Reconstructing Market Reactions to Consumption Harms

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Running Title: Reconstructing Market Reactions

Abstract:
We investigate dynamic market reactions from harmful events using phase space reconstruction to analyze nonlinear dynamical systems. Phase space reconstruction analysis is applied to U.S. beef consumption data, demonstrating market deviations and transitions from plausible, stable consumption patterns in response to product attributes (latent or nonlatent) coinciding with longer or shorter term human health harms (e.g., cholesterol) or food safety harms (e.g., E. coli and BSE). The results support complex, nonlinear dynamic behavioral responses to perceived consumption harms. Consistent with previous research, the perceived negative long run health effect from cholesterol caused consumers to transition their consumption behavior from a higher to a lower level while retaining a persistent seasonal pattern. In contrast, responses to food safety information (i.e., E. Coli or BSE) about beef derived from phase space reconstruction demonstrated temporary deviations from stable consumption patterns.

I. Introduction

Attributes of goods that are harmful or potentially harmful engender complex consumer reactions. Possible responses to potentially harmful attributes may vary by the source of the harm, the perceived riskiness of the harm, or the consumer's ability to mitigate that harm. Yet unclear is a more complete picture of the intertemporal nature of consumer responsiveness to perceived harms. Our interest is in applying phase space reconstruction at the market level to empirically reveal dynamic responsiveness of a representative individual potentially exposed to contaminated or unhealthy products, thereby uncovering information partially hidden to other approaches.

Market response to attributes (latent or nonlatent) influencing longer or shorter term human health or food safety harms are particularly important to characterize (Carter and Smith, 2007), as understanding consumer reactions plays an important role in mitigating cost of outbreaks and forming long term government and industry plans. In a span of less than twenty years the beef industry has faced significant health [e.g. cholesterol] and food safety harms [e.g., Escherichia coli (E. coli), salmonella, and Bovine Spongiform Encephalopathy (BSE)]. Kinnucan *et al*. (1997) reported significant longer run impacts from perceived health harms in meats. Using standard demand system models, Piggott and Marsh (2004), Marsh *et al*. (2004), Mazzocchi (2006), and Tonsor *et al*. (2010) reported shorter run impacts from food safety concerns such as E. coli and BSE. These studies applied standard demand system models investigating harms across meat types.

As a supplement to demand analysis, we examine consumer reactions to differentiated harms using phase space reconstruction. Phase space reconstruction offers alternative qualitative techniques to investigate short and long run consumer reactions to differentiated harms and alternative information that complement standard methods. Past evidence suggests that consumers respond disproportionately to negative information (Chang and Kinnucan, 1991; Piggott and Marsh, 2004), further motivating the interest in market reactions to consumption harms.

II. Modeling Framework

The general idea of phase space reconstruction is that a single scalar time series may have sufficient information with which to reconstruct the underlying dynamical system in an embedded phase diagram. The nonlinear time series methods employed in this paper are motivated and based on the theory of dynamical systems in phase space (Takens, 1980). Consider a temporal sequence of scalar values where *n* outcomes are observed as a subset of the total population and are denoted by the time series vector

$X_t = \left[x(t), x(t-1), ..., x(t-n)\right]'$, with the τ^{th} lag of this vector referred to as

$X_{t-\tau} = \left[x(t-\tau), x(t-1-\tau), ..., x(t-n-\tau)\right]'$.

The challenge is to convert the sequence of scalar observations into state vectors and then embed dynamics into a multi-dimensional phase space. We do this by employing the method of delays for reconstructing phase space developed by Takens (1980), Broomhead and King (1986), and based upon Packard *et al.*'s (1980) embedding theorem. Through estimation of an optimal time lag τ and minimum embedding dimension λ, a reconstruction of the underlying dynamic process can be made in the form of a phase space matrix $Y_\lambda = \left[X_t, X_{t-\tau}, X_{t-2\tau}, ..., X_{t-(\lambda-1)\tau}\right]$ with dimension $\left[(n-\lambda\tau)\times\lambda\right]$.

III. Empirical Application: U.S. Beef Consumption

Beef is a well-known staple in the American diet, and has been extensively studied (Kinnucan *et al*., 1997; Chavas, 2000; Marsh *et al*., 2004; Piggott and Marsh, 2004; Patil *et al*., 2005; Mazzocchi, 2006; Zhen and Wohlgenant, 2006; Mutondo and Rastegari Henneberry, 2007; Tonsor *et al*., 2010). Fig. 1 illustrates the seasonal patterns and trends that have occurred throughout the history of beef consumption from 1960:01-2007:02. Demand peaks in the summer months and is lowest in the winter with the average difference between the first and third quarter being 0.93 lbs per capita. This difference increases slightly for the period after 1980 and then stays relatively constant. In addition to the seasonal behavior, there appears to be an average level about which consumption has fluctuated since 1990. Fig. 1 also shows the ratio of beef price to the poultry price. As the relative price of beef to poultry increased during the early and middle part of the study period, per capita consumption of beef declined.

We examine five events for three different harms in beef consumption. These events are drawn from the economic literature (Piggott and Marsh, 2004; Marsh *et al*., 2004; Mazzocchi, 2006; Tonsor *et al*., 2010). For each of these five events we identify the corresponding time period wherein they occurred (see Fig. 1). First is the reaction consumers had to the information regarding the negative health effects of cholesterol. The cholesterol health effect is commonly associated with the downward trend that consumption takes in the mid-eighties (Kinnucan *et al*., 1997). The next two events can be attributed to food safety scares related to E. coli outbreaks as reported in Piggott and Marsh (2004). The first notable E. coli outbreak took place in 1993 when several people became ill after consuming fast-food products. A second outbreak of E. coli occurred in the mid-west during 1997 and resulted in a large recall. The last two events are the result of BSE being detected in cattle in 2003 (Washington) and 2005 (Texas). (For details on the modeling framework and empirical analysis see McCullough (2008).)

Empirical issues

The first minimum of the mutual information function determines the optimal time lag for the phase space reconstruction (Fraser and Swinney, 1986). The mutual information function for U.S. beef consumption decreases from lags 1 to 3 reaching a minimum of 10.68 at lag 3, therefore the optimal quarterly time lag for beef consumption is estimated to be $\tau = 3$. The graphical false nearest neighbors test is implemented to determine the minimum embedding dimension for the phase space reconstruction. The minimum embedding dimension is $\lambda = 2$, satisfying the rule that the entire density of observations is contained below a line of degree less than 90 for the two-dimension case (Aittokallio *et al.*, 1999).

Based on these two parameter estimates one can create a graphical representation with descriptive statistics of the underlying dynamics that drive beef demand from 1980:01 to 2007:02 (Fig. 2). The horizontal axis of the phase space in Fig. 2 is the observed time series; the vertical axis is the time series lagged three periods. One can interpret the reconstructed phase space similar to a phase diagram generated from a system of differential (difference) equations.

Interpreting the phase space reconstruction becomes clearer by comparing the original series in Fig. 1 and the reconstructed phase space in Fig. 2. In the following interpretations, we do not draw casual inferences but rather draw associations to the periods in which events occurred and to reported findings of previous studies. Seasonality of beef consumption is exhibited in the original time series and the reconstruction. If seasonality were the only persistent nonlinear process in beef consumption, the phase space reconstruction would be contained solely on the 45° line. This indicates the additional complexity of consumer behavior and the need for flexible estimation techniques.

Consumer reactions to cholesterol information: 1980-2007

During the late eighties information was published on the negative health effects of diets high in cholesterol such as that found in beef. Evidence suggests that this health effect resulted in a decrease in U.S. beef consumption (Kinnucan *et al*., 1997). Fig. 2 shows a period of more stable consumption cycles in the early 1980s (the cyclical pattern in the upper right sector), a transition period associated with consumer reaction to cholesterol information (from the upper right to the lower left sector), and more recent post 1990 stable "tighter" cycles at a lower level of consumption (in the lower left sector). Consumers reacted to the negative health information by decreasing their average level of consumption permanently while retaining a persistent seasonal pattern. The transition period illustrated in Fig. 2 is consistent with a longer run behavioral response and aligns with the empirical findings of Kinnucan *et al*. (1997).

Consumer reactions to E. coli and BSE: 1990-2007

To examine consumer's reactions to more recent E. coli and BSE concerns, the phase space trajectory is presented in Fig. 3 from 1990 to 2007. The reconstructed reactions from E. coli and BSE outbreaks are different than health concerns, as well as from one another. During an initial or novel outbreak of E. coli or BSE, beef consumption deviates for a brief period of time until returning to the normal cyclical behavioral pattern. This characterization is consistent with observed outliers in the data set (and discussed in more detail ahead).

As an additional measure, the magnitude and duration of the outbreaks (i.e., potential outliers in the data) are delineated using Euclidean distances from the phase space mean and normal confidence ellipsoids. Observations from the phase space reconstruction are comprehensively tested under the null hypothesis of being normally distributed using the Shapiro-Wilk *W* test for normal data (Royston, 1983) and the methods described by Johnson and Wichern (2002) to test for joint normality. With the bivariate normal distribution assumption verified, we define outlying observations as those lying on the largest confidence ellipsoids defined by $(x-\mu)' \Sigma^{-1}(x-\mu) \leq \chi_2^2(\rho)$ so that the probability of the observation, ρ, is very small. Applying this outlier analysis to the phase space reconstruction makes it possible to differentiate the perturbation magnitude of E. coli and BSE events discussed ahead.

E. coli

An initial inspection of the reconstruction suggests the outbreak of E. coli in 1993 exhibited a larger deviation than the second E. coli outbreak in 1997 (Fig. 3). This is also evident in the confidence ellipsoids where the 1993 (1997) E. coli trajectory has a maximum chi-square probability of 0.885 (0.738). A plausible explanation in the difference between the two outbreak trajectories may be attributed to consumers becoming less sensitive to negative information regarding E. coli (as E. coli can be cooked out of beef reducing contamination risk). Due largely to educational efforts of the United States government, consumers have become much more aware of the risks concerning food scares and the contaminant E. coli and have become more knowledgeable of better food handling procedures and practice them often (RTI, 2002).

BSE

The 2003 BSE incident (Fig. 3) resulted in a noticeably greater perturbation of consumption than those coinciding with E. coli outbreaks. The 2003 BSE trajectory lies well outside the 95% confidence ellipse while the 1993 E. coli trajectory does not. Unlike E. coli, BSE cannot simple be cooked out of beef. The uncertain nature of BSE appears to have played an important role in consumer reactions. There are no preventative actions for direct human protection against being contaminated by BSE other than abstaining from eating contaminated beef product. As well as the lack of preventative measures, there is evidence that oral exposure to BSE can lead to variant Creutzfeldt-Jakob's disease (Collinge, 1999). BSE is shown to be present in the central nervous system and bone marrow of cattle, portions not normally consumed, while E. coli may be found in meat. The actual risk of becoming infected by BSE is much lower than E. coli. This suggests that people's ignorance of the true probability of contamination may lead to stronger reactions to perceived longer run health impacts.

There have been two other confirmed cases of BSE infected cattle in the United States since 2003: one in Texas in June of 2005 and another in Alabama in March of 2006. The phase space reconstruction shows that although consumers reacted in a severe manner during the initial or novel 2003 BSE incident there is no discernable adverse reaction to the 2005 or 2006 incidences. A plausible explanation is that consumers have become less sensitive to negative information regarding BSE incidents since its initial appearance in the United States. Similar to E. coli, BSE has induced no apparent long-term trend to decrease beef consumption. In both cases perturbations during the periods of outbreak/incidents from the phase space mean were essentially short-lived and subsequent perturbations were less severe than the initial.

IV: Further Discussion: Theoretically Specifying Market Reactions

The analysis suggests that a plausible approach to theoretical modeling of consumer reactions to harms be an intertemporal expected utility perspective, incorporating consumer's risk perceptions and formation as subjective probabilities. While there has been a lot of debate on the theoretical formulation of subjective utility as well as what constitutes uncertain demand or ambiguity (see for instance Jones-Lee *et al*., 1985; Mukerji, 1998; Epstein and Zhang, 2001), there is no clear empirical formulation to draw on for practical applications. In the case of meat consumption we anticipate that both of these issues (subjectivity and ambiguity) are important in formulating a basis for estimating consumer behavior, leading to different market reactions.

Consider a simple structural decomposition of the risk of a particular harm using conditional probabilities:

$$Prob(harm) = Prob(harm \mid mitigation) * \left(1 - Prob(mitigation \mid presence)\right) * Prob(presence)$$

This decomposition demonstrates that the probability of harm is formed differently for E. coli relative to BSE, and could be based upon the interaction of ambiguity and subjective probabilities. The prevalence of the consumption harm deals with the ambiguity of harmful events as defined by Epstein and Zhang (2001). E. coli is prevalent throughout the beef supply chain (Perry *et al*., 2007), i.e., high *Prob*(*presence*). However, the harm can be mitigated by appropriate food preparation techniques, i.e., low *Prob*(*harm*|*mitigation*). Alternatively, the prevalence of BSE in the U.S. is estimated to be less than 1 BSE infected animal per one million adult cattle i.e., low *Prob*(*presence*), but mitigating BSE given its latent nature is extremely difficult (USDA-APHIS 2006). In both cases the perceived probability of a harm is arguably low in the U.S., but for different reasons.

This simple framework suggests that, when specifying theoretical models relating to harms, researchers should recognize risk perceptions, how they are structured, their potential changes over time, as well as consumer demographic variables (see Tepper and Rosenzweig (1999), Messer *et al.* (2011), and Piggott and Marsh (2004) for examples of this type of specification).

The *Prob*(*mitigation*|*presence*) structure can relate directly to consumer information on proper handling of harmful consumption goods. Efforts made by private or government agencies to increase this probability lead directly to a lower *Prob*(*harm*) and, given this specification, will result in reduced market reactions like those empirically shown in Lemming and Turner (2004) and Jin and Kim (2008). Under this specification, if the assumption of aversion to ambiguity, as defined by Mukerji (1998) in portfolio management, is present, then it is in the best interest of the producer to relate complete information to consumers when faced with possible harms to simultaneously both reduce variance on *Prob*(*presence*) and increase *Prob*(*mitigation*|*presence*).

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Figures

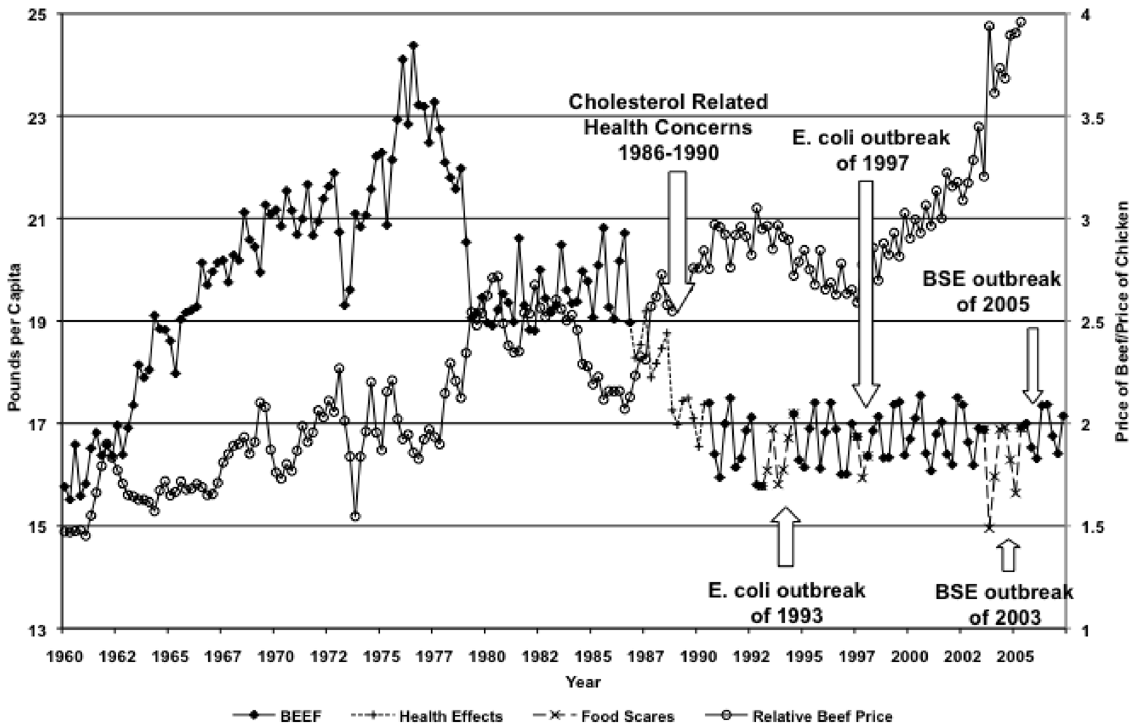

Fig. 1. United States consumption of beef with indicated Health Effects and Food Scares; 1960:01-2007:02

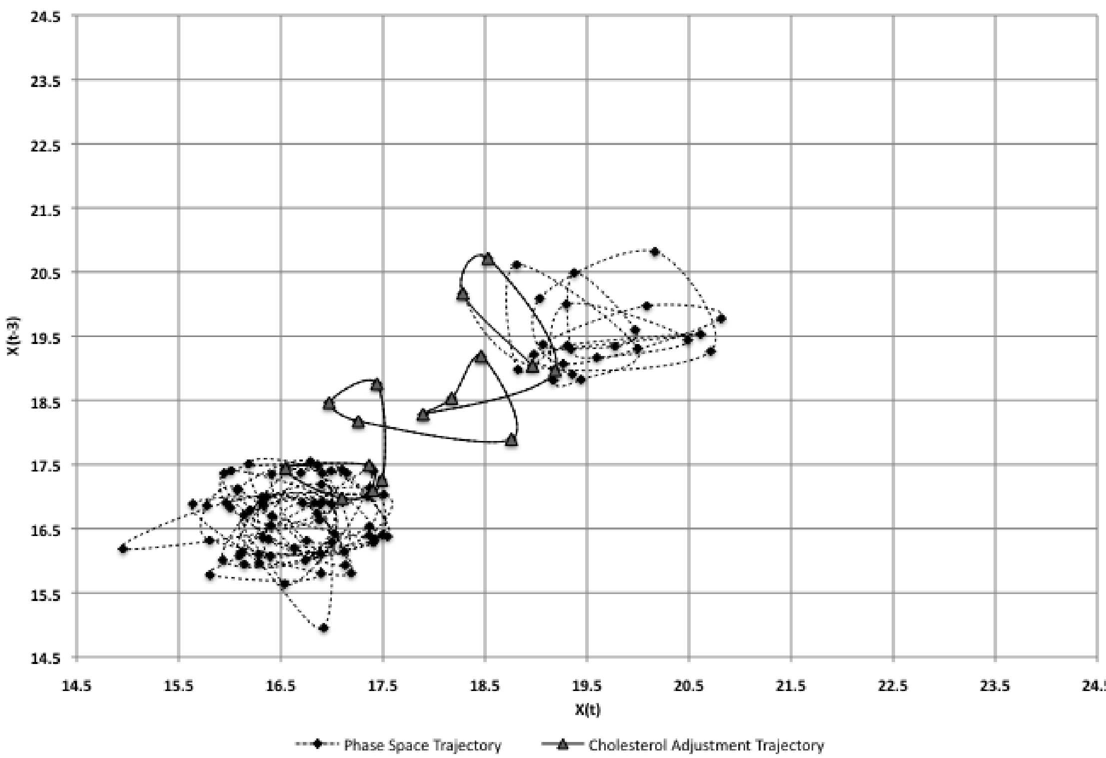

Fig. 2. The effects of cholesterol on U.S. beef consumption; 1980:01-2007:02

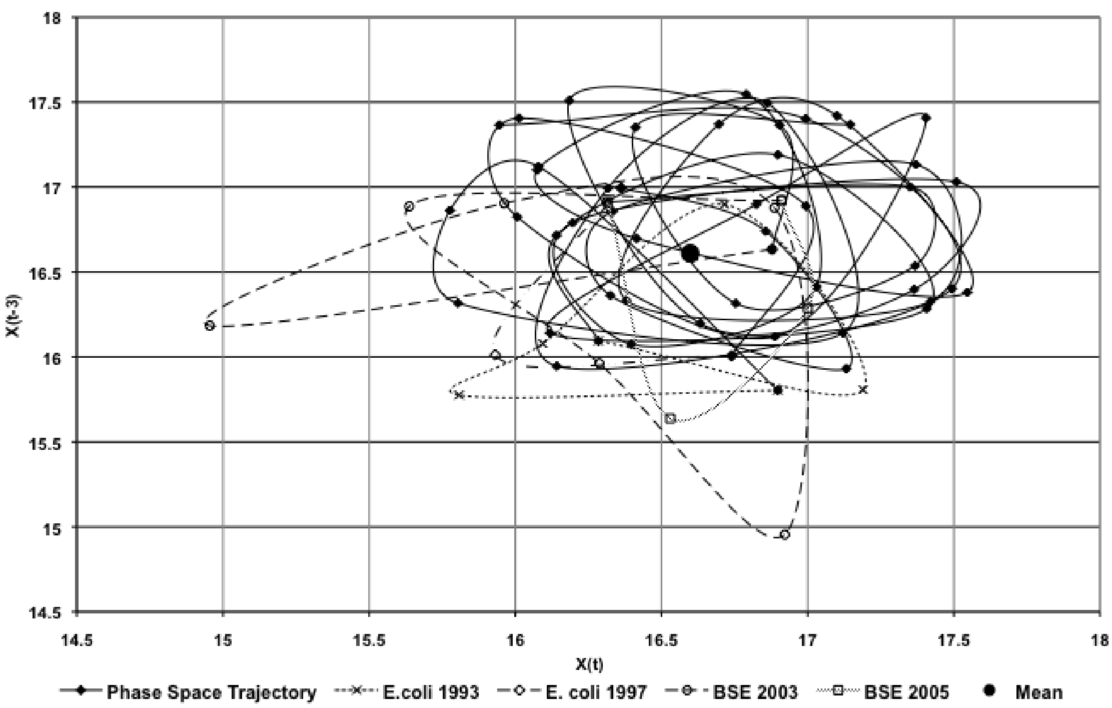

Fig. 3. Reconstructed phase space post the effects of cholesterol; 1990:01-2007:02