} \frac{\partial S_{it+2}}{\partial C_{it}} + \ldots. \tag{13}$$

There are a few useful partial derivatives: $\frac{\partial U_t}{\partial C_{it}} = \alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it}$, $\frac{\partial U_t}{\partial S_{it}} = \gamma_i C_{it}$, and $\frac{\partial S_{it+k}}{\partial C_{it}} = \rho_i^{k-1} (1-\rho_i)$. These partial derivatives along with equation (13) allow one to write the derivative of lifetime utility with respect to the ith meat consumption in period t as

$$\frac{\partial U}{\partial C_{it}} = \alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it} + \beta (1-\rho_i) \gamma_i C_{it+1} + \beta^2 \rho_i (1-\rho_i) \gamma_i C_{it+2} + \ldots, \tag{14}$$

or in a more compact form,

$$\frac{\partial U}{\partial C_{it}} = \alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it} + \gamma_i (1-\rho_i) \sum_{k=1}^{\infty} \beta^k \rho_i^{k-1} C_{it+k}. \tag{15}$$

Defining $B_{it} \equiv \beta \rho_i B_{it+1} + \beta C_{it+1}$, equation (15) can be written even more compactly as

$$\frac{\partial U}{\partial C_{it}} = \alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it} + \gamma_i \left(1 - \rho_i\right) B_{it}. \tag{16}$$

To derive the Euler equation for consumption, consider a reduction in C_{it} by an epsilon amount ε. If the consumer invests the saved expenditures εP_{it} in an asset with a rate of return of $1 + r$ over one period, consumption expenditures in period $t + 1$ will increase by $\varepsilon P_{it} \left(1 + r\right)$. The optimal consumption path is such that the loss in utility in period t equals the discounted increase in utility in period $t + 1$ as a result of the increased expenditures for consumption, i.e.,

$$\frac{\partial U}{\partial C_{it}} = \beta \frac{\partial U}{\partial C_{it+1}} \frac{P_{it}}{P_{it+1}} \left(1 + r\right) \tag{17}$$

The term $\frac{P_{it}}{P_{it+1}} \left(1 + r\right)$ can be interpreted as a commodity-specific rate of return. Following this logic, the intertemporal Euler equation for the ith meat is

$$\begin{aligned} &\alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it} + \gamma_i \left(1 - \rho_i\right) B_{it} \\ &\qquad = \beta R_{it+1} \left(\alpha_{it+1} + \sum_{j=1}^{3} \beta_{ij} C_{jt+1} + \gamma_i S_{it+1} + \gamma_i \left(1 - \rho_i\right) B_{it+1} \right) \end{aligned} \tag{18}$$

where $R_{it+1} = \frac{P_{it}}{P_{it+1}} \left(1 + r\right)$. Equation (18) can be used to develop an empirical equation that identifies all that we need to know about the intertemporal nonseparable preferences for meats in order to simulate dynamic consumption responses to various food safety expectations scenarios. In the rational addiction literature, a popular alternative approach is to assume an outside good whose demand is not habitual and to exploit the within-period marginal rate of substitution between the habitual good and the outside good to derive a dynamic representation of the demand for the habitual good. A prominent example of the latter approach is Becker, Grossman, and Murphy's (1994) rational cigarette demand model. In our context, equation (18) is the preferred approach for three reasons. First, as we will describe momentarily, a plausible simplifying assumption would allow equation (18) to transform possibly nonstationary data into their stationary first differences. Second, when food is hypothesized to be habitual, it is difficult to identify an outside good whose demand may be *a priori* assumed to be static. Nondurable expenditures on other goods do not appear to be a good candidate, because Fuhrer (2000), Ravn, Schmitt-Grohé, and Uribe (2006), and others have found that preferences for nondurables are not time-separable. Third, unlike the conventional rational addiction model, the marginal utility of wealth, which is not constant absent perfect foresight, is not embedded in the coefficients of the current empirical model (see Becker, Grossman and Murphy [1994] footnote 2). This property is desired in our empirical analysis, because, unlike many rational addiction studies that use panel data, we cannot use two-way fixed effects to control for unanticipated changes in wealth.

Following Fuhrer (2000), we approximated the right-hand side of equation (18) with a first-order Taylor series expansion about the sample means $\overline{k}_i$, $\overline{C}_j$, $\overline{S}_j$, and $\overline{R}_i$

$$\begin{aligned}\alpha_{it} + \sum_{j=1}^{3} \beta_{ij} C_{jt} + \gamma_i S_{it} + \gamma_i (1-\rho_i) B_{it} \\ = \beta \overline{R}_i \left(\alpha_{it+1} + \sum_{j=1}^{3} \beta_{ij} C_{jt+1} + \gamma_i S_{it+1} + \gamma_i (1-\rho_i) B_{it+1} \right) \\ + \delta_i R_{it+1} + h_i \quad (19)\end{aligned}$$

where

$$\delta_i = \beta \left(\alpha_{i0} + \alpha_{i1} \overline{k}_i + \textstyle\sum_{j=1}^{3} \beta_{ij} \overline{C}_{jt+1} + \gamma_i \overline{S}_{it+1} + \gamma_i (1-\rho_i) \overline{B}_{it+1} \right)$$
$$\text{and } h_i = -\beta \overline{R}_i \left(\alpha_{i1} \overline{k}_i + \textstyle\sum_{j=1}^{3} \beta_{ij} \overline{C}_{jt+1} + \gamma_i (1-\rho_i) \overline{B}_{it+1} \right).$$

Finally, we approximated $\delta_i R_{it+1}$ with a first-order Taylor series expansion about the sample mean prices. This transforms $\delta_i R_{it+1}$ from price ratios to price differences, i.e., $\delta_i R_{it+1} \approx \delta_i + \phi_i \left(P_{it} - P_{it+1}\right)$, where $\phi_i = \frac{\delta_i}{\overline{P}_i}$. There are two reasons for performing the last transformation. First, expressing prices in constant dollars and assuming real interest rate is negligible in the context of meat purchases, r drops out from R_{it}. Second, the price ratio R_{it} is transformed into price difference to facilitate simulation of dynamic consumption responses to transitory or permanent changes in price levels in section 4.

Ignoring the constant terms, using the approximation $\beta \overline{R}_i = 1$ and introducing uncertainty, equation (19) implies

$$E_t\left(\alpha_{i1}\Delta k_{it+1} + \sum_{j=1}^{3}\beta_{ij}\Delta C_{jt+1} + \gamma_i \Delta S_{it+1} + \gamma_i\left(1-\rho_i\right)\Delta B_{it+1} - \phi_i \Delta P_{it+1}\right) = \varepsilon_{it}, \quad (20)$$

where Δ is the first-difference operator and ε_{it} is the expectation error reflecting, for example, unexpected innovations in prices and food safety events. δ_i and ϕ_i are not fully constrained in the estimation, that is, not all the parametric restrictions from the Taylor series expansions are imposed. A downward-sloping demand curve requires $-\frac{\phi_i}{\beta_{ii}} > 0$ suggesting that an increase in the price of good i in period t results in postponed consumption of the good.

U.S. meat consumption exhibits strong seasonality: poultry consumption spikes in the last quarter of the year because of Thanksgiving, pork consumption peaks in the same quarter partly due to higher demand for hams during Christmas and New Years, and beef sales are higher in the summer partly resulting from higher demand associated with outdoor grilling. Seasonal fluctuations in consumption make identification of the coefficient, γ_i, on the habit term in equation (20) more difficult. It is not appropriate to remove seasonality using dummy variables before equation (20) is estimated, because seasonality itself has evolved over time. More importantly, if it is plausible to treat seasonality as traditions, we would want to embed seasonality into the intertemporal maximization problem. The reason is that tradition is a mild form of habits (Becker 1996) and incorporating mild habits in the analysis might be empirically important for commodities such as foods, whose consumption is more likely to be habitual than addictive. Therefore, instead of estimating equation (20) directly, we estimate the following equation in fourth-differenced form

$$E_t\left(\alpha_{i1}\Delta_4 k_{it}+\sum_{j=1}^{3}\beta_{ij}\Delta_4 C_{jt}+\gamma_i\Delta_4 S_{it}+\gamma_i\left(1-\rho_i\right)\Delta_4 B_{it}-\phi_i\Delta_4 P_{it}\right)=\varepsilon_{it}, \qquad (21)$$

where Δ_4 is the fourth-difference operator. Although equation (21) is not an exact representation of the first-order conditions of a consumer optimizing from one period to the next, we believe it is more empirically appropriate given its parsimony in dealing with the presence of stochastic seasonality in U.S. meat consumption. Previous studies of quarterly U.S. and UK nondurable expenditures have recognized the importance of accounting for stochastic seasonality in habit formation and pursued similar approaches (Ferson and Harvey 1992; Osborn 1988).

4 Empirical Results

4.1 Econometric Results

Equations (21) for beef, pork, and poultry were estimated as a system using U.S. per capita data over the 1979Q1–2005Q4 period.[2] The generalized method of moments (GMM) was used to estimate the demand parameters. We selected two alternative sets of instruments.

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[2] All consumption and price data were taken from the *Red Meat Yearbook* and *Poultry Yearbook* (U.S. Department of Agriculture).

The first instrument set includes price at t, quantities at $t - 1$, and food safety indices at t through $t - 3$. These instruments are also seasonally differenced. If there are no unmeasurable lifecycle variables in equation (21), quantities at $t-1$ are valid instruments because they are predetermined as of period t. However, Becker, Grossman, and Murphy (1994) argue that unmeasurable life-cycle variables in the utility function would affect consumption in all periods through the consumer's intertemporal optimization. Consequently, the error term ε_{it} is serially correlated, and this serial correlation invalidates using quantities in any period as instruments. This concern led us to select a second instrument set that includes prices at $t - 1$ through $t - 3$, food safety indices at t through $t - 3$, and per capita personal consumption expenditures at t through $t - 3$. Again, the instruments are seasonally differenced.

In estimation, the parameters β_{11}, β_{22}, and β_{33} were normalized to one in equations (21). Time preference β was not estimated but fixed at 0.98 per quarter. We followed the standard practice in the rational addiction literature that uses one-period lagged consumption to approximate the habit stock, i.e. $\rho_i = 0$. Fuhrer (2000) shows this approximation is reasonable and works well empirically in his model of habitual nondurable expenditures. Quantity, price, and news index data over the 1979Q1–1980Q4 periods were used in seasonal differencing and generating lags. We accounted for serially correlation in the residuals by using the Newey and West (1987) heteroskedasticity and autocorrelation consistent (HAC) covariance estimator. Results for equations (21) using the first and second instrument sets are reported in Tables 4 and 5, respectively.

The data fit the model reasonably well. A number of the coefficients are precisely estimated, and the Hansen's J statistic indicates that the overidentifying restrictions are not rejected using either instrument set. Consistent with downward-sloping demands, the coefficients $(-\phi_i)$ on price differences are positive and highly significant. The statistically significant coefficients γ_i on the habit terms suggest that demand for meat is habitual.

Most of the coefficients on current and lagged food safety index variables are statistically significant. Consistent with *a priori* expectations that news on the safety of a meat species adversely affects its own demand, the coefficients on current and lagged pork safety variables are negative in both models. In the poultry equation, the contemporaneous effect of poultry safety news is estimated to be positive and statistically significant. Nevertheless, the coefficient on the lagged poultry safety news is negative, statistically significant, and similar in magnitude to the coefficient on the contemporaneous poultry safety index. The coefficients on current and lagged beef safety indices alternate in signs, but the net effect appears to be negative on beef demand.

4.2 Distinguishing Between Rational Expectations, Static Expectations, and Myopia Toward Food Safety

To determine the degree of consumer rationality in food safety behavior, we used the consumption function (equations (21)) and the estimated parameters to simulate demand over the period 1981Q1-2005Q4 under four different assumptions about how consumers form expectations about future food safety. We describe the four scenarios below.

- Scenario 1. Consumers are myopic about the effect of current and previous food safety information on future utility through the habit stocks. The effect of food safety information is confined to current utility.
- Scenario 2. Consumers are aware that current and previous food safety events affect not only current but also future utility through the habit stocks. However, consumers form static expectations of future food safety events. Namely, the level of expected future food safety is equal to past level.
- Scenario 3. Consumers are forward looking in terms of expectations about future food safety events. Food safety expectations can be represented by a vector autoregression

(VAR) regression fitted to the food safety indices.

- Scenario 4. As in Scenario 3, consumers form rational expectations of the future safety of food. The level of food safety expectations for each meat equals the mean of each subsample period identified in Table 2.

In all four cases, we assumed consumers form rational price expectations. The price expectations are characterized by a vector autoregressive (VAR) regression fitted to seasonally differenced prices. Maintaining rational price expectations allows us to attribute differences in simulated consumption across scenarios to differences in assumptions about consumer food safety expectations.

When there are three state variables (i.e. habit stocks), it is very difficult to obtain analytical solutions to the optimal consumption paths for forward-looking consumers. Fortunately, an AIM algorithm capable of solving linear rational expectations models with dozens of state and control variables has been developed by Anderson and Moore (1985) and applied in several empirical studies (Fuhrer and Moore 1995; Fuhrer, Moore, and Schuh 1995; Fuhrer 2000).[3] We applied the AIM procedure to the solution of equations (21) for the optimal consumption path under the four food safety expectations scenarios and a VAR process for price expectations.

To solve for the optimal consumption path, we write the following system of deterministic linear difference equations

$$\sum_{m=-\omega}^{0} H_m x_{t+m} + \sum_{m=1}^{\theta} H_m E_t\left(x_{t+m}\right) = 0. \tag{22}$$

The system (22) comprises equations (21), VAR equations for beef, pork, and poultry prices, and, depending on which one of the four food safey expectations scenarios is under consideration, three equations that govern the evolution of the food safety indices over time.

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[3] A very useful review of the AIM procedure is in Zagaglia (2005).

Besides structural parameters of the consumption function (21), the matrices H_m's also contain parameters of the VAR price and food safety index equations. The vectors x_{t+m}'s contain meat quantities, meat prices, and food safety indices in period $t+m$ regardless of whether the variable is endogenous, exogenous, or predetermined.

The AIM algorithm allows us to solve expectations of the future in terms of current and lagged variables

$$E_t\left(x_{t+n}\right) = \sum_{m=-\omega}^{-1} F_m E_t\left(x_{t+n+m}\right),\ n > 0 \tag{23}$$

The elements in the matrices F_m's are called reduced-form solution coefficients to distinguish them from the structural parameters in the H_m's. Equation (23) is used to substitute out the expectations in equation (22) to derive a set of constrained consumption decision rules in terms of variables observable in period t

$$\sum_{m=-\omega}^{0} G_i x_{t+m} = 0, \tag{24}$$

where the matrices G_i's contain parameters of the consumption decision rules solved by the AIM algorithm. One advantage of equations (24) is that it allows us to solve for the optimal levels of beef, pork, and poultry consumption in terms of current and lagged prices and food safety indices with restrictions implied by our assumptions of price and food safety expectations fully imposed. Holding parameters of the price expectations equations constant, a comparison of consumption levels solved under different scenarios of food safety expectations would indicate whether consumer food safety behavior is indeed forward looking.

Table 6 reports the ratios of the mean squared simulation errors (MSSE) of Scenario 3 and 4, respectively, to the MSSE of Scenario 1, where the simulation error is calculated as the difference between the simulated and actual consumption. Table 7 presents the ratios of the MSSE of Scenario 3 and 4, respectively, to the MSSE of Scenario 2. If the ratio is less than one, it suggests a model assuming forward-looking food safety behavior performs better than a model in which consumers are either myopic about future food safety or form static expectations of future food safety events. Inspection of Tables 6 and 7 reveals that except for a few ratios for pork and poultry, where the ratio is virtually one, models assuming rational food safety behavior perform better than the models with myopic food safety behavior or static food safety expectations.

To quantify the long-run effect of the 1993 *E. coli* outbreak on meat demand, we simulated demand for beef, pork, and poultry by holding the levels of food safety news indices after the outbreak 1) at their preoutbreak means, and 2) at their postoutbreak means. The long-run difference between the two cases is then the long-run effect of the 1993 outbreak on meat demand. We calculated that the long-run effect is to reduce annual per capita demand for beef by 0.544 lb, pork by 0.538 lb, and poultry by 0.004 lb. Using the 2005 average beef price, this reduction in beef demand amounts to about $0.66 billion per year in lost revenue for the beef industry alone.

Finally, we present the simulated long-run price and food safety elasticities in Tables 8 and 9. A long-run demand response was simulated by giving a permanent shock to price or food safety index when consumption is initially at the sample means. Among the three meats, demand for pork is most price elastic and poultry is least price elastic. The food safety elasticities are extremely small in magnitude. The estimated pork demand is the most elastic to its own food safety shocks when the second instrument set is used in estimation. Even in this case, the quantity of pork demanded would only reduce by 1.45% in the long run if pork safety index is permanently increased by 100%. Nevertheless, as illustrated by the counterfactual simulation of the 1993 Jack in the Box incidence, a moderate increase in negative publicity about food safety imposes diffused and relatively small costs on individual consumers but huge costs on the industry.

5 Conclusion

Our results indicate that U.S. consumers responded rationally to the *E. coli* O157:H7 contamination of beef at Jack in the Box in 1993. Consumer demand for beef was shown to exhibit habit formation, and consumers were shown to take into account the effect of current choices of beef consumption on future marginal utilities of beef consumption. Because future marginal utilities are affected by the quality of beef consumed, consumers responded to the 1993 *E. coli* outbreak by reducing beef consumption on the presumption that there would be increased risk of *E. coli* O157:H7 contamination of beef in the future. The results, therefore, suggest that consumers believed that neither industry nor government would implement regulations that would significantly prevent the outbreak of *E. coli* O157:H7 in the future.

As discussed in section 2, one of the most important direct consequence of the 1993 incidence was the mandatory adoption of PR/HACCP programs at all meat manufacturing facilities. If implementation of PR/HAACP significantly reduced the risk of *E. coli* O157:H7 contamination of beef and this information was communicated to consumers, we would expect consumers to change their behavior toward beef purchases. For the rational addiction model we used, we would expect a change in the parameters of the structural model after implementation of PR/HAACP compared to before. We performed the Lagrange multiplier (LM) test for a structural break in the structural parameters of equations (21) in 1992Q4. The LM test statistic is chi-square distributed with p degrees of freedom, where p is the number of parameters whose stability is a concern (Hall 2004). The test statistic is evaluated at 12.20 when the first instrument set is used and at 4.45 when the second instrument set is used. With 21 (22 if the model using instrument set 2 is evaluated) degrees of freedom, the null hypothesis of parameter stability is not rejected. Thus, our results indicate that PR/HAACP did not have a significant impact on consumer purchases of beef.

Whether regulations have an impact on consumer demand for beef depends in part on how the benefits of the regulation are communicated to consumers. Available evidence, however, indicates that consumer awareness of *E. coli* O157:H7 is high and that consumers use certain safe handling methods to minimize the risk of *E. coli* O157:H7 (RTI 2001). This would suggest that PR/HAACP has not been effective in reducing the risk of *E. coli* O157:H7 contamination. The evidence also suggests that consumers have responded rationally by reducing beef consumption more compared to myopic behavior because of perceived increased risk of *E. coli* O157:H7 contamination in the future. Hence, consumers are not ignorant and the private market has provided a greater incentive for firms to supply safe beef than if consumers were ignorant of food pathogen issues.

This study is a further example of how market effects can undermine attempts at regulation, consistent with one of Pelzman's theses (Pelzman 2004). Consumers have taken actions to minimize the effect of E. coli contamination; therefore, the PR/HAACP regulations for reducing *E. coli* O157:H7 contaminations may have been rendered ineffective. By using safer handling methods, cooking meat longer, reducing consumption of hamburgers, and substituting cuts that are less likely to have *E. coli* O157:H7 (Ralston et al. 2001), consumers have not only responded rationally but have made the necessity of regulations unnecessary.

References

[1] Anderson, Gary, and George Moore. 1985. "A Linear Algebraic Procedure for Solving Linear Perfect Foresight Models." *Econ Lett* 17: 247-252.

[2] Bai, Jushan, and Pierre Perron. 1998. "Estimating and Testing Linear Models with Multiple Structural Changes." *Econometrica* 66: 47-78.

[3] Bai, Jushan, and Pierre Perron. 2003a. "Computation and Analysis of Multiple Structural Change Models." *Journal of Applied Econometrics* 18: 1–22.

[4] Bai, Jushan, and Pierre Perron. 2003b. "Critical Values for Multiple Structural Change Tests." *Econometrics Journal* 6: 72–78.

[5] Becker, Gary S., and Kevin M. Murphy. 1988. "A Theory of Rational Addiction." *J Polit Econ* 96: 675–700.

[6] Becker, Gary S., Michael Grossman, and Kevin M. Murphy. 1994. "An Empirical Analysis of Cigarette Addiction." *Am Econ Rev* 84: 396–418.

[7] Becker, Gary S., 1996. *Accounting for Tastes.* Cambridge, MA: Harvard University Press.

[8] Bockstael, Nancy E., and Kenneth E. McConnell. 1993. "Public Goods as Characteristics of Non-market Commodities." *Economic Journal* 103: 1244–57.

[9] Carter, Colin A., and Aaron Smith. 2006. "Estimating the Market Effect of a Food Scare: The Case of Genetically Modified Starlink Corn." *Rev Econ Stat* 89: 522–533.

[10] Ferson, Wayne E., and Campbell R. Harvey. 1992. "Seasonality and Consumption-Based Asset Pricing." *Journal of Finance* 47: 511–552.

[11] Fuhrer, Jeffrey C. 2000. "Habit Formation in Consumption and its Implications for Monetary-Policy Models." *Am Econ Rev* 90: 367–390.

[12] Fuhrer, Jeffrey C., and George Moore. 1995. "Inflation Persistence." *Q J Econ* 110: 127–59.

[13] Fuhrer, Jeffrey C., George Moore, and Scott Schuh. 1995. "A Comparison of GMM and Maximum-Likelihood Estimates of Quadratic Cost Inventory Models." *Journal of Monetary Economics* 35: 115–157.

[14] Hall, Alastair. 2004. *Generalized Method of Moments*. Oxford University Press.

[15] Martin, Richard. 1993. "Food Poisoning Crisis Jolts Jack in the Box." *Nation's Restaurant News* (Feb. 1).

[16] Newey, Whitney K., and Kenneth D. West. 1987. "A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix." *Econometrica* 55: 703–708.

[17] Osborn, Denise. 1988. "Seasonality and Habit Persistence in a Life Cycle Model of Consumption." *Journal of Applied Econometrics* 3: 255–266.

[18] Pelzman, Sam. 2004. "Regulation and Natural Progress of Opulence." 2004 Distinguished Lecture, AEI-Brookings Joint Center for Regulatory Studies, Washington, DC.

[19] Piggott, Nicholas E., and Thomas L. Marsh. 2004. "Does Food Safety Information Impact U.S. Meat Demand?" *Am J Agric Econ* 86: 154–74.

[20] Ralston, Katherine, C. Philip Brent, Yolanda Starke, Toija Riggins, and C-T. Jordan Lin. 2002. "Consumer Food Safety Behavior: A Case Study in Hamburger Cooking and Ordering." Agricultural Economics Report No. 804. Washington, DC: U.S. Department of Agriculture.

[21] Ravn, Morten, Stephanie Schmitt-Grohé, and Martín Uribe. 2006. "Deep Habits." *Rev Econ Stud* 73: 195–218.

[22] Research Triangle Institute (RTI). 2001. *PR/HAACP Rule Evaluation Report: Changes in Consumer Knowledge, Behavior, and Confidence Since the 1996 PR/HACCP Final Rule*. Research Triangle Park, NC: RTI.

[23] Schlenker, Wolfram, and Sofia B. Villas-Boas. 2009. "Consumer and Market Responses to Mad-Cow Disease." *Am J Agric Econ* forthcoming.

[24] Stigler, George J., and Gary S. Becker. 1977. "De Gustibus Non Est Disputandum." *Am Econ Rev* 67: 76–90.

[25] Zagaglia, Paolo. 2005. "Solving Rational-Expectations Models through the Anderson-Moore Algorithm: An Introduction to the Matlab Implementation." *Computational Economics* 26: 91–106.

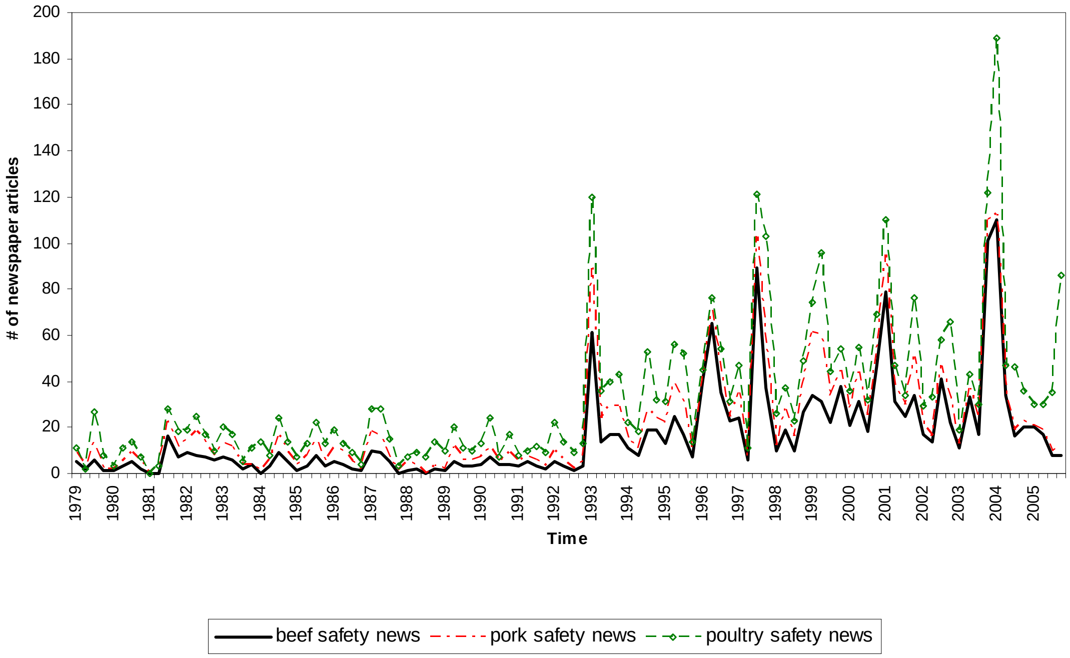

Figure 1: Food safety news article counts

Table 1: Tests of multiple unknown break points in food safety media indices

Number of breaks	Locations	supF_T $(l+1\|l)$
Beef safety		
1	1992Q4	65.71***$(l=0)$
2	1992Q4, 2003Q3	2.78$(l=1)$
Pork safety		
1	1992Q4	24.78*** $(l=0)$
2	1992Q4, 2000Q2	13.77** $(l=1)$
3	1987Q2, 1992Q4, 2000Q2	1.34 $(l=2)$
Poultry safety		
1	1997Q2	26.08*** $(l=0)$
2	1992Q4, 2000Q3	4.55 $(l=1)$

Note: With a minimum of 20 quarters per segment and T=108, the critical values are 8.16 and 12.27 for $l=0$ at the 5 and 1 percent levels, respectively, and 12.53 and 16.57 for $l=1$ at the 5 and 1 percent levels, respectively, where l is the number of break points. ** and *** indicate statistical significance at 5 and 1 percent levels, respectively.

Table 2: Intercept estimates for subperiods of food safety media indices

Intercepts for subperiods		
Beef index, one break date		
1979Q1-1992Q4	1993Q1-2005Q4	
4.036	29.115	
(0.522)	(4.462)	
Pork index, two break dates		
1979Q1—1992Q4	1993Q1 – 2000Q2	2000Q3—2005Q4
3.536	10.400	5.500
(0.371)	(1.732)	(1.026)
Poultry, one break dates		
1979Q1 – 1997Q2	1997Q3 – 2005Q4	
6.973	18.088	
(0.775)	(2.932)	

Note: Standard errors of the estimated intercepts are reported in parentheses.

Table 3: Confidence intervals for the estimated break dates in food safety media indices

Break dates	
Beef index	
1992Q4	
[1992Q4 – 1992Q4]	
Pork index	
1992Q4	2000Q2
[1987Q1 – 1993Q1]	[1998Q2 – post-2005Q4]
Poultry index	
1997Q2	
[1990Q1 – 1998Q1]	

Note: 95 percent confidence intervals are reported in brackets.

Table 4: Estimated parameters for equation (21) using the first set of instrumental variables

	Equation		
	Beef	Pork	Poultry
Intercept	-0.0575	-0.1310	0.1705
	(0.0244)	(0.0253)	(0.0320)
Price	0.8161	1.3525	1.6003
	(0.0809)	(0.1412)	(0.4057)
Beef quantity	—	-0.1017	-0.1402
		(0.0349)	(0.0684)
Pork quantity	0.0175	—	-0.0102
	(0.0294)		(0.0577)
Poultry quantity	-0.0965	0.1420	—
	(0.0534)	(0.0432)	
Habit	0.2424	0.2561	0.2587
	(0.0367)	(0.0331)	(0.0373)
Own food safety index in t	-0.0026	-0.0036	0.0077
	(0.0007)	(0.0024)	(0.0019)
Own food safety index in $t-1$	0.0017	-0.0056	-0.0071
	(0.0007)	(0.0018)	(0.0011)
Hansen's J-stat	21.34		
Sample size (1981Q1 – 2005Q4)	100	100	100

Note: Standard errors are reported in parentheses. With 36 degrees of freedom, the overidentification restriction is not rejected. Wald test is used to select the optimal number of lags for food safety indices. Specifically, we started from $t-3$ and sequentially reduced the number of lags until food safety coefficients on the last lags became statistically significant. The test results suggest one lag for beef, pork, and poultry indices provides the best model fit.

Table 5: Estimated parameters for equation (21) using the second set of instrumental variables

	Equation		
	Beef	Pork	Poultry
Intercept	0.0128	-0.1327	0.1982
	(0.0171)	(0.0146)	(0.0308)
Price	0.4677	0.4911	1.2808
	(0.0676)	(0.1262)	(0.3477)
Beef quantity	—	-0.0327	-0.1235
		(0.0314)	(0.0443)
Pork quantity	0.0065	—	0.0603
	(0.0202)		(0.0388)
Poultry quantity	-0.1779	0.2478	—
	(0.0348)	(0.0370)	
Habit	0.2952	0.4178	0.2374
	(0.0269)	(0.0286)	(0.0372)
Own food safety index in t	-0.0032	-0.0013	0.0071
	(0.0006)	(0.0016)	(0.0012)
Own food safety index in $t-1$	0.0020	-0.0042	-0.0069
	(0.0006)	(0.0012)	(0.0010)
Own food safety index in $t-2$	-0.0017	—	—
	(0.0004)		
Hansen's J-stat	24.60		
Sample size (1981Q1 – 2005Q4)	100	100	100

Note: Standard errors are reported in parentheses. With 56 degrees of freedom, the overidentification restriction is not rejected. Wald test is used to select the optimal number of lags for food safety indices. Specifically, we started from $t-3$ and sequentially reduced the number of lags until food safety coefficients on the last lags became statistically significant. The test results suggest two lags for beef index and one lag for pork and poultry indices provide the best model fit.

Table 6: Comparisons of mean squared simulation errors, rational food safety expectations v. myopia

	Instrument			
	set 1		set 2	
Equation	I	II	I	II
beef	0.946	0.955	0.903	0.915
pork	0.934	0.932	0.940	0.939
poultry	0.997	0.988	1.001	0.992

Note: Columns I and II report the ratio of the mean squared simulation errors of scenario 3 and 4, respectively, to that of scenario 1. A ratio less than one indicates that a model assuming forward-looking consumer food safety behavior outperforms a model in which consumers are assumed to be myopic.

Table 7: Comparisons of mean squared simulation errors, rational v. static food safety expectations

	Instrument			
	set 1		set 2	
Equation	I	II	I	II
beef	0.953	0.962	0.885	0.896
pork	1.005	1.003	0.891	0.890
poultry	0.959	0.950	0.946	0.938

Note: Columns I and II report the ratio of the mean squared simulation errors of scenario 3 and 4, respectively, to that of scenario 2. A ratio less than one indicates that a model assuming forward-looking consumer food safety behavior outperforms a model in which consumers are assumed to form static food safety expectations.

Table 8: Long-run price and food safety elasticities, instrument set 1

	Price		
Quantity	Beef	Pork	Poultry
Beef	-0.349	0.125	0.079
Pork	-0.016	-0.598	0.011
Poultry	0.039	-0.098	-0.208

	Food safety index		
Quantity	Beef	Pork	Poultry
Beef	-0.0015	0.0005	0.0003
Pork	-0.0002	-0.0081	0.0002
Poultry	0.0000	0.0000	0.0003

Note: Elasticities are calculated at sample means.

Table 9: Long-run price and food safety elasticities, instrument set 2

	Price		
Quantity	Beef	Pork	Poultry
Beef	-0.259	0.162	0.061
Pork	0.014	-0.601	-0.044
Poultry	0.080	-0.350	-0.188

Quantity	Food safety index		
	Beef	Pork	Poultry
Beef	-0.0065	0.0043	0.0015
Pork	0.0003	-0.0145	-0.0011
Poultry	0.0003	-0.0023	-0.0003

Note: Elasticities are calculated at sample means.