ABSTRACT

ZHEN, CHEN. Food Safety, Habits, and Rational Expectations in U.S. Meat Demand. (Under the guidance of Michael K. Wohlgenant.)

The objective of this dissertation is to explore the theoretical and empirical implications of a meat demand model with rational habits. To introduce consumption dynamics, habit persistence is used to motivate intertemporally related preferences. The impact of food safety information on meat consumption is systematically analyzed. Important differences between myopic habits and rational habits are underscored. Theoretical predictions are tested using U.S. consumption data and food safety indices compiled based on articles from four major U.S. newspapers during the 1980(3)-2005(4) period.

Assuming rational expectations, Hansen's (1982) generalized method of moments (GMM) is implemented to investigate the Euler equations implied by a demand model with habits. Empirical evidence suggests that, at quarterly frequencies, habit persistence dominates inventory behavior in beef consumption during the post-1998 sample period, while pork and poultry demands exhibit mild degrees of inventory adjustment overall for this period. A plausible explanation for the dominance of habits in beef demand since 1998 is that the low carb-high protein fad may have helped to increase the degree of habits for beef. This is consistent with the theoretical prediction that an increase in the perceived benefits of long-term consumption of a good is likely to strengthen the degree of habit persistence of that good.

With GMM estimates of preference parameters at hand, demand elasticities to price and food safety shocks that are expected to be transitory or permanent can be computed. The standard procedure is to linearize the Euler equations and derive analytical results for elasticities. Nevertheless, linearization is not attempted here. Instead, a numerical procedure is invoked to compute approximate solutions to the Euler equation under various shock scenarios. The simulated elasticities are sensible and consistent with theoretical predictions. Specifically, using 2004(4) prices and food safety levels as benchmark values, the short-run own-price elasticity of beef demand for a permanent price increase is more than twice of its counterpart for a price increase that is expected to be transitory. The long-run own-price elasticity of beef for a permanent price change is about 30% higher than the short-run elasticity. The food safety elasticities are generally small in magnitude with the long-run own-effect elasticity on beef of about -0.015 being the largest.

A model for food safety policy analysis should be closely tied to the objectives of consumers and to the decision rules of policy makers, and should explicitly embed expectations that are most relevant for consumers when consumption is temporally dependent. Although some reduced-form dynamic models of meat demand have been developed to capture dynamic interactions among demands over time, these are unlikely to be adequate in modeling expectations. Food safety shocks that were largely transitory in the past may be perceived by consumers as being more persistent in nature if happen again in the future, and vice versa. This is the essence of the classic Lucas (1976) critique applied to food safety analysis. The distinct own-price elasticities of beef demand for price changes of different durations provide corroborating evidence that the Lucas critique can be quantitatively important in modeling meat demand.

Keywords: food safety, habit persistence, meat demand, nonlinear rational expectations model.

FOOD SAFETY, HABITS, AND RATIONAL EXPECTATIONS IN U.S. MEAT DEMAND

By

CHEN ZHEN

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

ECONOMICS

Raleigh

2006

APPROVED BY:

Michael K. Wohlgenant (Chair of Advisory Committee)	Nicholas E. Piggott
Walter N. Thurman	Barry K. Goodwin

Dedicated to

My parents, Zhen Guoliang and Chen Qiuxia,

and my sweetheart, Zhang Wei

Biography

Zhen, Chen was born in Beijing on August 16th, 1977 as the only child to Zhen Guoliang and Chen Qiuxia. He spent most part of his childhood in Langfang, a small town (by Chinese standard) 50 miles to the east of Beijing, and graduated from the high school affiliated with the China Petroleum Pipeline Engineering Corporation where his parents worked. After obtaining a BS degree in economics from University of Colorado at Denver in 1999, he enrolled into the graduate program in applied economics at Montana State University and received a MA degree in 2001. In August 2001, he started his Ph.D. study in the economics graduate program at North Carolina State University.

Acknowledgements

My deepest gratitude goes to my advisor Dr. Michael Wohlgenant for his enlightenment, encouragement, and entertainment during the incubation and writting of this dissertation, without of which a successful completion would not be possible. I would also thank Dr. Nicholas Piggott for his candid advices at several critical stages of my graduate study. My appreciations also go to Dr. Wally Thurman and Barry Goodwin for their thoughtful and helpful comments and suggestions on the research. I also thank my professors at Montana State University, Randy Rucker, Charles Steele, Ron Johnson, Dave Buschena, and Joe Atwood for helping me to build a knowledge base that went a long way toward preparing for an excellent doctoral program.

I deeply appreciate the help and friendship offered by my friends in the department—Syed Wadood, Tullaya Boonsaeng, Carlos Carpio, Moinul Islam, Varun Kshirsagar, Nick Kuminoff, Dequan He, Jaren Pope, Henry Kuo, Kostas Kyriakoulis, Peyton Ferrier and many others. They made an otherwise stressful process a happy journey.

My parents have supported and encouraged me since I started college. I thank my sweetheart Winnie's love, understanding, and support whenever it was needed.

Contents

List of Tables

List of Figures

Chapter 1

Introduction

Every year in the United States foodborne diseases cause thousands of premature deaths and cost society billions of dollars (USDA, 2000). Sporadic outbreaks of food contamination are the subject of public attention and may adversely affect consumer demand for the implicated food products. Although foodborne pathogens have been found in a myriad of food types, meat products remain a major source. It is important to examine whether food safety information affects consumer demand in the long run, and if so, by how much? The purpose of this dissertation is to investigate the effects of news media coverage of food contamination outbreaks on U.S. consumption of beef, pork and poultry products in the short run and the long run.

A small but growing economics literature examines the impact of food safety events on consumer demand. Burton and Young (1996) built indices of media coverage of bovine spongiform encephalopathy (BSE) by counting the number of newspaper articles that mentioned BSE. When these indices were incorporated in a demand system, statistically significant impacts of BSE articles on beef and other meats were detected. Henson and Mazzocchi (2002) examined security price data of a number of food manufacturers that were publicly traded on the London Stock Exchange. Their results indicated that the public announcement of a possible link between BSE and a new variant of its human equivalent Creutzfeldt-Jacob disease (CJD) by the British government in 1996 negatively affected beef product manufacturers but profited manufacturers of other meats. Similar results were reported using U.S. data. Thomsen and McKenzie (2001) found that a class 1 meat recall resulted in a 1.5-3% loss in shareholder wealth, while less serious hazards had no discernible adverse impact on stock market returns of the implicated food company.

Several studies found that the effects of food safety on U.S. meat demand have been small in magnitude relative to price and health effects. Dahlgran and Fairchild (2002) constructed an adverse publicity index of salmonella contamination of chicken using multiple sources of TV and print news. Their results indicated that consumer response to chicken contamination publicity was small and short-lived with less than 1% reduction in consumption at the height of the exposure. Flake and Patterson (1999) studied the impact of beef safety information on meat demand in a system of demand functions framework. Their food safety information index was based on the number of Associated Press articles on Escherichia coli (E. coli), salmonellosis and BSE. They found that the negative effect of beef safety stories on beef consumption was small (when compared to health effect) and only marginally statistically significant. The analysis by Piggott and Marsh (2004) is the first demand study that incorporated multiple food safety indices constructed individually for beef, pork and poultry. In contrast to ealier studies, they were able to investigate both the own- and cross-effects of food safety indices on meat types. While statistically significant food safety effects were detected, their economic significance appeared to be modest relative to price and expenditure effects. These results were confirmed by Marsh, Schroeder and Mintert (2004) who found small effects of meat product recalls on U.S. meat demand.

Most of the studies on meat demand follow the static demand system paradigm in that the consumption decisions are functions of current prices, income, and possibly a few other demographic and health variables. These models assume that preferences are separable over time, and therefore consumption decisions in period t are independent of consumption in period $t-1$. Exceptions include Pope, Green and Eales (1980) and Holt and Goodwin (1997) where dynamic aspects of meat demand are explored by testing for the existence of habit formation. In their studies, the household is backward-looking in that habits play a passive role and do not alter the duality theorems of standard static optimization. This type of habits is called myopic habits. In contrast, estimation in this dissertation is based on the optimality conditions (Euler equations) derived from an intertemporal optimization problem assuming rational expectations.

The rational expectations model of meat demand is implicitly motivated by the Lucas (1976) critique which asserts that parameters of conventional macroeconomic models rest critically on parameters dictating agents' expectations processes and are possibly unstable in a varying economic environment. To overcome this problem, some empirical studies focus on the estimation of "deep" behavioral parameters that have explicit structural interpretations. For demand models, expectations are important for modeling demand with habits while almost irrelevant for demand models that are intertemporally separable. Food safety and habit persistence are not two unrelated issues that may be treated separately. Habituation of demand provides a convenient tool with which consumption dynamics could be rationalized. Under habit persistence, food scares that may have a short-lived direct impact on demand could have protracted indirect effects by changing the level of habit stock. More importantly, if meat consumption is habit-forming, rational consumers respond more to permanent food safety shocks than to transitory shocks. But this distinction is not implied by a reduced-form myopic demand model with habit persistence.

This dissertation is structured as follows. The next chapter briefly reviews the literature on meat demand other than the one related to food safety, and the economic literature on habits. This motivates the development of a meat demand model with habits. Chapter 3 presents a modified Becker and Murphy (1988) model of habits augmented to include food safety information. In this section, important theoretical implications of rational habit formation are underscored. In chapter 4, a rational expectations econometric model of habits is proposed and estimated with U.S. meat consumption data and information on food safety. Because the constructed food safety information indices represent a meticulous effort to distinguish the information contents of media reports, the procedure followed to collect the food safety information are documented in this chapter. Due to the nonlinear nature of the empirical model, no closed-form solution exists for the household's dynamic optimization problem. To estimate the model, GMM that does not require explicit solution to the household's decision problem is applied to the econometric estimation. In chapter 5, the GMM parameter estimates from the previous chapter are used to calibrate the household preferences. Based on this calibrated model, approximate solutions to the household's consumption decisions are computed numerically, and demand elasticities for different price and food safety shocks in the short run and the long run are calculated. Chapter 6 concludes the dissertation.

Chapter 2

Literature Review

2.1 Previous Research on Meat Demand Other Than Food Safety

During the past two decades, meat consumption in developed economies and in the United States in particular has been the focus of much economic research. It is often hypothesized that structural break has occurred that shifted consumer preferences away from red meat toward chicken and fish (e.g., Chavas 1983; Thurman 1987; Chalfant and Alston 1988; Sakong and Hayes 1993). Although agricultural economists still debate whether consumption can be explained by variations in prices and income alone or that other factors are also responsible, findings of structural change are common. The most often speculated cause of preference change is the effect of health information on cholesterol and saturated fat in red meat. Kinnucan et al. (1997) find that the number of published medical articles on cholesterol has a significant effect on meat demand and this variable has a larger elasticity than any of the price elasticities. McGuirk et al. (1995) arrive at the same conclusion. But these observations do not completely dispel the skepticism. Most studies that do confirm a structural break suggest that it occurred somewhere between the middle and late 1970s. However, Robenstein and Thurman (1996) found that the red meat futures market did not respond to the release of articles in the *Wall Street Journal* on the adverse health effects of dietary cholesterol. Furthermore, all of the "strong" and most of the "moderate" and "weak" articles on cholesterol were published after 1982. The newspaper index of cholesterol in McGuirk et al. also indicates that consumers were not bombarded with such information until the early 1980s. Public concerns about food safety issues have recently stimulated research on the economic impacts of food contamination outbreaks (e.g., Thomsen and McKenzie 2001; Piggott and Marsh 2004). Unlike heart disease linked to cholesterol and dietary fats, ailments due to intake of contaminated food are much more acute and sustained consumption is not required to develop the symptoms.

Davis (1997) questions the methodological foundation of the research on structural break in meat demand. He advocates that researchers should not be pinned down on testing for structural break *per se*, which, by the laws of logic, is not valid. Instead, a more progressive and fruitful approach is to relax some of the theoretical assumptions embedded in the classical static demand paradigm that is widely followed in the meat demand literature. Studies on cholesterol and food safety information effects are considered progressive, because the list of potentially important determinants of meat demand is expanded beyond the contemporaneous prices and income.

Economists recognize that people dine for entertainment as well as for nourishment (Muth 1966). Consumer preferences for different foods are based on their nutritional content, palatability, consumer's social status, prestige and habits. If nourishment was the sole purpose of dining, the monetary cost of the diet would be very low. With the knowledge of nutrition at that time, Stigler (1945) estimates that the minimum cost of subsistence in 1944 was $59.88 (in current dollars). This accounts for only less than a quarter of the actual per capita food outlay in that year. Silberberg (1985) finds that as income rises, a lower proportion of food expenditure is allocated to pure nutrition.

Individuals may develop habits over certain food stuff because previous experience with it induces better appreciation. In the U.S., poultry consumption is a prominent example of evolving dietary pattern. During World War II, unlike many food commodities, poultry was not rationed because it was not an important component of people's diet. Poultry products marketed were primarily whole birds. Starting from the 1950's the integrated form of production continuously drove down poultry prices. Poultry products started to be marketed in parts and deboned ready-to-cook forms. New chicken recipes were invented. Fast-food restaurants started to offer such a vast variety of chicken meals as nuggets, patties, breast fillets and popcorn chicken. Franchised restaurants like the Kentucky Fried Chicken were configured to serve exclusively chicken. From 1960 to 1999, per capita consumption of poultry products has almost tripled from about 50% to roughly 150% of beef consumption.

This observation has been the momentum behind the huge literature on structural break in meat demand.

It is postulated in this study that past (learning) experience with a food product boosts consumer's current appreciation of this particular food—the essential argument made in Stigler and Becker (1977). The medical mechanism by which cigarettes and cocaine hook addicts up is not needed to induce habits, although recent research indicates that consumption of certain foods may be addictive in the same way as the use of harmful drugs (Wang et al. 2004).

2.2 Economic Models of Habits

Economic consumption models with habits differ from each other by their distinct approaches to two basic factors. The first factor concerns the constancy of consumer tastes. Endogenous tastes models such as Ryder and Heal (1973) incorporate habits by invoking the concept of subsistence consumption. Dynamics is introduced as past consumption increases current level of subsistence demand. Because subsistence consumption does not affect utility directly, a higher level of past consumption results in a lower current level of utility holding current consumption constant.

On the other hand, Stigler and Becker (1977) and Boyer (1978, 1983) posit that tastes do not change, but consumption knowledge does. In their models, habits are modeled as a learning-by-doing process. The individual learns from past consumption experience. The more he learns the more utility he can get out of a given level of current consumption. Hence, past consumption is considered to be the consumption capital that results in better appreciation of current consumption. Despite this sharp distinction between the two model classes, the mathematics are the same and the characteristics of the optimal consumption path are not much different (Phlips 1983; Boyer 1978).

The second factor is related to consumer rationality. Early literature on habits tends to model habit-formation as "myopic" or backward-looking (e.g., Pollak and Wales 1969; Pollak 1970). The consumer is myopic in the sense that he is not aware of the impact of his current consumption decision on future preferences. More recent models explore the implications of consumer rationality on the optimal consumption path of temporally interdependent preferences (e.g., Ryder and Heal 1973; Boyer 1978, 1983; Becker and Murphy 1988). This dissertation focuses on issues associated with the second factor, and studies the theoretical and empirical implications of incorporating habits and rationality into the model of meat demand.

Chapter 3

Theoretical Model

For expository ease, the theoretical framework is set up in a deterministic and continuous-time environment. Assume that there exists a representative consumer who maximizes lifetime utility. For now, assume that there are only two goods, the food service that is potentially habit-forming, and all-other-goods. The food service provides both nourishment and entertainment. To prepare the food, three inputs—the quantity of raw food material c, its quality k, and the consumption capital S—are needed. Consider the household food production function

$$f = g(c, k, S) \tag{3.1}$$

where f is the food service, and $g(\cdot)$ represents the production technology. The quality k measures the quality attributes of the food material. For instance, k can be an indicator of food contamination outbreaks, a higher value of which indicates more severe contamination incidence so that the perceived quality of c is lower while the incidence lasts. Its value is neither chosen nor priced but exogenous to the household. In this case, the outbreak can be considered a public good that is a quality characteristic of the privately consumed good (Bockstael and McConnell 1993; Piggott and Marsh 2004). Plausible assumptions of the production function include: $g_c > 0$, $g_{cc} < 0$, $g_k < 0$, $g_s > 0$, and $g_{ss} < 0$. Consider food preparation and consumption as a "learning-by-doing" process, the consumption capital S summarizes the experience and knowledge acquired from previous cooking and dining activities. Define the consumption capital stock to be an exponentially weighted sum of past levels of consumption: $S(t) = \int_0^t e^{-\delta(t-\tau)} c(\tau) d\tau$, where δ is the rate of capital depreciation. Differentiating this with respect to t results in the equation of motion for the capital stock

$$\dot{S} = c(t) - \delta S(t). \tag{3.2}$$

The consumer maximizes the lifetime utility function:

$$U(0) = \int_0^T e^{-\rho t} u[y(t), g(t)] dt, \tag{3.3}$$

subject to (3.2) and the budget constraint:

$$\int_0^T e^{-rt} [y(t) + p(t)c(t)] dt \leq w(0), \tag{3.4}$$

where ρ is the rate of time preference; $y(t)$ is the composite good consumed at time t whose price is normalized to unity; r is the real interest rate; $p(t)$ is the price of raw food material c at time t; and $w(0)$ is the period 0 value of lifetime wealth. For the utility-maximizing individual, the decision variables are $y(t)$ and $c(t)$. The budget constraint (3.4) is valid if there are perfect capital markets where consumers can borrow at the interest r.

The optimal paths of $c(t)$ and $y(t)$ are determined by the first-order conditions:

$$e^{-\rho t} u_y(t) = e^{-rt} \mu \tag{3.5}$$

$$e^{-\rho t} u_c(t) = e^{-rt} \mu p(t) - e^{-\rho t} \left[\int_t^T e^{-(\rho+\delta)(\tau - t)} u_s(\tau) d\tau \right]. \tag{3.6}$$

Equation (3.5) 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 (3.6) is the sum of all future benefits (costs if $u_s < 0$) accrued through the effect of an infinitesimal increase in $c(t)$ on future capital stocks. Hence, equation (3.6) says that the marginal utility of $c(t)$ equals the marginal cost of buying one unit of consumption minus (plus) the utility value of future benefits (costs). If $u_s \neq 0$, we see from (3.6) that there is a wedge between current marginal utility of $c(t)$ and current marginal cost. In the absence of this wedge, consumption of the rational consumer responds immediately and fully to outside shocks. This is a fundamental distinction between myopic and rational consumer behavior.

3.1 Dynamic Behavior

For sake of convenience, assume that the rate of time preference is equal to the real interest rate. Assume also an instantaneous quadratic utility function in order to linearize the first-order conditions (3.5) and (3.6)[1]:

$$\begin{aligned} u(t) &= \alpha_y y(t) + \alpha_c c(t) + \alpha_s S(t) + \frac{\alpha_{yy}}{2}[y(t)]^2 + \frac{\alpha_{cc}}{2}[c(t)]^2 + \frac{\alpha_{ss}}{2}[S(t)]^2 \\ &\quad + \alpha_{yc} y(t)c(t) + \alpha_{ys} y(t)S(t) + \alpha_{cs} c(t)S(t) + \alpha_{ck} c(t)k(t). \end{aligned} \tag{3.7}$$

Note that the product quality k enters jointly with c, consistent with the notion that this quality characteristic alone has no value to the individual. Next, differentiate (3.7) with respect to c, y, and S and substitute (3.5) into (3.6). Differentiate equation (3.6) with respect to t and use (3.6) to substitute out the integral term from the result. Then use equation (3.5) to eliminate $y(t)$. Performing these operations yields a differential equation for $c(t)$ of the form:

$$\begin{aligned} A_1 \dot{c}(t) &= B_1 + B_2 + (\rho+\delta)A_1 c(t) + [(\rho+2\delta)A_2 + A_3]S(t) \\ &\quad - (\rho+\delta)\alpha_{ck} k(t) - \mu\dot{p}(t) + \alpha_{ck}\dot{k}(t) \end{aligned} \tag{3.8}$$

where $A_1 = \frac{\alpha_{yc}^2}{\alpha_{yy}} - \alpha_{cc}$, $A_2 = \frac{\alpha_{ys}\alpha_{yc}}{\alpha_{yy}} - \alpha_{cs}$, $A_3 = \frac{\alpha_{ys}^2}{\alpha_{yy}} - \alpha_{ss}$, $B_1 = (\rho+\delta)[\frac{\alpha_{yc}\alpha_y}{\alpha_{yy}} - \alpha_c] + \frac{\alpha_{ys}\alpha_y}{\alpha_{yy}} - \alpha_s$, and $B_2 = (r+\delta)\mu p(t) - \frac{\mu}{\alpha_{yy}}[(\rho+\delta)\alpha_{yc} + \alpha_{ys}]$. Differentiate equation (3.2) with respect to t and use (3.2) and (3.8) to eliminate $c(t)$ and $\dot{c}(t)$, respectively, from the result. This procedure gives a second-order linear differential equation in $S(t)$

$$(D^2 - \rho D - A)S(t) = A_1^{-1}[B_1 + B_2 - (\rho+\delta)\alpha_{ck}k(t) - \mu\dot{p}(t) + \alpha_{ck}\dot{k}(t)] \tag{3.9}$$

where $DS(t) = \frac{dS(t)}{dt}$, and $A = A_1^{-1}[A_1\delta(\rho+\delta) + A_2(\rho+2\delta) + A_3]$. Equation (3.9) has two characteristic roots, $\lambda_1, \lambda_2 = \frac{\rho \pm \sqrt{\rho^2+4A}}{2}$, both of which are real. To see this, concavity of the utility function implies: $A_1 > 0$, $A_3 > 0$ and $A_1A_3 > A_2^2$. Therefore, whatever sign A_2 takes, $\rho^2 + 4A = A_1^{-1}[A_1(\rho+2\delta)^2 + 4(\rho+2\delta)A_2 + 4A_3] > 0$. To obtain the solution to (3.9), set the right-hand side of (3.9) equal to $-A\psi(t)$ where $\psi(t)$ is a function of the variables in (3.9), and rewrite (3.9) as

$$(D-\lambda_1)(D-\lambda_2)S(t) = -A\psi(t). \tag{3.10}$$

The solution to equation (3.10) takes the positive unstable root (λ_1) forward and the negative stable root (λ_2) backward (Sargent 1987). Following this procedure yields

$$\begin{aligned} S(t) &= e^{\lambda_2 t}\left[S(0) - \frac{1}{\lambda_1-\lambda_2}\int_0^\infty A\psi(\tau)e^{-\lambda_1\tau}d\tau\right] \\ &\quad + \frac{1}{\lambda_1-\lambda_2}\left[\int_t^\infty A\psi(\tau)e^{\lambda_1(t-\tau)}d\tau + \int_0^t A\psi(\tau)e^{\lambda_2(t-\tau)}d\tau\right]. \end{aligned} \tag{3.11}$$

[1]Linearization of the first-order conditions is done only to examine local dynamic behavior of the optimal consumption strategies. More general functional forms can be used in empirical work.

Equation (3.11) is the calculus of variations solution to the consumer's dynamic optimization problem. It expresses the optimal path of the state variable $S(t)$ as a two-sided distributed lag of the forcing function $\psi(t)$. Since $p(t)$ and $k(t)$ are elements of $\psi(t)$, current consumption capital stock depends on the entire time path of future and past prices and quality characteristic. The impact of the lead or lag forcing function on current consumption capital declines at an exponential rate. From equation (3.2), it is clear that $c(t)$ also depends on all past and future values of its own prices and quality characteristic.

The stable root λ_2 is associated with the speed of convergence of the system to its steady state. To see this, suppose that the forcing function is constant at $\overline{\psi}_1$, implying $\dot{k} = \dot{p} = 0$ such that $S(t)$ reaches its corresponding steady-state value $\overline{\psi}_1$. Now, let there be an unexpected permanent change in the price or quality characteristic that increases ψ to $\overline{\psi}_2$. Substituting $\psi(t) = \overline{\psi}_2$ into (3.11) results in the path by which $c(t)$ travel to its new steady-state $\overline{\psi}_2$

$$S(t) = e^{\lambda_2 t}(\overline{\psi}_1 - \overline{\psi}_2) + \overline{\psi}_2. \tag{3.12}$$

Larger (absolute) values of λ_2 imply higher speeds at which $c(t)$ converges to its long-run steady state.

The relationship between $c(t)$ and $S(t)$, as $S(t)$ moves toward its new steady state, is obtained by using equation (3.12) in equation (3.2):

$$c(t) = (\delta + \lambda_2)S(t) - \lambda_2\overline{\psi}_2. \tag{3.13}$$

The term $(\delta + \lambda_2)$, or equivalently $-[(\rho + 2\delta)A_2 + A_3]$, has to be greater than, equal to, or less than zero for $c(t)$ and $S(t)$ to be positively related, unrelated, or negatively related, respectively. Equation (3.13) indicates that the less negative λ_2 is, the higher the degree of adjacent complementarity for the consumption of c[2]. In other words, goods that are strongly adjacently complementary (habitual) adjust to their steady states relatively slowly[3].

[2] The concept of adjacent complementarity first appeared in Ryder and Heal (1973), where a consumption behavior is said to display adjacent complementarity if an increase in the current consumption of a commodity raises future consumption of the same commodity. This property of consumption dynamics is more commonly known as habit formation.

[3] Becker and Murphy (1988) argue that it is possible to have an extreme case where the degree of adjacent complementarity is so strong that even λ_2 is positive, making λ_2 also unstable. In this type of situation, consumption either decreases to zero or moves up to a higher equilibrium associated with a stable λ_2. Becker (1996) defines addiction as extreme habits. While this type of explosive consumption behavior is critical in analyzing addictive behaviors, it is likely to be less relevant in the present context where food consumption may be more plausibly characterized as being potentially habitual.

In terms of the parameters of the utility function (3.7), adjacent complementarity requires

$$(\rho + 2\delta)\left(\frac{\alpha_{ys}\alpha_{yc}}{\alpha_{yy}} - \alpha_{cs}\right) < \left(\alpha_{ss} - \frac{\alpha_{ys}^2}{\alpha_{yy}}\right). \tag{3.14}$$

People develop habits on, say, beef if increased past beef consumption increases present consumption. However, $u_{cs} = \alpha_{cs} > 0$ alone is not sufficient to induce habitual consumption for rational consumers. Beef offers not only nourishment but also palatability. While the level of nourishment largely depends on the quantity of beef consumed (c), the degree of palatability relies on the knowledge (S) about how to prepare beef. The rational consumer realizes that as the quantity of beef consumed increases, consumption capital will also rise for all future periods. In other words, a rational consumer takes into account increases in future utility resulting from an increase in current beef consumption. Beef consumption will be habitual only if, *ceteris paribus*, an increase in the marginal utility of beef induced by a small increment in the consumption capital (α_{cs}) sufficiently outweighs the corresponding decrease in the marginal utility of the capital stock (α_{ss}).

Time preference and the rate of consumption capital depreciation are also important determinants of the degree of habits. Inequality (3.14) indicates that the more the rational consumer discounts future utility or the faster consumption capital decays, the higher the degree of adjacent complementarity. By the first-order condition (3.6), a larger ρ and larger δ reduce future benefits and thus raise $u_c(t)$. Therefore, for beneficial habit formation, the level of consumption is lower if the time discount or capital depreciation rate is increased.

Intertemporal movement of consumption can be illustrated qualitatively by a phase diagram in the (c, S) space such as in figure 3.1 (e.g., Abel 1982). The $\dot{S} = 0$ curve is the loci where consumption capital is stationary, i.e. $c = \delta S$. The p^1p^1 curve represents the loci where $\dot{c} = 0$. It is clear from equation (3.8) that the p^1p^1 curve is positively sloped when consumption of c displays adjacent complementarity. The system has a saddle-point structure with a stable (b_1b_1) and an unstable (b_0b_0) manifold. The stable manifold leads to the long-run equilibrium point E_1, while the unstable one breaks away from that point. The rational consumer always stays on the stable manifold.

3.1.1 Impacts of Permanent Price and Quality Shocks on Consumption

The most salient feature of the time nonseparable consumption model is its distinction between short-run and long-run response to permanent price and quality changes. In the United States, the real price of poultry relative to beef has steadily declined from one-half that of beef to about one-third over the last forty years. Meanwhile, the dispersion of health information on cholesterol and saturated fat during the last two decades may have altered consumers' perception of the quality of poultry and red meat.

Assume the drop in relative poultry price and rise in perceived quality relative to red meat are permanent. The size of the long-run response to such changes depends on the degree of adjacent complementarity. Differentiate (3.10) with respect to the quality characteristic k at the steady state and make use of the steady-state condition $\bar{c} = \delta\overline{S}$. This operation yields the long-run response of consumption to a permanent shift in product quality, which is income-compensated to hold the marginal utility of wealth constant:

$$\frac{d\bar{c}}{dk} = \frac{(\rho + \delta)\alpha_{ck}}{A_1 A} < 0 \tag{3.15}$$

where $\bar{c}$ denotes the steady-state value of consumption, and "good" news is represented by a drop in the value of k. The term A_1A has to be positive so that $\lambda_2 < 0$ for the system to be stable. Recall from equation (3.13) that a higher degree of adjacent complementarity implies lower A_1A. Hence, food commodities that are more habit-forming respond more to permanent quality change in the long run. In the case of a permanent price change, the income-compensated long-run response of consumption is

$$\frac{d\bar{c}}{dp} = -\frac{\delta(r + \delta)\mu}{A_1 A} < 0. \tag{3.16}$$

Graphically, the time path of $c(t)$ is illustrated in figure 3.2. Suppose the individual is initially on point E_1, the long-run equilibrium associated with $\overline{S} = \overline{\psi}_1$. When the unanticipated news that higher cholesterol is linked to greater chance of heart attack is announced, consumption of poultry products jumps vertically to point F on the stable manifold associated with the new long-run equilibrium E_2 and moves toward the new steady state over time. The quantity in (3.15) measures the vertical distance between E_1 and E_2. For red meat, the cholesterol information may cause a permanent drop in product quality. So its demand works in the opposite direction—a vertical drop followed by gradual movement toward a lower steady-state equilibrium.

The hazard associated with cholesterol and saturated fats in red meat is long-term and chronic and requires sustained consumption. This information may not only affect quality but also consumption capital in the utility function. In fact, it is plausible that cholesterol information causes little or no change in k, but a much greater change in the parameter values of the utility function. Negative health news for red meat may have reduced the value of α_s, α_{ys} and possibly α_{ss}. Taking the differential of A_1A with respect to α_{ys} and α_{ss} yields

$$d(A_1A) = \left[(\rho + 2\delta)\frac{\alpha_{yc}}{\alpha_{yy}} + \frac{\alpha_{ys}}{\alpha_{yy}}\right]d\alpha_{ys} - d\alpha_{ss}. \tag{3.17}$$

If $\alpha_{yc} \geq 0$ and $\alpha_{ys} > 0$, the term in the brackets on the right-hand side of (3.17) is negative. Since a higher A_1A is associated with a lower degree of adjacent complementarity, negative health news could lower the degree of habit formation of red meat.

The long-run response of consumption to a change in wealth is derived by differentiating (3.9) with respect to μ at the steady state and using the condition $\overline{c} = \delta\overline{S}$

$$\frac{d\overline{c}}{d\mu} = -\frac{\delta}{A_1A}\left[(r + \delta)p - \frac{(\rho + \delta)\alpha_{yc} + \alpha_{ys}}{\alpha_{yy}}\right]. \tag{3.18}$$

Because greater wealth lowers the marginal utility of wealth μ, the food commodity c is a normal good if (3.18) is less than zero. If the cholesterol information has reduced α_{ys} but raised A_1A, equation (3.18) should be less negative for red meat consumption. The same argument applies to demand response to quality shock (3.15) and price change (3.16). Indeed, Sarmiento (2005) finds that demand for red meat has become less price responsive and less income elastic in the 1990s than in the 1950s and 1970s.

3.1.2 Time Path of Consumption Responses to Temporary Changes

As an example, suppose there is an unanticipated outbreak of bird influenza in Southeast Asia. The clean-up effort will take time $\hat{T}$ after which the quality of chicken products is expected to return to its normal level. If the consumer is at a steady state $S = \overline{\psi}_1$ at $t = 0$, the moment right before the incidence, and if the jump in k results in $\psi(\tau) = \overline{\psi}_2$ for $\tau \in (0, \hat{T}]$ in equation (3.11), and $\psi(\tau) = \overline{\psi}_1$ for $\tau \in (\hat{T}, \infty)$, the initial response of consumption capital to the postulated square wave pulse in $k(\tau)$ is obtained by taking the unstable positive root λ_1 forward and rearranging terms:

$$\dot{S}(0) = \lambda_2(\overline{\psi}_1 - \overline{\psi}_2)(1 - e^{-\lambda_1 \hat{T}}). \tag{3.19}$$

Because $\frac{\partial \psi(\tau)}{\partial k(\tau)} < 0$, the food safety incidence that raises k will cause an initial drop in consumption capital. The size of this drop is larger if the incidence is more permanent (higher $\hat{T}$). Equation (3.12) implies that the initial response of S to a permanent jump in k is $\lambda_2(\overline{\psi}_1 - \overline{\psi}_2)$. For the initial response to a temporary outbreak to be κ percent of the initial impact response to a permanent quality change, the incidence has to last for time $\hat{T} = -\frac{ln(1-\kappa)}{\lambda_1}$.

Note that equation (3.19) equals the size of the initial jump in consumption c when the individual is assumed to be at its long-run equilibrium before the outbreak. The initial response to a temporary shock is smaller than that due to the permanent change because a rational consumer knows that food consumption is habitual and that quality of the product will eventually return to its initial value.

The path of poultry consumption is also illustrated in figure 3.2. Before the news of a fluenza outbreak the consumer is at the steady state point E_1. The unexpected incidence induces the individual to reduce poultry consumption to J_1 right after the news is reported. The curve p^3p^3 represents the $\dot{c} = 0$ loci corresponding to the declined quality of poultry products as the incidence lasts. Since the consumer believes that the event will be temporary, point J_1 will not be on the stable manifold associated with the lower equilibrium E_3 but somewhere above it. Suppose duration of the outbreak is precisely foreseen. Then the size of the initial reduction will be calculated such that by the moment the incidence comes to a halt, the individual is already on J_2—the point on the stable manifold leading toward the initial steady state E_1. The time path of consumption in response to temporary quality deterioration is characterized by an initial drop in consumption followed by gradual return to its pre-outbreak level. The effect of a temporary price hike would be analogously analyzed.

3.2 Rationality versus Myopia

The prediction that the long-run response to a permanent shock is larger than the short-run response is not unique to the rational habit persistence model. Myopic habits similarly imply sluggish adjustment of consumption to permanent price or quality change. The more elastic long-run demand is also a possible outcome under myopic habit persistence. For example, in their test of myopic habit persistence, Heien and Durham (1991) find that consumption adjusts to permanent price change more in the long run than in the short run. In fact, there has been a long history to include lagged consumption in the system of demand analysis (e.g., Pollak and Wales 1969; Houthakker and Taylor 1970). The success of using lagged consumption in predicting current consumption has been accredited to habit effects, cost of adjustment or simply ignorance on the part of the researcher. In the meat demand literature, Pope, Green and Eales (1980) and Holt and Goodwin (1997) explicitly model myopic habit persistence and find it to be an important feature of consumer preferences for meat products. Some studies also recognize the importance of consumption dynamics by first-differencing the data (e.g., Eales and Unnevehr 1988), because the use of first-differenced data implicitly assigns a massive weight to lagged consumption.

In a myopic habits model the consumer does not take into account the impact of current consumption on future utility. Because of this ignorance, he makes systematic errors in his intertemporal optimization. The individual is constantly surprised in each period to learn that his past consumption of the good contributes to the buildup of the capital stock. The leads to period-by-period re-planning of intertemporal demand conditional on the current level of consumption capital stock. This ignorance implies that the consumption path of a myopic individual is qualitatively different from the demand path of a rational consumer when faced with a transitory price or quality shock.

To demonstrate this difference, it is helpful to describe the myopic consumer's problem in a discrete-time environment so that the period-by-period re-planning of consumption schedule is clearly defined. To preserve comparability with the rational habits model, assume that the myopic consumer maximizes the discrete-time version of the lifetime utility (3.3) subject to the lifetime budget constraint (3.4). This setup actually retains the minimal consumer rationality in allocating limited resources across time periods. So the only myopia on the part of the individual is about how the consumption capital is seen to evolve over time. Myopic agents believe that the capital stock is static while it evolves according to the discrete-time version of (3.2), $S_{t+1} = c_t + (1-\delta)S_t$. Suppose at the beginning of period 0, the consumer initially plans according to the first-order conditions: $\partial u_t/\partial \tilde{y}_t = \Big[(1+\rho)/(1+r)\Big]^t \mu_0$

and $\partial u_t/\partial \tilde{c}_t = \Big[(1+\rho)/(1+r)\Big]^t \mu_0 p_t \ \forall t \geq 0$. The tilde over y and c denotes that these are planned quantities that may or may not be the same as the realized consumption for $t > 0$. The first and second first-order conditions are, respectively, the discrete-time equivalents of (3.5) and (3.6), except that the second term on the right-hand side of (3.6) is absent from its myopic discrete-time counterpart. The subscript 0 on μ emphasizes that, in period 0, the myopic consumer expects the marginal utility of wealth to be fixed during the life cycle.

Use the discrete-time version of the quadratic utility function (3.7) to obtain the first-order conditions, assume $\rho = r$, and eliminate consumption of other goods y. Upon completing these steps, one is able to write the following equation for planned consumption

$$\tilde{c}_t = A_1^{-1}\left[\mu_0\left(\frac{\alpha_{yc}}{\alpha_{yy}} - p_t\right) - A_2 S_0 + \alpha_{ck} k_t + \left(\alpha_c - \frac{\alpha_{yc}\alpha_y}{\alpha_{yy}}\right)\right]. \tag{3.20}$$

If the myopic consumer is not initially in a steady state, the realized c_t will be different from the one planned for at the beginning of period 0 because the capital stock S_t will not be the same as S_0. Replacing S_0 in (3.20) with S_t gives the realized consumption at t that is income-compensated to hold the marginal utility of discounted wealth fixed at μ_0.

Unlike rational consumers' consumption, the demand by myopic consumers is largely backward-looking. The only forward-looking component is the marginal utility of discounted wealth that is implicitly a function of the money endowment, prices and quality characteristics in all periods. For c and S to be positively related, one needs $A_2 < 0$ since $A_1 > 0$ by the strict concavity of the utility function. From the definition of A_2, adjacent complementarity requires $\frac{\alpha_{ys}\alpha_{yc}}{\alpha_{yy}} < \alpha_{cs}$. If consumption of meat is considered to be beneficial even after negative information becomes available (i.e., $\alpha_{ys} > 0$) and if $\alpha_{yc} \geq 0$, this inequality will hold insofar as greater past consumption increases present marginal utility of consumption, i.e. $\alpha_{cs} > 0$.

While $A_2 < 0$ is a sufficient condition for people to develop myopic habits, it is necessary but not sufficient to induce habitual consumption for rational consumers who also evaluate future benefits derived from the current level of consumption. The magnitude of $-A_1^{-1}A_2$ in (3.20) relative to $\delta + \lambda_2$ in (3.13) is indeterminate, i.e. the degree of adjacent complementarity of a myopic person relative to that of a rational individual is unknown a priori. Nevertheless, it is possible to have the case where $-A_1^{-1}A_2 > 0$ but $\delta + \lambda_2 = 0$. When $\delta + \lambda_2$ is equal to zero, rational consumers behave as if preferences are intertemporally separable. Therefore, with truly rational behavior, the dynamic relationship between c and S is different from that of myopic consumers.

The approach herein is to model past quantities consumed as part of the consumption capital that induces better present appreciation of the good. But it has been a popular practice to let current utility level depend on the difference between present consumption and a weighted sum of past levels of consumption (e.g., Constantinides 1990; Dynan 2000). Under this formulation, the good must display adjacent complementarity regardless of the values of other parameters in the utility function (see Becker 1996, p. 122). Muellbauer (1988) shows that, conditional on this latter specification of preferences, myopic persons tend to experience habitual consumption less than rational consumers do. The real possibility that myopic consumption may be more habitual than rational consumption under current preference setup qualifies Muellbauer's result.

To see how myopic consumers respond differently from rational individuals to quality or price shocks consider the poultry contamination scenario applied to a myopic consumer. Suppose that in period 0 the individual is at a steady state. At the beginning of period 1, quality k increases immediately due to the contamination accident, and remains at this level until the crisis is salvaged $\hat{T}$ periods later. Unlike rational habit formation, whether this event is anticipated or not has no effect on the magnitude of the initial reaction by myopic consumers because there is no lead price or quality characteristic in the determination of consumption. In other words, expectations play no role in myopic persons' consumption decision except for their role in the calculation of μ. The initial quality deterioration causes c to drop instantly and consequently lowers S. This in turn further decreases the level of c until the end of period $\hat{T}$ when the accident comes to an end. Hence, in contrast with a rational consumer, a myopic consumer continuously reduces consumption until meat quality goes back to its original level.

In principle this distinction could be used to distinguish empirically rational habits from myopic habits. But the temporary nature of the incidence has to be known *a priori* for the rational and myopic individuals to react differently. It is not immediately clear how uncertainty about the future of an outbreak or price hike will play in the consumer's decision making. But if this uncertainty makes rational consumers respond as if shocks were permanent, behavioral differences between rational and myopic consumers facing a truly transitory event will be much less clear-cut. In this case both types of consumption paths are characterized by gradual adjustment over time, although there is no reason to expect that the size and speed of adjustment will be identical.

There are a few studies on meat demand in reaction to food safety concerns. Marsh, Schroeder, and Mintert (2004) find, using the Rotterdam model, that the USDA meat product recall events significantly affect U.S. consumer demand for meat. But the impacts of recalls on meat demand are small in magnitude. Using the AIDS model, Piggott and Marsh (2004) are able to estimate statistically significant but small effects of newspaper articles on food safety issues on consumer preferences for meat. The upshot from these two studies is that information on meat product quality has a very small influence on U.S. meat demand. But, this does not necessarily suggest that consumers do not care about food safety. If meat consumption is habitual and if consumers are rational, meat quality shocks that are believed to be transitory will have much smaller effects on quantity consumed than shocks thought to persist for much longer periods. This raises the question of how the credibility of government agencies and the food industry in dealing with food contamination situations interacts with consumer demand. Government health and agricultural agencies and the food industry may often be the only sources of information for the wider public. If their reputation for offering trustworthy food safety information is damaged, it may be extremely costly to restore consumer confidence.

3.3 Empirical Implications

Equation (3.2) specifies current capital stock as an exponentially weighted sum of all past levels of consumption. Following Becker, Grossman, and Murphy (1994), suppose that current consumption capital is equal to the quantity consumed in the last period, i.e. $S_t = c_{t-1}$. The current utility in period t becomes $u_t = u(y_t, c_t, c_{t-1})$. If the consumption decision is made at the beginning of each period, under uncertainty the representative consumer maximizes the following discrete-time intertemporal value function

$$V(w_t, c_{t-1}) = \max_{y_t, c_t} \Big\{ u_t + \beta E_t \big[V(w_{t+1}, c_t) \big] \Big\} \tag{3.21}$$

where w_t is the lifetime wealth discounted to the beginning of period t, the discount factor $\beta = (1+\rho)^{-1}$ and E_t is the expectation operator conditional upon the information available at t. The wealth equation of motion is: $w_{t+1} = (1+r_t)(w_t - y_t - c_t p_t)$, where r_t is the risk-free interest rate at t. The standard Euler equation for the expected utility maximizing consumer who revises plans according to newly available information is: $\gamma_t = \beta(1+r_t)E_t[\gamma_{t+1}]$, where γ_t is the marginal utility of wealth at time t. The first-order conditions are

$$\frac{\partial u_t}{\partial y_t} = \beta(1+r_t)E_t[\gamma_{t+1}] \tag{3.22}$$

$$\frac{\partial u_t}{\partial c_t} + \beta E_t\left[\frac{\partial u_{t+1}}{\partial c_t}\right] = p_t \beta(1+r_t)E_t[\gamma_{t+1}]. \tag{3.23}$$

Using (3.22) to eliminate $E_t[\gamma_{t+1}]$ from the right-hand side of (3.23) and replacing expectations at t with their corresponding realized values yields

$$\frac{\partial u_t}{\partial c_t} + \beta \frac{\partial u_{t+1}}{\partial c_t} - p_t \frac{\partial u_t}{\partial y_t} = \varepsilon_t \tag{3.24}$$

where ε_t is the part of $\frac{\partial u_{t+1}}{\partial c_t}$ that is unanticipated at the beginning of period t. If consumers form rational expectations, ε_t will be orthogonal to I_t—the information set at the beginning of period t, i.e. $E[\varepsilon_t \cdot z_{it}] = 0$ for all $z_{it} \in I_t$. In principle, any price, income and quality variable dated at t or earlier, and quantity at $t-1$ or earlier could be included in I_t. GMM can be used for consistent estimation of the parameters in (3.24), given some parametric form chosen for the utility function (e.g., quadratic or Translog).

Alternatively, one could follow the method of solution by Becker, Grossman, and Murphy (1994) by noting that when the marginal utility of wealth is constant over time, $\rho = r$, and the utility function (as before) is quadratic, equation (3.22) can be used to eliminate consumption of other goods, y_t, from the marginal utility of consumption in equation (3.23) to yield the estimating equation corresponding to equation (3.24):

$$c_t = \theta c_{t-1} + \beta\theta E_t[c_{t+1}] + \theta_1 E_t[p_t] + \theta_2 E_t[k_t] + e_t \tag{3.25}$$

where

$$\theta = \frac{-(\alpha_{cs}\alpha_{yy} - \alpha_{yc}\alpha_{ys})}{(\alpha_{cc}\alpha_{yy} - \alpha_{yc}^2) + \beta(\alpha_{ss}\alpha_{yy} - \alpha_{ys}^2)},$$
$$\theta_1 = \frac{\alpha_{yy}\gamma}{(\alpha_{cc}\alpha_{yy} - \alpha_{yc}^2) + \beta(\alpha_{ss}\alpha_{yy} - \alpha_{ys}^2)},$$
$$\theta_2 = \frac{-\alpha_{yy}\alpha_{ck}}{(\alpha_{cc}\alpha_{yy} - \alpha_{yc}^2) + \beta(\alpha_{ss}\alpha_{yy} - \alpha_{ys}^2)}.$$

Equation (3.25) and its parametric restrictions succinctly subsume the dynamic properties of rational habit formation discussed in the previous sections. While this specification is for a single equation, it can be easily generalized to the multiple goods case inherent in meat consumption (beef, pork, poultry, and fish) by regarding the variables c, p, and k as vectors of consumption, prices, and quality characteristics. Clearly, rational consumption behavior has a forward-looking dimension that is absent from myopic consumption behavior. Shocks to consumption in this period, whether through prices or perceived quality changes affect not only current consumption but also future consumption.

Using the method of Sargent (1987), the solution to the second-order difference equation (3.25), assuming the error term e_t is serially uncorrelated, can be characterized as follows:

$$(1 - \phi_1 B)c_t = \phi_1 \theta^{-1}(1 - \phi_2^{-1} B^{-1})^{-1}(\theta_1 E_t[p_t] + \theta_2 E_t[k_t]) + e_t \tag{3.26}$$

where ϕ_1, ϕ_2 are the characteristic roots of the second-order homogenous difference equation associated with (3.25) such that $\phi_1\phi_2 = \beta^{-1}$, $\phi_1 + \phi_2 = (\beta\theta)^{-1}$, with $0 < \phi_1 < 1 < \beta^{-1} < \phi_2$. The operator B is the backward shift operator. Consumption in the current period is a function of initial period consumption, all future expected prices, and all future expected quality changes. The effects on current consumption have two dimensions: (a) adjustment costs (as reflected in θ) from changing consumption, (b) expectations of current and future price and quality changes. It is necessary to specify both dimensions in order to determine whether quality changes, like food safety occurrences, are perceived to be transitory or permanent.

If instead one estimated the myopic, reduced form, relationship

$$c_t = \pi_1 c_{t-1} + \pi_2 p_t + \pi_3 k_t + v_t, \tag{3.27}$$

there would be no reason *a priori* to believe that it is possible to identify either transitory or permanent effects from quality change and/or price change. The reason one should not expect (3.27) to equal (3.26) is because the variable, or variables, used to explain quality may not have historically evolved over time in the same way consumers might view quality shocks to occur in the future. This can be seen most clearly by assuming that quality changes evolve over time according to the first-order autoregressive process $k_t = \varphi k_{t-1} + \nu_t$, where $0 \leq \varphi \leq 1$, and ν_t is a non-serially correlated disturbance term with zero mean and constant variance. If shocks to quality are permanent, $\varphi = 1$; if shocks are transitory, $\varphi = 0$. Using this specification for quality shocks in (3.26) yields the short-run and long-run effects of a change in quality as follows:

$$\left.\frac{\partial c_t}{\partial k_t}\right|_{c_{t-1}} = \frac{\phi_2\theta_2}{(\phi_2 - \varphi)} \tag{3.28}$$

$$\frac{\partial c_t}{\partial k_t} = \frac{\phi_2\theta_2}{(1-\phi_1)(\phi_2 - \varphi)}. \tag{3.29}$$

The corresponding short-run and long-run effects of the reduced-form model (3.27) are as follows:

$$\left.\frac{\partial c_t}{\partial k_t}\right|_{c_{t-1}} = \pi_3 \tag{3.30}$$

$$\frac{\partial c_t}{\partial k_t} = \frac{\pi_3}{(1-\pi_1)}. \tag{3.31}$$

Note carefully that in general the short-run result for the reduced-form, equation (3.30), does not tell us whether the result is a transitory shock (cf. equation (3.28)); and the long-run result, equation (3.31), does not tell us whether the result is a permanent shock (cf. equation (3.29)). The effect of quality changes, if measured by some index of food safety or cholesterol intake, only shows the impact of the historical effect of past health information on consumption. It most likely would be a mix of transitory and permanent shocks and therefore, the result estimated by (3.27) would be some hybrid of transitory changes and permanent changes. In order to determine what the impact of transitory or permanent effect would be, one would need to estimate the deeper structural parameters in equation (3.25) and then derive the results using equations (3.28) and (3.29) when $\varphi = 0$, for transitory effects, and $\varphi = 1$, for permanent effects.

To complicate the analysis further, the consumer-perceived quality characteristic k is not observable by econometricians. Newspaper article indices, as have been used in a number of studies, are one way to proxy the quality information available to the public. But the amount of public information may not match perfectly with consumers' perception of product quality. For instance, a one-month-only skyrocketing of the news reporting of BSE incidences may change the perceived beef quality for more than a month. How news information is processed by consumers and is transformed into quality perception is complex and difficult to quantify, even if the rational model of consumption behavior is used.

3.4 Does the Model Match Reality?

Traditionally, macroeconomists have been interested in the role of rational habit persistence in solving the "equity premium puzzle" of Mehra and Prescott (1985) or other relevant issues. Empirical tests of rational consumption habits deliver mixed results. As practitioners attempt to use micro level data for such tests, they usually find that most of the available data sets contain very limited information on household consumption. Nevertheless, food consumption is readily available and reported. Actually, all of the only five published empirical studies with micro data test the significance of rational habit persistence in food consumption. Naik and Moore (1996) use the Panel Study of Income Dynamics (PSID) data and find rational habits being an important feature of household food consumption. But Dynan (2000) fails to estimate statistically significant rational habit effects on the consumption of food in the PSID data. Meghir and Weber (1996) also do not find evidence of rational habits in food consumption at home in the Consumer Expenditure Survey (CEX). Guariglia and Rossi (2002) use data from the British Household Panel Survey for the period 1992-97. Their results indicate significant nonseparability in consumer preferences. But this consumption interdependence takes the form of durability as opposed to habit persistence. Carraso, Labeaga, and López-Salido (2005) improve on the econometric technique used in Meghir and Weber and provide evidence that time-nonseparability is an important characterization of food-at-home consumption for a panel of Spanish households[4].

For more disaggregated commodities, the rational addiction literature offers much evidence in favor of modeling some harmful addictive substances such as cigarettes in a rational habits framework (e.g., Chaloupka 1991; Becker, Grossman and Murphy 1994; Gruber and Köszegi 2001). Richards, Patterson, and Tegene (2004) employ a panel data of the U.S. households' snack consumption and find evidence of rational addiction to carbohydrates. However, Adda (2001) uses the 1996 "mad cow" crisis as a natural experiment to study the attitudes of a panel of French households toward health risks. He largely rules out intertemporal nonseparability in consumer preferences for beef. Instead, his results are interpreted in favor of a theory of endogenous discount rate such as Grossman (1972).

[4]Their parameter estimate on the food habit term is interpreted as evidence of habit formation. But it is really an indication of durability because the estimated parameter implies that food demand in the previous period reduces the marginal utility of current food consumption.

The model of rational consumer behavior developed in this chapter offers substantive insight into how food safety concerns as manifested in perceived quality changes can affect consumer response in the short-run and the long-run. It has been shown that the effects are both qualitatively and potentially quantitatively different than models based on myopic, static consumer behavior. Not only are the time paths of adjustment between rational and myopic models different, but consumers' expectations of how permanent or transitory they believe food safety and other quality changes to be can influence the level of consumption. Being able to identify and quantify expectations separate from adjustment costs associated with habit persistence and other adjustment costs is absolutely essential to quantifying how permanent or transitory changes in food safety events and/or cholesterol concerns will be on consumption in the short-run and long-run.

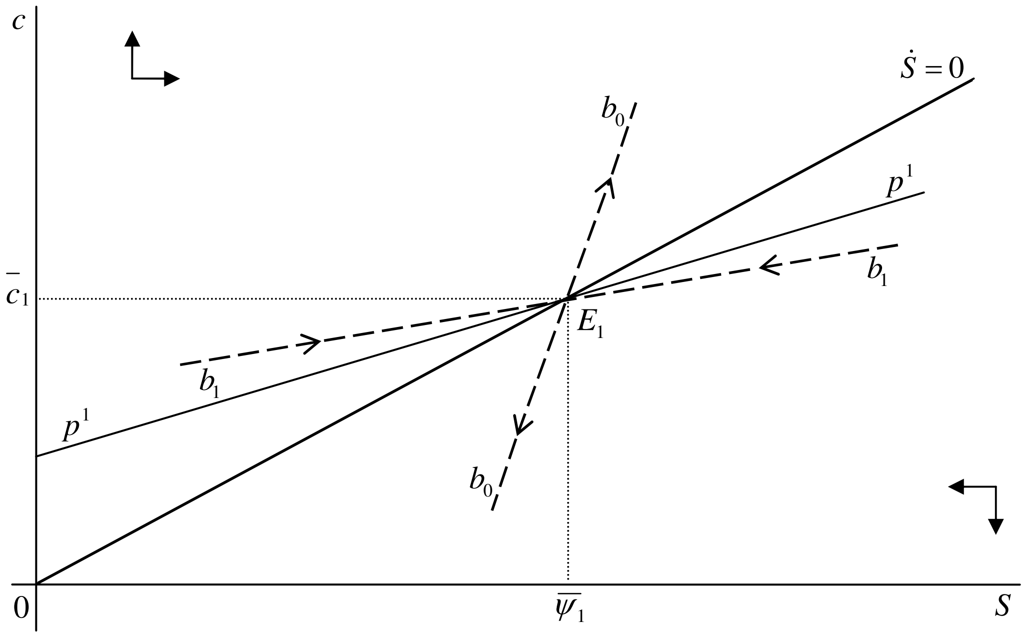

Figure 3.1: Local structure of a steady state

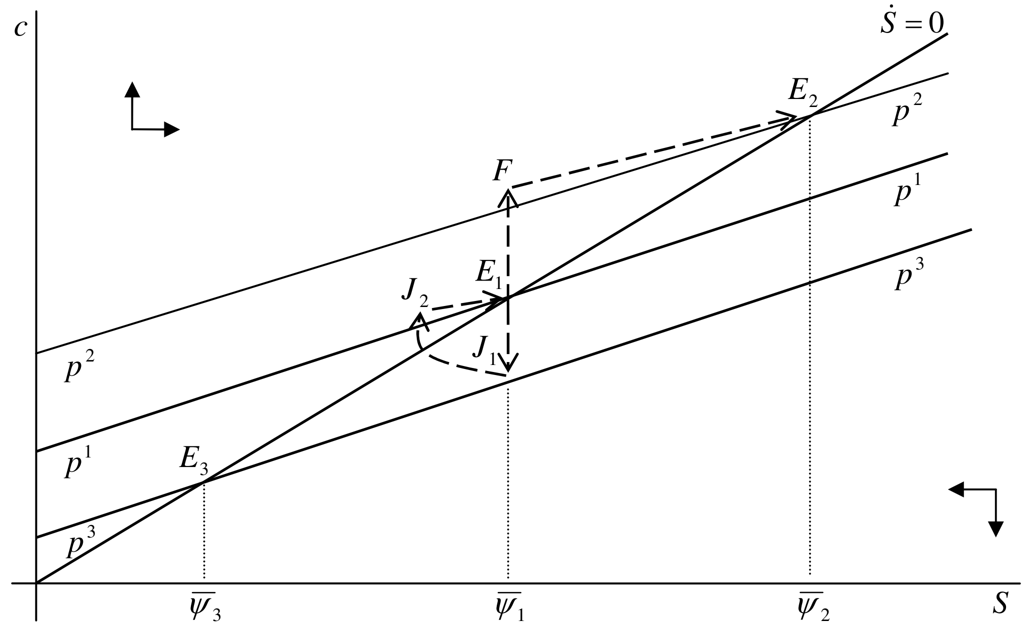

Figure 3.2: Consumption responses to price and quality shocks

Chapter 4

Econometric Model

The contribution of this section is two-fold. First, newspaper articles are differentiated by their contents, an improvement over existing meat safety indices in the literature. Second, a rational habit persistence model is estimated with U.S. meat data. The estimated structural parameters can then be used to simulate demand responses to price and food safety shocks under different expectations schemes.

The plan of this section is as follows. In section 4.1, the theoretical model is generalized to the case that allows several goods to be habit-forming. Section 4.2 discusses data used in the empirical analysis with special attention to the food safety data. In section 4.3 the econometric technique used to obtain estimates of preference parameters is outlined, and then empirical results are presented and discussed. Finally, section 4.4 provides concluding remarks of this chapter.

4.1 Intertemporally Nonseparable Preferences

The simplest way to introduce time-nonseparable preferences is to let current consumption depend on consumption in the previous period. It is the most common approach to consumption dynamics in the empirical literature on habit persistence (e.g., Becker, Grossman and Murphy, 1994; Dynan, 2000). The representative household maximizes in period t the present value of a lifetime utility

$$U_t = \sum_{\tau=t}^{\infty} \beta^{\tau-t} u_t \text{ with } u_t = u(X_\tau, X_{\tau-1}, y_\tau, Z_\tau), \tag{4.1}$$

subject to

$$\sum_{\tau=t}^{\infty} (1+r_\tau)^{t-\tau}(Y_\tau - y_\tau - P'_\tau X_\tau) = w_t \tag{4.2}$$

where X_τ is a vector of N consumption goods (e.g., meats) in period τ, β is the discount factor, r_τ is the riskless interest rate in period τ, y_τ represents expenditures on all other goods at τ, P_τ is the price vector corresponding to X_τ, Y_τ is the household income at τ, and w_t is the present value of lifetime assets at t. The vector Z_τ contains variables that measure the quality aspects of the goods at τ. The idea is to let $X_{\tau-1}$ be the vector of habit stock variables to proxy past consumption experience. From the theoretical model discussed earlier, a necessary condition for good i to be habit-forming is: $\partial u_\tau/\partial x_{i\tau}\partial x_{i\tau-1} > 0$. Assuming Y is exogenous, the decision variables for the household are $\{X_\tau\}_{\tau=t}^{\infty}$ and $\{y_\tau\}_{\tau=t}^{\infty}$.

The marginal utility of good i implied by the assumed utility structure is

$$MU_{it} = \frac{\partial u_t}{\partial x_{it}} + \beta\left[\frac{\partial u_{t+1}}{\partial x_{it}}\right] \text{ for } i = 1, ..., N \tag{4.3}$$

Therefore, with intertemporally nonseparable preferences, the marginal utility of x_i equals the marginal utility of current consumption plus its discounted marginal effect on the utility in the next period. It distinguishes a rational household from a myopic one because the rational household is aware of the impact of its current consumption on future utility and makes explicit use of this information when optimizing intertemporally, while the myopic household ignores such information.

The Lagrangian of the household's optimization at time t can be written as

$$L = U_t + \lambda_t\big[w_t - \sum_{\tau=t}^{\infty}(1+r_\tau)^{t-\tau}(Y_\tau - y_\tau - P_\tau' X_\tau)\big]. \tag{4.4}$$

The Lagrange multiplier, λ_t, can be interpreted as the marginal utility of wealth. Assuming weak separability between X and y, the sequence $\{X_\tau\}_{\tau=t}^{\infty}$ must satisfy the following system of first-order necessary conditions (FOCs) derived from differentiating (4.4) with respect to X_t, X_{t+1},X_{t+2},...

$$\frac{MU_{i\tau}}{p_{i\tau}}\big[\beta(1+r_\tau)\big]^{\tau-t} = \lambda_t, \quad i = 1, ..., N \text{ and } \tau = t, ..., \infty. \tag{4.5}$$

where $p_{i\tau}$ is the price of good i at time τ. The econometricians do not observe λ_t, therefore it must be substituted out. There are two ways to achieve this. The first involves using the ith FOC for $\tau = t+1$ to eliminate λ_t in the ith FOC for $\tau = t$, which yields a system of N Euler equations

$$\frac{MU_{it}}{p_{it}} = \frac{MU_{it+1}}{p_{it+1}}\beta(1+r_\tau), \quad i = 1, ..., N. \tag{4.6}$$

Alternatively, one can use the jth FOC for $\tau = t$ to substitute out λ_t in the ith FOC for the same period $(i \neq j)$. Performing this procedure gives a system of $N-1$ equations

$$\frac{MU_{it}}{p_{it}} = \frac{MU_{jt}}{p_{jt}}, \quad i \neq j. \tag{4.7}$$

Meghir and Weber (1996) call the later system of equations marginal rate of substitution (between goods i and j) equations (MRSs). In (4.6) X_{t-1}, X_t, X_{t+1}, and X_{t+2} are present, while equations (4.7) involve only X_{t-1}, X_t, and X_{t+1}. The dynamic structure of equations (4.6) is richer, but estimating equations (4.7) alone is sufficient in terms of identifying the underlying parameters governing the consumption dynamics, provided that the true household preferences are not time-separable. If preferences are indeed separable over time, consumption dynamics in this particular application will be much less interesting. Thus, the econometric estimation will be based on equations (4.7).

Following Piggott and Marsh (2004), let Z contain indices of public information on the product safety of X, with the index z_i linked to the quality of good i. The index could be a measure of the extensiveness of product recalls or intensity of media reports of food contaminations. A higher value of z_i indicates increased adverse publicity on the quality of good i implying $\partial u/\partial x_i \partial z_i < 0$. If preferences are time-separable, z_i would have its immediate and full effect on x_i by reducing the level of its consumption. However, if consumption of x_i is habitual, the effect of an increase in z_i on x_i has several dimensions. Consumption responses to a change in product quality are different in the short run than in the long run. For a transitory increase in z_i, holding the increment in z_i constant, the size of the immediate decline in consumption of x_i is an increasing function of the expected duration of the adverse publicity. In the long run, x_i returns to its equilibrium level prior to the negative quality shock. On the other hand, a quality deterioration that is expected to be permanent would gradually reduce x_i to a new long-run equilibrium at a lower level. The sluggish adjustment in x_i causes the long-run demand response to be larger than the short-run response, and the difference between them increases with the degree of habit persistence. The cross-effects of food safety events on other goods depend on the nature of these goods (substitutes or complements) and would be interesting to investigate in the empirical analysis.

4.2 Food Safety Indices and Meat Data

The economic studies of food safety often use mass-media indices to approximate the true consumer's perception of food quality. This approach is similar to the methodology followed by the literature studying the adverse effects of cholesterol and saturated on demand for red meats, where the common practice is to single out articles from either medical journals or the popular press relating cholesterol to cardiovascular diseases. These articles are then aggregated and the resulting series is incorporated into a demand equation or system to capture shifts in consumer preferences. However, there is little guidance on how article contents should be differentiated, leaving substantial scope for researchers to proceed. This appears less of a problem for health concerns than for food safety concerns, because medical evidence against high cholesterol and dietary fats is overwhelming. Regardless of how the public reacts to the evidence, there is less randomness and subjectiveness in categorizing the content of an article as being negative vs. being positive about a particular food; of course, researchers may disagree on the degree of seriousness of the content.

In contrast, the content of media coverage of food safety events is much more diverse in the sense that a nonnegligible portion of the news cannot be unambiguously labelled as positive or negative. For example, in the midst of the BSE crisis in Britain, the news that EU banned UK exports of beef products to other European countries might not provide an assurance to consumers in those countries; even though the intent of the ban was to restore consumer confidence of beef safety. A substantive body of the literature circumvents this empirical complications by assuming that all news is "bad".

Several studies have attempted to explore the potential differential effects of "good" and "bad" news. In their study of the effects of negative TV press on fresh meat demand in Belgium, Verbeke and Ward (2001) recognized the difficulty of categorizing some of the media reports of food safety issues. They concluded that it is impractical to econometrically separate out the negative and positive effects of different media coverage. As a compromise, they used the number of "negative" minus "positive" TV reports as the food safety index. Similarly, the beef media index in Flake and Patterson (1999) is the number of "negative" net of "positive" Associate Press news reports on beef safety. Smith, van Ravenswaay and Thompson (1988) examined the effect of media coverage of the 1982 heptachlor contamination of fresh fluid milk in Oahu, Hawaii, on milk sales. In this study, newspaper articles were not only classified as negative or positive, but also weighted based on their likelihood of affecting demand negatively or positively. Their statistical results indicate that negative media has a much larger effect on sales than positive media.

The food safety indices in this dissertation are based on full-text articles and abstracts from four U.S. newspapers—*Christian Science Monitor*, *New York Times*, *Wall Street Journal*, and *Washington Post*. These newspapers are selected because they are available for searching during the entire sample period (1980(3) to 2005(4)). The search engine used was LexisNexis Academic. Keywords searched were specified in Piggott and Marsh, which were *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 locate articles related to beef, pork, and poultry food safety, respectively. Every article was read to determine its pertinence to food safety with irrelevant ones dropped from the information base. Articles regarded as being positive about a meat species were separated from negative articles. Depending on my subjective judgment of the likelihood that the article would adversely affect consumer demand for a meat species, negative articles were assigned a score of 0, 0.25, 0.5 or 0.75, with 0 being the least likely and 0.75 the most likely. Similarly, all positive articles were also scored. For each meat type, quarterly negative-news indices (NIDX) were constructed by adding up scores on negative articles, and positive-news indices (PIDX) by adding up scores on positive articles, related to this meat. Figure 4.1 plots these data series for the 1980(3)-2005(4) period. Expanding the pool of newspapers beyond the current four papers is not feasible because of the sheer volume of information that has to be processed. Another reason for using only these four newspapers is that it minimizes double-counting, and the number of food safety articles is far less trending than if all newspapers in the LexisNexis database are used[1].

The scoring rules adopted in the construction of media indices are as follows. For a newspaper article reporting a food safety outbreak, it would be scored higher than it would

[1]The number of newspapers archived in the LexisNexis database has been increasing over time, from 4 in 1981 to 47 in 2005.

otherwise be if the incidence occurs in the United States, or if human death is involved. A few examples should make the description concrete. The US media followed the pork dioxin contamination incidence in Belgium, in May 1999. Most of the news articles related to this event were classified as negative and scored 0.5 because there was no indication that the contaminated products had entered the US market. If similar outbreaks had occurred in the United States, related news reports would have been unequivocally scored 0.75. An article that reports a product recall due to food safety concerns was categorized as negative and scored 0.75, because previous studies suggest that food bans or recalls negatively impact demand for the implicated product (e.g., Swartz and Strand, 1981; Marsh, Schroeder, and Mintert, 2004). The scores assigned to policy articles are more variable and may be classified as negative or positive depending on the content and phrasing of the arguments. When the overall message conveyed by an article could not be unambiguously labelled as negative or positive, the article was treated as negative and assigned a score lower than news reports covering the same event but were clearly negative. News pieces on outbreaks of bird flu overseas before 2005 typically received scores no higher than 0.5 and were categorized as negative. Reports of bird flu inside the United States prior to 2005 were scored 0.25 because those were never the human-threatening strain (H5N1). Scores on similar news since 2005 (inclusive) could be as high as 0.75 due to the alert for potential worldwide pandemic that often appeared in the articles. A typical article on BSE would score 0.75 if the case was in North America, and 0.5 if only Europe was involved; and it could be classified as negative in beef index but positive in pork and poultry indices if the latter two meat species were explicitly mentioned in the text. News on foot-and-mouth disease was excluded because the disease is not considered a food safety issue by the USDA. Articles on animal growth hormone were not incorporated into the media indices, but reports on antibiotics in animal drugs were included.

Because the data span some 25 years, substantial efforts were exerted to make the coding practice as consistent as possible from the beginning to the end of the sample period. Over the entire sample, beef on average suffered a higher degree of negativity than pork or poultry on average. The NIDX takes a mean of 11.24 for beef, 4.03 for pork, and 6.67 for poultry. But this is not the case during the 1980-1992 subsample period. In fact, from 1980 to 1992, poultry safety attracted more media attention than beef and pork. The NIDX values for beef, pork and poultry in the 1980-1992 period are 2.78, 2.38 and 3.52, respectively. In the first quarter of 1993 an outbreak of E. coli bacteria poisoning traced to hamburgers at a fast-food chain in the Northwest received intense media coverage and caused beef NIDX to peak at 45.75. This incident ignited heavy criticism over the soundness of the nation's meat and poultry inspection system that brought the pork NIDX to its maximum at 20.75 and poultry NIDX to one of its highest at 23. This event became a vital catalyst to USDA's implementation of the Pathogen Reduction/Hazard Analysis and Critical Control Point (PR/HACCP) system for meat and poultry inspection in the late 1990s. The 1997(3) peak in beef NIDX was due to a massive recall of 25 million pounds of ground beef in the Midwestern United States. Media reports of beef safety surged drastically in 2003(4) and 2004(1) when the first case of BSE in the U.S. was discovered in Washington state.

The poultry NIDX reached one of its highest levels at 24.25 when fear of listeria contamination prompted gigantic recall of chicken and turkey products in the fourth quarter of 2002. A peak score of 34.5 coincides with the outbreak of avian flu in Asia in 2004(1). The highest poultry NIDX (37.75) occurred in the last quarter of 2005 following warnings of potential international bird influenza pandemic.

Unlike beef and poultry, pork received less media attention partly because it was less often implicated in large-scale outbreaks than beef and poultry. However, listeria and other bacteria contaminations have been traced to products with pork as the ingredient from time to time.

In contrast to the number of negative news reports that constantly made the headlines, articles that can be classified as being positive occur rather sporadically. In addition, some of the non-zero beef, pork and poultry PIDXs during the late 1990s were a result of favorable coverage following the implementation of the PR/HACCP system.

Quarterly meat data during the 1980(3)-2005(4) period are used in the empirical analysis. The disappearance data published in the United States Department of Agriculture (USDA) Economic Research Service (ERS) *Red Meats Yearbook* and *Poultry Yearbook* are taken to be the basic consumption quantity data for the period 1982-2003. Per capita consumption data for 2004 and 2005 are from the February 15, and June 15, 2006 issues of ERS *Livestock, Dairy, and Poultry outlook*, respectively. The beef price is the average retail price of choice beef. The pork price is the average retail price of pork. Following the procedure specified in Piggott and Marsh, the poultry price is a weighted average of chicken and turkey retail prices. Quantity data are converted to retail weight using the conversion factors available online from the ERS *Food Consumption Data System*. Population data used to convert aggregate quantities to per capita values are mid-quarter total U.S. population from the Department of Commerce, Bureau of Economic Analysis(BEA).

Figure 4.2 illustrates the real quarterly per capita expenditures on beef, pork and poultry. Seasonality is apparent in all three series. Beef expenditure peaks in the second and third quarter corresponding with the summer grilling season. For poultry, expenditure is the highest in the fourth quarter partly because of the high demand around Thanksgiving. Pork expenditure also reaches its highest level in the fourth quarter, partly because demand for hams is strong during the winter holiday season.

Apart from seasonality, meat expenditures appear to trend differently before and after 1998. This is most evident for beef but less obvious for poultry and pork. In 1998, beef expenditure reversed its nearly two-decade downward trend and continued to rise until the end of the sample. One probable explanation is that the high protein-low carbohydrate diet fad may have shifted consumer preferences toward meat products.

4.3 Empirical Implementation

4.3.1 Direct Translog Preferences

For this study, a flexible direct translog utility function augmented to include habits is used to describe the household preferences over consumption goods 1 (beef), 2 (pork) and 3 (poultry)

$$u_t = \sum_{i=1}^{3} a_i \ln x_{it} + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} b_{ij} \ln x_{it} \ln x_{jt} + \sum_{i=1}^{3} b_i \ln x_{it} \ln x_{it-1} \tag{4.8}$$

where a_i, b_{ij} and b_i are parameters to be estimated. The last term on the right-hand-side of the above equation is responsible for capturing any potential intertemporal nonseparability in the preferences. Christensen and Manser (1977) estimated U.S. consumer preferences for meats with a static direct translog utility function. Meghir and Weber (1996) and Carrasco, Labeaga and López-Salido (2005) used the same preferences structure as (4.8) to test for intertemporal nonseparable preferences with U.S. and Spanish micro data, respectively. Following the discussion in section 2, habit persistence implies $b_i > 0$ while durability or inventory adjustment[2] implies $b_i < 0$. If $b_i = 0\ \forall i$ time separable preferences follow. Habit persistence may arise because it is costly for the household to adjust consumption in response to changes in the economic environment. These costs may involve the cost of learning and perfecting new recipes and any psychological disutility from switching to new cuisine. Conversely, inventory adjustment may be a result of hoarding on the part of the household to take advantage of supermarket specials or an appetite for food diversities. Finally, additive separability for any two goods (i, j) is implied if $b_{ij} = 0$.

To incorporate the effects of food safety information on the household preferences, the parameter a_i is further specified to be a linear function of the household's perception of meat safety. That is,

$$a_i = a_{i0} + a_{i1}bs_t + a_{i2}ps_t + a_{i3}cs_t \tag{4.9}$$

where bs_t, ps_t and cs_t are, respectively, consumer perceptions of the safety of beef, pork and poultry. Because there is no way to determine *a priori* the most appropriate way of representing these perception variables with the news indices, performance of a few alternative representations will be examined in more detail in sub-section (4.3.3).

4.3.2 Estimation Strategy

When estimating a dynamic rational expectations model, GMM is the natural choice. In section (4.1), the household's optimization with many-goods is performed under perfect foresight. Under uncertainty, the lifetime utility maximization in period t is executed utilizing information available at t. Using the direct utility function (4.8), the marginal utility of consumption (4.3) under uncertainty becomes

$$MU_{it} = \frac{a_{it}}{x_{it}} + \sum_{j=1}^{3} b_{ij}\frac{\ln x_{jt}}{x_{it}} + b_i\frac{\ln x_{it-1}}{x_{it}} + b_i\beta E_t\left[\frac{\ln x_{it+1}}{x_{it}}\right]. \tag{4.10}$$

Here, E_t is the expectation operator conditional upon information available in period t. Next, use (4.10) to derive a system of two estimable equations corresponding to (4.7)

$$\begin{aligned} e_{it} = &\left[\frac{a_{1t}}{m_{1t}} + \sum_{j=1}^{3} b_{1j}\frac{\ln x_{jt}}{m_{1t}} + b_1\frac{\ln x_{1t-1}}{m_{1t}} + b_1\beta\frac{\ln x_{1t+1}}{m_{1t}}\right] \\ &- \left[\frac{a_{it}}{m_{it}} + \sum_{j=1}^{3} b_{ij}\frac{\ln x_{jt}}{m_{it}} + b_i\frac{\ln x_{it-1}}{m_{it}} + b_i\beta\frac{\ln x_{it+1}}{m_{it}}\right] \end{aligned} \tag{4.11}$$

[2] In this paper, the terms inventory adjustment and durability are used interchangeably.

where $i = 2$ (pork), 3 (poultry), m_{jt} is the expenditure on the jth meat at t. Note that in (4.11) the expectations are replaced by their realizations less innovations. The innovations are expectation errors made by the household in the intertemporal optimization process, and are incorporated in the error term e_{it}. The parameters of good 1 (beef) appear in both equations with a_{10} normalized to 1. It is common in the literature on models of dynamic opitimizing behavior to fix the value of β *a priori* because doing this makes the Euler equation linear in both the parameters and (transformed) variables[3] .

There is another justification for preserving the linearity of the regression. Since seasonally unadjusted data are used for estimation, seasonality has to be accounted for. If the transformed variables in (4.11) are better characterized as nonstationary seasonal processes, seasonal differencing is more appropriate. At quarterly frequencies, this amounts to fourth-differencing the transformed variables in (4.11) that is feasible due to the linearity of the regression.

Under uncertainty and assuming rational expectations, the error term $\Delta_4 e_{it} = e_{it} - e_{it-4}$ is orthogonal to variables in the information set (Ω_t) as of period t. That is, when evaluated at the true parameter values,

$$E\big[(\Delta_4 e_{2t}\ \Delta_4 e_{3t})' | \Omega_t\big] = 0. \tag{4.12}$$

The instrumental variables in the information set include choice variables dated $t-1$ and earlier, demand shifters and prices dated t and earlier. Furthermore, e_{it} is serially uncorrelated since it is in the information set at period $t+1$. The population moment conditions used by the GMM estimation of parameters can be summarized as

$$E\big[(\Delta_4 e_{2t} \Delta_4 z_{2t}'\ \Delta_4 e_{3t} \Delta_4 z_{3t}')'\big] = 0 \tag{4.13}$$

where $\Delta_4 z_{2t}$ and $\Delta_4 z_{3t}$ are the corresponding $R \times 1$ vectors of fourth-differenced instruments. The sample counterparts of (4.13) can be formed as

$$f_T = \frac{1}{T} \sum_{t=1}^{T} (\Delta_4 e_{2t} \Delta_4 z_{2t}'\ \Delta_4 e_{3t} \Delta_4 z_{3t}')' \tag{4.14}$$

[3]Examples include Meghir and Weber (1996), Carrasco, Labeaga and López-Salido (2005) for habit formation models; Fuhrer, Moore and Schuh (1995) and their references for the linear quadratic model for inventory holdings.

where T is the sample size. The GMM estimator makes the $2R$-dimensional function f_T close to zero in the sense of minimizing the following quadratic form:

$$Q_T = f_T' W_T f_T. \tag{4.15}$$

Here W_T is a positive semi-definite weighting matrix that can be a function of sample information. For example, it can be specified to be the inverse of the variance-covariance matrix of the sample moment condition f_T.

Note that every variable in (4.11) is divided by an expenditure at t. Therefore, all of the transformed variables are endogenous and have to be instrumented. To imitate the variables in (4.11) as closely as possible, the list of instruments includes food safety variables dated t and $t-1$ and quantities demanded at $t-2$, all of which are first divided by expenditures dated $t-2$ and then fourth-differenced. The beef/pork and beef/poultry equations are estimated jointly imposing equality of the beef parameters across equations and $b_{ij} = b_{ji}$. In the instrument set, the prices and demand quantities are lagged for two periods to avoid potential inconsistency from GMM estimation if their values at $t-1$ are somehow correlated with GMM residuals at t.

4.3.3 Results and Discussion

There are many ways in which the newspaper indices discussed earlier could be used to represent consumers' perception of meat safety. Because there is no strong *a priori* reason for preferring one to the other, two alternative combinations of indices, denoted by model 1 and 2, are used to proxy the bs, ps, and cs variables in (4.9).

In model 1, bs_t (or ps_t or cs_t) is the square root of the beef (or pork or poultry) NIDX at t net of the square root of the beef (or pork or poultry) PIDX at t. Following Flake and Patterson, the media indices were introduced in square root form to account for the diminishing marginal effect of information. Model 1 imposes the restriction that positive media has a quantitative identical but opposite effect on consumption than negative media. The construction of model 2 is similar to model 1 except that the PIDXs were not used. It follows from the hypothesis that "good" news has no effect on consumer demand. The time spent on constructing the information-weighted food safety indices is substantially more than aggregating the newspaper articles linearly by quarter. To investigate whether this exercise yields significantly different economic implications for consumer behavior, in model 3, instead of using indexes based on the four U.S. newspapers, the safety indexes in Piggott and Marsh extended to cover the 1980(3)-2005(4) period are taken to approximate the "true" consumer perception of food safety. These indexes do not distinguish potentially positive news from negative news, and articles are weighted equally. However, the Piggott and Marsh indexes are based on up to fifty domestic and international newspapers which may contain more food safety information useful to U.S. consumers than the four U.S. newspapers. Similar to model 1 and 2, the square roots of these indexes are used for estimation.

An empirical issue in conducting GMM estimation is to choose the lag order of the error term when estimating the variance-covariance matrix of the sample moment conditions (4.14). According to the rational expectation hypothesis, the forecast error e_{it} is serially uncorrelated. Thus, strict adherence to economic theory suggests that the lag order should be zero. However, depending on model specification and data, this theoretical restriction may not be upheld in empirical applications. In a study of intertemporal substitution in import demand, Nishiyama (2005) specifies a lag order of one for covariance matrix of the error term, although economic theory implies a lag order of zero assuming a representative household and rational expectations. An alternative is to let data decide the appropriate lag length using, for instance, the heteroscedasticity and autocorrelation consistent (HAC) covariance estimator of Newey and West (1987). This analysis follows the latter solution method and investigates the correlation structure of the estimated error term. The number of autocovariances (i.e., the lag order or bandwith) included in the HAC covariance estimator is determined using Newey and West's (1994) nonparametric method.

The coefficient estimates and standard errors reported in table 4.1, 4.2, and 4.3 are the optimal two-step GMM estimates obtained by exploiting the Newey and West covariance estimator in the second step. Hansen's J is a test for overidentifying restrictions. It is asymptotically $\chi^2(q-k)$ distributed, where q is the number of moment conditions and k is the number of model parameters. It is a test of the extent to which the error term $\Delta_4 e_{it}$ is orthogonal to the instruments. There are 24 instruments in each z_{it} $(i = 2, 3)$ resulting in a total of 48 moment conditions. The test statistics are 13.97 for model 1, 14.85 for model 2, and 9.84 for model 3, which should be compared to a χ^2 with 13 degrees of freedom. The 10% critical value is 19.81. Thus, none of the models is statistically rejected. Using Newey and West's (1994) procedure for bandwidth selection, the estimated bandwidth values of 0, 2, and 3 are used to form the HAC covariance estimator in the second step for model 1, 2, and 3, respectively. The three models are also estimated with the bandwidth restricted to equal 1. Although not reported here, this leads to results very similar to those in table 4.1, 4.2, and 4.3.

The likelihood ratio test statistics of the null that food safety information at $t-1$ does not directly influence consumption decision at t are 22.3 for model 1, 32.6 for model 2, and 20.4 for model 3. These statistics are $\chi^2(9)$ distributed under the null, which is rejected at 5% level (critical value = 16.92) for all three models. It is not feasible to test further lags in food safety information, because this will result in too many moment conditions relative to the sample size.

The *a priori* expectation is that the own-effects of food safety information are negative, while the cross-effects are less obvious. Inspecting the estimated parameters on food safety information indicates that only three out of eighteen parameters are precisely estimated in model 1. These results suggest that the own- and cross-effects of beef safety information at t are negative. One should refrain from drawing inferences on the own- and cross-effects of pork and poultry safety information, as the related coefficient estimates are not statistically different from zero.

The estimated food safety coefficients in model 2 follow the similar pattern. In terms of the effects of contemporary food safety information, only the own- and cross-effects of beef safety are negative and statistically significant. The effects of pork and poultry safety information are not precisely estimated. Interestingly, according to the results in model 2, pork safety information at $t-1$ has statistically significant direct negative effects on demands for beef, pork, and poultry at t. Because relatively few articles contained in the pork media index were exclusively about pork safety, it is not clear from these results whether concerns over pork safety spill over into the demand for beef and poultry. The estimated parameters for model 3 are comparable to model 1 and 2, except that the estimated coefficients on cross-products of contemporary poultry safety information and beef, pork, and poultry consumption are positive and statistically significant at the 5% level. This result is counter-intuitive since at least one would expect a negative effect of poultry safety information on poultry consumption. On the other hand, note that in table 4.3 the coefficients on cross-products of lagged poultry safety information and demand quantities are negative, and approximately half the size (in absolute value) of their counterparts on contemporary poultry safety information. To determine whether the estimated model parameters imply sensible consumption responses to price and food safety changes, it is important to compute demand elasticities, which is the subject of chapter 5.

If adverse health information reduces the degree of habit persistence of red meat, then the low carb-high protein movement popular during the past a few years may have increased the degree of habits for red meat. To exploit this hypothesis, a dummy variable, D98, that is equal to zero prior to 1998 and one thereafter is included in the model. It interacts with the a_{i0}'s in (4.9) and with the b_i's in (4.8). The former interaction is intended to capture changes in the intercepts, while the latter is designed to approximate any potential shift in the degree of habit persistence. At quarterly frequencies, model 1, 2, and 3 all point to an increase in the degree of beef habit around 1998. However, no statistically significant changes in pork and poultry habits are found. If the low carb-high protein fad was the sole rationale for the estimated increase in beef habit, we would expect that the degree of habit persistence for pork should also increase. For instance, the Atkins Diet recommends consumption of bacon. It is conjectured that improvement in beef quality partly due to the USDA certification program in the 1990s may have contributed to the increase in the degree of beef habit.

An important caveat is that $b_i > 0$ alone is not enough to induce habit persistence. Recall the disscussion in section (3.1), for intertemporal demand to display adjacent complementarity (habit formation), the magnitude of $\partial u_t/\partial x_{it}x_{it-1}$ has to be sufficiently greater than the absolute value of $\partial^2 u_t/\partial x_{it-1}^2$. It is apparent from inspecting the inequality (3.14) that a sufficient condition for habit persistence also depends upon the cross marginal utilities between the good of interest and other goods. In Becker, Grossman, and Murphy, whether the demand for a good is adjacently complementary is determined by the sign of the coefficients on the lead and lagged consumption due to their use of a linear-quadratic utility function. However, under current preference specification, how large b_1 has to be is an empirical question and the answer to it has to be postponed until chapter 5 where demand elasticities are numerically computed.

Fourth-differencing appears to be sufficient to render the $\Delta_4 e_{it}$'s white noise for most of the models. Graphical inspection of the error terms in model 1 and 2 shows that the assumption of homoscedastic innovation may be difficult to maintain. Table (4.4) reports the standard Lagrange Multiplier tests for the absence of ARCH effects. Under the null the test statistic $ARCH(\kappa)$ is $\chi^2(\kappa)$ distributed where κ is the lag order of the ARCH effect. These test results confirm the presence of conditional heteroscedasticity in all residual series of model 1 and 2. Also reported in table (4.4) are Ljung-Box test results for autocorrelation in the error terms. The test statistic $LB(\kappa)$ is $\chi^2(\kappa)$ distributed under the null of no serial correlation, where κ is the lag order of the serial correlation. The Ljung-Box test may show spurious evidence of serial correlation when the series is conditionally heteroscedastic. Diebold's (1987) correction for ARCH effects is applied to the calculation of these Ljung-Box statistics. The corrected Ljung-Box statistic with eight lags cannot reject the null of no serial correlation for the $\Delta_4 e_{it}$'s at the 10% level. Note that residuals in model 3 provide no evidence of ARCH effects, thus their corresponding Ljung-Box test statistics are not subject to Diebold's correction. The computed $LB(4)$ and $LB(8)$ values for model 3 are very close to their counterparts for model 1 and 2, and the the null of serially uncorrelated GMM residuals cannot be rejected for model 3 at the 1% and 5% levels.

4.4 Concluding Remarks

The objective of this chapter has been to test for rational habit formation and the effects of food safety information on U.S. meat consumption. Under rational expectations the representative household maximizes the life-time utility taking into account the effect of its current consumption decision upon future utility. Habits provide such a mechanism through which current levels of consumption could affect future utility. To investigate the effects of food safety information on meat demand, food safety news articles from the popular press were compiled into information indices. These indices are then used to approximate the "true" consumers' perception of food safety.

U.S. quarterly data on meat consumption are used to estimate the model. The results indicate that the potential degree of habit persistence for beef increased around 1998, while there were no discernible shifts in the potential degree of habits for pork and poultry. Whether beef consumption is actually habit-forming after 1998 will not be clear until demand elasticities are computed in chapter 5. However, the intertemporal optimization nature of the consumer's problem means that these elasticities cannot be easily calculated. In fact, the consumer's problem is non-linear and has to be solved numerically. Once this step is complete, consumption responses to price and food safety shocks can be simulated under various expectations schemes.

In the empirical analysis, we have specified that only one-period lagged levels of consumption enter the current utility function and hoped this would be enough to capture habit formation in meat demand at quarterly frequencies. Although this is consistent with the approach followed by most studies on habit formation under rational expectations, it is not innocuous. It is plausible that consumption at nearby dates is substitutable (durable) while habits develop over a longer time span. In Becker and Murphy, it was shown that the degree of habit persistence is positively related to the rate at which the habit stock depreciates. Becker (1996) defined traditions as mild habits whose habit stocks depreciate more slowly and are likely to be related to behavior in the more distant past. In the case of food, the rate of depreciation of its habit stock may be quite low compared to substances that are clearly addictive to many people, such as cigarettes. For instance, once the household learns a new recipe, its knowledge capital may not quickly dissipate. It follows that it is desirable to account for consumption experiences in the more distant past than just one quarter ago.

Therefore, a more fruitful formulation of the problem may be to explicitly model short-run durabilities and long-run habit formation (see, for example, Heaton, 1995). This requires additional lags of consumption to enter the utility function. As Heaton pointed out, these additional terms imply a larger MA structure in the error term of (4.11). It makes the estimation of the asymptotic covariance matrix of the GMM estimator more difficult. A practical solution to this problem is to follow Heaton (1995)'s Simulated Methods of Moments approach. Exploration of this possibility is outside of the scope of this dissertation but should be pursued in future research.

Finally, it is important to realize that these results are conditional on the chosen functional form. Future research should consider other specifications of the utility function and the way that food safety variables enter the household preferences.

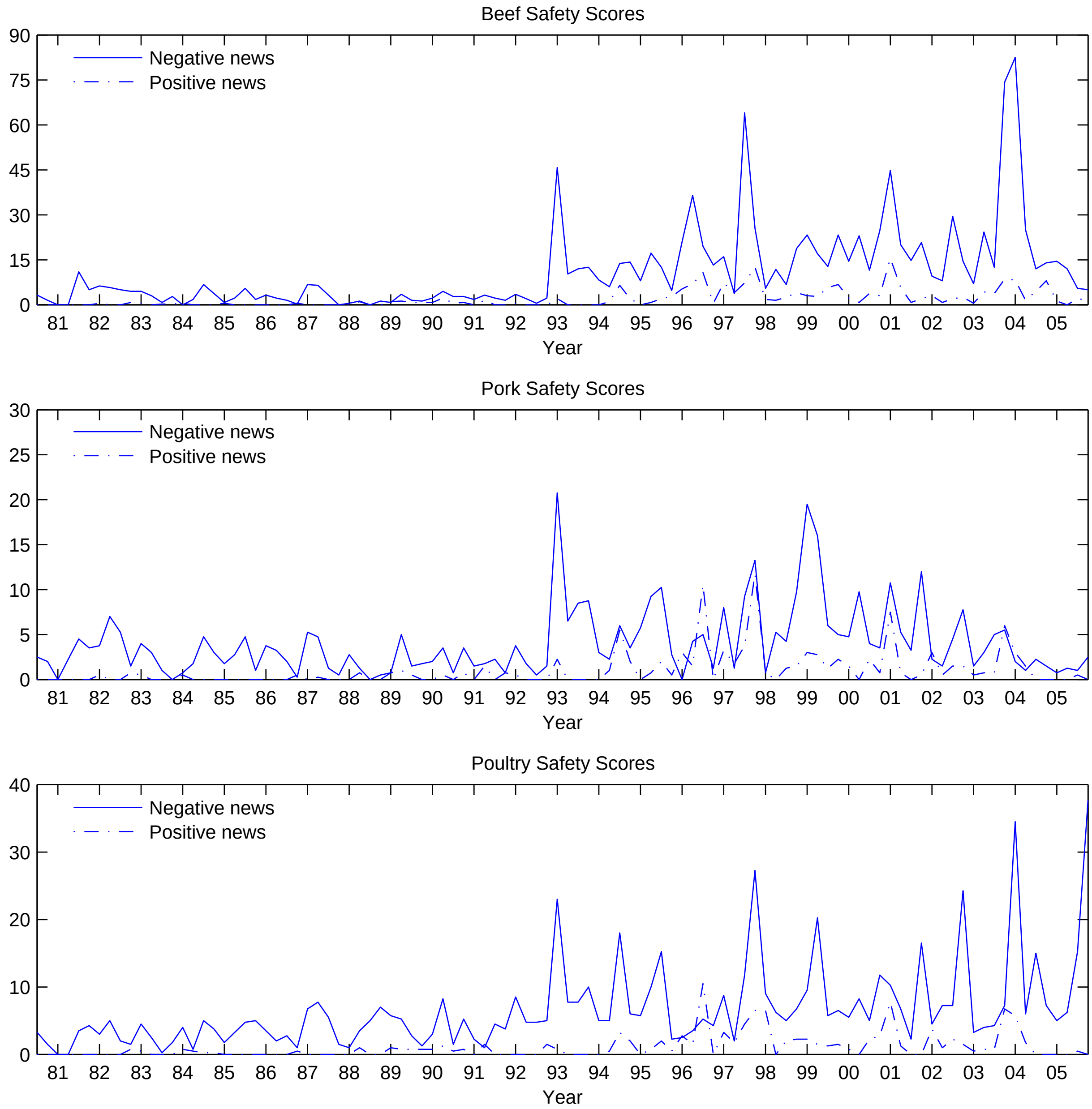

Figure 4.1: U.S. quarterly meat safety indices

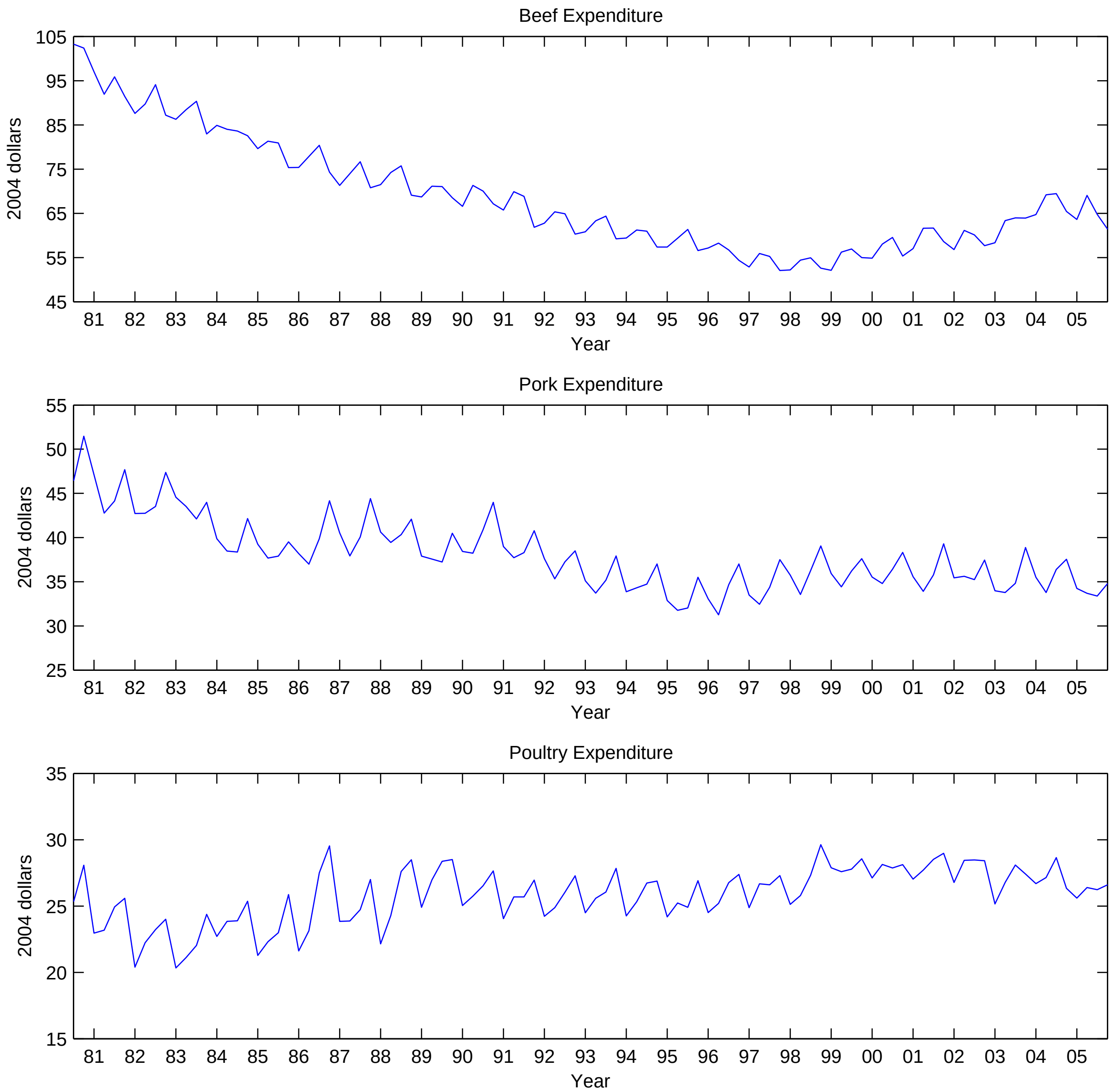

Figure 4.2: U.S. quarterly per capita real meat expenditures

Table 4.1: GMM estimates (1)

	model 1		
	Beef(t)	Pork(t)	Poultry(t)
beef safety(t)	-0.440**	-0.256**	-0.192**
	(0.122)	(0.073)	(0.055)
pork safety(t)	0.297	0.191	0.136
	(0.198)	(0.115)	(0.082)
poultry safety(t)	0.174	0.101	0.074
	(0.141)	(0.082)	(0.058)
beef safety($t-1$)	0.006	0.006	0.005
	(0.110)	(0.064)	(0.047)
pork safety($t-1$)	-0.206	-0.128	-0.094
	(0.158)	(0.091)	(0.065)
poultry safety($t-1$)	-0.010	-0.048	-0.040
	(0.142)	(0.082)	(0.058)
beef(t)	-16.305**		
	(1.115)		
pork(t)	-9.494**	-5.161**	
	(0.342)	(0.464)	
poultry(t)	-7.475**	-3.982**	-3.053**
	(0.308)	(0.256)	(0.747)
habit	-1.197	-0.250	-0.062
	(0.677)	(0.406)	(0.337)
habit*D98	2.337*	0.347	-0.048
	(1.079)	(0.357)	(0.299)
const	100	53.231**	41.362**
	(—)	(2.834)	(2.088)
const*D98	-11.804	-1.057	0.820
	(6.349)	(1.819)	(2.012)
Hansen's J	13.97		
LR	22.26		
bandwidth	0		

Note: [a] The parameters and standard errors (in parentheses) are multiplied by 100 to facilitate presentation. [b] *Denotes significance at the 5% level. **Denotes significance at the 1% level. [c] The food safety indexes are constructed as the square roots of the negative news indexes (NIDXs) minus the square roots of the corresponding positive news indexes (PIDXs).

Table 4.2: GMM estimates (2)

	model 2		
	Beef(t)	Pork(t)	Poultry(t)
beef safety(t)	-0.213**	-0.126**	-0.093**
	(0.077)	(0.045)	(0.035)
pork safety(t)	0.185	0.114	0.084
	(0.125)	(0.077)	(0.056)
poultry safety(t)	0.071	0.043	0.024
	(0.113)	(0.066)	(0.050)
beef safety($t-1$)	0.014	0.002	0.009
	(0.076)	(0.044)	(0.034)
pork safety($t-1$)	-0.384*	-0.226*	-0.176*
	(0.183)	(0.101)	(0.076)
poultry safety($t-1$)	0.024	0.021	0.007
	(0.128)	(0.073)	(0.052)
beef(t)	-15.611**		
	(0.948)		
pork(t)	-9.732**	-5.874**	
	(0.338)	(0.304)	
poultry(t)	-7.303**	-3.932**	-3.143**
	(0.247)	(0.277)	(0.495)
habit	-1.504**	0.046	0.064
	(0.585)	(0.249)	(0.238)
habit*D98	2.541**	-0.086	-0.206
	(0.833)	(0.349)	(0.246)
const	100	54.261**	40.435**
	(—)	(1.806)	(1.831)
const*D98	-12.936**	1.127	1.782
	(4.885)	(1.800)	(1.673)
Hansen's J	14.85		
LR	32.63		
bandwidth	2		

Note: [a] The parameters and standard errors (in parentheses) are multiplied by 100 to facilitate presentation. [b] *Denotes significance at the 5% level. **Denotes significance at the 1% level. [c] The food safety indexes are the square roots of the NIDXs.

Table 4.3: GMM estimates (3)

	model 3		
	Beef(t)	Pork(t)	Poultry(t)
beef safety(t)	-0.148** (0.044)	-0.082** (0.025)	-0.062** (0.019)
pork safety(t)	0.071 (0.039)	0.034 (0.024)	0.027 (0.019)
poultry safety(t)	0.140* (0.061)	0.078* (0.034)	0.058* (0.026)
beef safety($t-1$)	0.020 (0.031)	0.011 (0.018)	0.009 (0.014)
pork safety($t-1$)	0.052 (0.064)	0.025 (0.037)	0.021 (0.029)
poultry safety($t-1$)	-0.070 (0.046)	-0.037 (0.025)	-0.029 (0.019)
beef(t)	-16.612** (0.656)		
pork(t)	-10.051** (0.245)	-5.777** (0.422)	
poultry(t)	-7.063** (0.222)	-3.605** (0.274)	-3.225** (0.472)
habit	-1.120** (0.420)	0.306 (0.250)	0.179 (0.185)
habit*D98	3.251** (0.618)	0.100 (0.216)	-0.184 (0.239)
const	100 (—)	52.104** (1.853)	38.170** (1.979)
const*D98	-17.317** (3.587)	-0.153 (1.170)	1.377 (1.492)
Hansen's J	9.84		
LR	20.44		
bandwidth	3		

Note: [a] The parameters and standard errors (in parentheses) are multiplied by 100 to facilitate presentation. [b] *Denotes significance at the 5% level. **Denotes significance at the 1% level. [c] The food safety indexes are the square roots of the Piggott and Marsh (2004) food safety indexes extended to the 1980(2)-2005(4) period. They are the quarterly aggregate number of articles on beef, pork, and poultry safety from up to fifty domestic and international newspapers.

Table 4.4: Analysis of the GMM residuals

		$ARCH(2)$	$ARCH(4)$	$LB(4)$	$LB(8)$
model 1	$\Delta_4 e_{2t}$	16.7**	16.4**	8.7	12.1
	$\Delta_4 e_{3t}$	17.4**	17.8**	3.7	5.8
model 2	$\Delta_4 e_{2t}$	10.1**	16**	9.3	10.5
	$\Delta_4 e_{3t}$	15.4**	25.8**	5.9	9
model 3	$\Delta_4 e_{2t}$	4.1	3.1	6.7	11.4
	$\Delta_4 e_{3t}$	5.7	3.9	6.7	7.2

Note: [a] *Denotes significance at the 5% level. **Denotes significance at the 1% level.

Chapter 5

The Elasticities

The objective of this chapter is two-fold. First, given that the GMM estimation has offered statistical evidence of time nonseparable preferences, it is necessary to evaluate the economic significance of modeling time-nonseparability under rational expectations. To achieve this, demand responses to price changes and food safety events are simulated under different hypothetical expectations schemes. Second, dynamic simulations could serve as an additional test of the econometric specifications in chapter 4. Ferguson (2000) re-examined the rational addiction model of coffee consumption by Olekalns and Bardsley (OB hereafter) which was published to provide supportive evidence for the theory of rational addiction. Using OB's parameter estimates, Ferguson projected U.S. coffee consumption for the next 22 years (since 1991) and found that projected consumption values are extremely unrealistic.

This chapter is organized as follows. Section (5.1) describes procedures involved in conducting numerical dynamic simulations for rational habit persistence models. In section (5.2), an example is provided to make the presentation concrete. Conclusions are provided in section (5.3).

5.1 Numerical Method

5.1.1 The Consumer's Problem

The dynamic system that characterizes the consumer's intertemporal optimization problem is nonlinear, therefore the consumption decision has to be computed using recursive dynamic programming techniques. Because there are three unknowns (beef, pork, and poultry consumption, or x_{1t}, x_{2t}, and x_{3t}), the system of two MRS equations (4.7) that was previously used to econometrically identify parameters of the household preferences in chapter 4 is underidentified if the goal is to simulate consumption responses to price and food safety shocks of various durations. Recall that the unobservable marginal utility of wealth at t (λ_t) in the FOCs of pork and poultry was substituted out using the FOC of beef during the GMM estimation. However, this trick can no longer be used in simulating demand responses when preferences are time-nonseparable. The common practice in the rational addiction literature has been to assume that λ is a constant and estimates a reduced-form Euler equation with λ buried under the coefficient estimates. This can be potentially problematic because, under uncertainty, the marginal utility of wealth is not fixed rather it should fluctuate with the arrival of new information on commodity prices, income and preferences shocks. A makeshift solution for the present is to "guess" the true value of λ_t and simulate demand responses to price and food safety shocks conditional upon the chosen value of λ_t.

The equilibrium condition for the household's consumption decisions is

$$0 = \frac{a_{it}}{m_{it}} + \sum_{j=1}^{3} b_{ij}\frac{\ln x_{jt}}{m_{it}} + b_i\frac{\ln x_{it-1}}{m_{it}} + b_i\beta E_t\left[\frac{\ln x_{it+1}}{m_{it}}\right] - \lambda_t, \quad i = 1, 2, 3. \tag{5.1}$$

Because the dynamic rational expectations model will be solved using several MATLAB routines developed by Miranda and Fackler (2002), it is useful to write (5.1) in the following general form conforming with their notations:

$$f(X_{t-1}, X_t, E_t h(X_t, X_{t+1})) = 0. \tag{5.2}$$

Here, the equilibrium function f maps $R^{d_s \times d_x \times d_h}$ into R^{d_x}, where d_s, d_x, and d_h denote the dimensionality of the state space, response space, and expectation space, respectively. According to (5.1), the expectation space is three-dimensional, and the expectation function h is

$$h(X_t, X_{t+1}) = b_i\beta\left[\frac{\ln x_{it+1}}{m_{it}}\right], \quad i = 1, 2, 3. \tag{5.3}$$

In the most general case where $b_i \neq 0 \; \forall i$, the dimension of the state space is three. In order to describe the procedures used to solve the habit persistence model, the following discussion focuses on the case where $d_s = 1$. The presentation can be easily generalized to include multiple state variables but at the expense of cumbersome notations to keep track of the different dimensions. The MATLAB codes admit cases where $d_s > 1$. But for now, assume that $b_2 = b_3 = 0$, the three-dimensional response function at t can then be written as $X_t = x(s_t)$, where the state response $s_t = x_{1t-1}$.

5.1.2 Approximation of Expectations

To transform the infinite-horizon optimization problem to a finite-horizon one, one assumes that the system (5.1) reaches its steady-state T periods from the current period t, namely, $s_{t+T} = s_{t+T+1} = ... = s_{t+\infty}$. This effectively cuts off the consumption dynamics at T. The finite-horizon approximate solution converges to the true infinite-horizon solution as T increases (Miranda and Glauber, 1993). In general, to solve the equilibrium condition (5.2) for X, one can either directly approximate the response function $x(\cdot)$ or first approximate the expectation function $h(\cdot)$ and then recover values of X using, for instance, Newton's method. However, approximation of h typically encounters less difficulties than direct approximation of the response function (Miranda and Fackler, p. 292).

Before describing the recursive dynamic programming procedures, it is necessary to explain how h is to be approximated. For the equilibrium condition in period τ, the expectation function can be written as $h(s_{\tau+1}, x(s_{\tau+1}))$. Linear interpolation is a common method used to approximate an analytically intractable real-valued function, in this application, h. Define the approximant of the ith element of h as

$$\hat{h}_i(s_{\tau+1}) = \sum_{j=1}^{n_i} c_{ij}\phi_{ij}(s_{\tau+1}), \quad i = 1, 2, 3 \tag{5.4}$$

where the basis functions ϕ_{i1},ϕ_{i2},...,ϕ_{in_i} are linearly independent functions supplied by the researcher, the basis coefficients c_{i1},c_{i2},...,c_{in_i} are to be computed, the number n_i is called the degree of interpolation, and $s_{\tau+1}$ is called an interpolation node.

The basis functions are often specified as polynomials of increasing order. Given that there are n_i basis functions, one need at least n_i distinct interpolation nodes to compute the basis coefficients. When interpolating h_i over a bounded interval $[a, b]$ of s, instead of using interpolation nodes that are evenly spaced, one could use the Chebychev nodes:

$$s_{m\tau+1} = \frac{a+b}{2} + \frac{b-a}{2}\cos\left(\frac{n_i - m + 0.5}{n_i}\pi\right), \quad m = 1, 2, ..., n_i. \tag{5.5}$$

The lower bound a and upper bound b are predetermined by the researcher. For a n_ith-degree Chebychev approximant for h_i, the interpolation matrix that contains the individual basis functions $\phi_{ij}(\cdot)$ is

$$\Phi_i = \begin{bmatrix} 1 & s_1 & \dots & s_1^{n_i-2} & s_1^{n_i-1} \\ 1 & s_2 & \dots & s_2^{n_i-2} & s_2^{n_i-1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 1 & s_{n_i} & \dots & s_{n_i}^{n_i-2} & s_{n_i}^{n_i-1} \end{bmatrix} \tag{5.6}$$

where the time subscript on s is dropped for the moment without confusion. Given n_i basis coefficients and n_i interpolation nodes, computing values of the basis coefficients entails solving a system of n_i linear equations.

Instead of using high-degree polynomials, such as the Chebychev-node interpolant, piecewise polynomial splines are also frequently used to approximate a real-valued function over the bounded interval $[a, b]$.

Implementation of the recursive dynamic program involves $T + 1$ steps, which are discussed below in turn:

1. In period $t + T$ the equilibrium condition is

   $$f(s_T, X_T, E_t h(s_{T+1}, X_{T+1})) = 0$$

   where $X_T = X_{T+1}$ because the system is assumed to be at its steady state; and for this reason, time subscript can be dropped at this step without causing confusion. First, using the Chebychev nodes within the prespecified interval $[a, b]$ of s and initial guess of the corresponding values of X, compute an approximant of h. Denote c^T as the 1×3 cell array that contains $n_1 \times 1$, $n_2 \times 1$, and $n_3 \times 1$ column vectors of the computed basis coefficients for $\hat{h}_1$, $\hat{h}_2$, and $\hat{h}_3$, respectively. Conditional on c^T and the predetermined Chebychev nodes, updated values of X can be recovered using Newton's method. Second, use the updated X to update h and repeat the above procedure to update c^T. The process is iterated until the computed c^T converges.

2. In period $t + T - 1$ the equilibrium condition is

   $$f(s_{T-1}, X_{T-1}, E_t h(s_T, X_T)) = 0.$$

   First, compute X_T using c^T from the first step and initial guess of X_{T-1} at the pre-selected Chebychev nodes. Then approximate h at these values of X's. Denote the computed 1×3 cell array of basis coefficients c^{T-1}. Next, using Newton's method, conditional upon c^{T-1}, update X_{T-1} so that X_T and h can be also updated. With new values of h at hand, c^{T-1} can be re-computed. The process is repeated until convergence in c^{T-1} is achieved.

The process is repeated recursively backward until period t is reached.

Completion of the above procedure renders values of $h(s_{t+1}, X_{t+1})$ in period t at the selected interpolation nodes. These values of h has to be compared with their counterparts associated with longer T's in order to decide how far into the future the dynamic programming procedure has to start from.

5.2 An Example

To make the description concrete, let's simulate demand responses under different expectations scenarios starting at the last quarter of 2004, i.e., $t = 2004(4)$. This quarter is randomly selected, other points of time in the sample could have been used as examples instead.

Simulating demand responses to price and food safety shocks entails explicit assumption of the expectations process of the household. Recall that, in chapter 4, the GMM technique does not require the econometrician to know exactly how consumers' expectations are formed, only that the expectation errors are orthogonal to information available to the consumer when consumption decisions are made. This property has been acclaimed to be one of the major advantages of GMM estimation.

Now assume that at $t = 2004(4)$ the household forms static expectations, namely, it anticipates no changes in prices and levels of food safety events in the subsequent periods. Also, assume that, the system (5.1) at t is initially at a steady state. Note that, during the post-1998 sample period, only b_1 is precisely estimated while b_2 and b_3 are not statistically significant and much smaller in magnitude. It is conjectured that a one-dimensional state response function, in which $s_t = x_{1t-1}$, may be sufficient to capture demand dynamics. To test whether this is the case, the expectation function $h(\cdot)$ at t is approximated assuming three-dimensional state space ($d_s = 3$). Cubic spline interpolants with 5 nodes for each of s_{1t}, s_{2t}, and s_{3t} are specified. The corresponding upper and lower bounds for the s_{it}'s are [12 18], [10 15], and [21 28], which encompass the observed maximum and minimum quantities of beef, pork, and poultry demanded, respectively, during the post-1998 period. Because of the assumed static expectations, all prices and food safety indices at $t+1$ are equal to their counterparts at t. The household preferences are calibrated using parameter estimates from model 2 in table 4.2.

After the numerical interpolation procedure (step 1 in sub-section 5.1.2) is completed, postoptimality analysis has to be done to check on the quality of the solution. The values of the equilibrium condition, f, and the interpolation residual as a percentage of the expectation function, $\frac{|h-\hat{h}|}{h}$, have to be evaluated at arbitrary points in s. The reason for doing this is that at the prespecified interpolation nodes, both f and $\frac{|h-\hat{h}|}{h}$ are designed to be as close to zero as possible. The arbitrary points in s_i are introduced by creating 10 linearly equally spaced points between every two adjacent nodes. At these evaluation points, average values of the equilibrium condition and the interpolation residual are 0.29E-12 and 1.4%, 0.14E-12 and 1.2%, 0.11E-12 and 0.7% for beef, pork, and poultry, respectively. The interpolation residuals are small although not trivial. Increasing the number of interpolation nodes or switching to Chebychev interpolants does not further improve the results.

At the pre-specified interpolation nodes and λ_t and the 2004(4) prices and food safety levels, the predicted steady-state beef and pork quantities are lower than the observed demand in 2004(4) with seasonality removed, while the predicted poultry demand is higher than the actual demand. The value of λ_t was set at 9E-4, although the λ_t implied by $\frac{MU_{2t}}{p_{2t}}$ evaluated at actual de-seasonalized quantities is 1.1E-4[1]. The reason for doing this is that at this implied value and its vicinity convergence difficulty was encountered.

Figure 5.1 illustrates the computed relations between meat demands and their own lagged demands near a steady state at 2004(4) prices and food safety levels. Figure 5.1a shows that the optimal beef quantity demanded is an increasing function of lagged beef demand when lagged pork and poultry quantities are 12.5 lbs and 22.167 lbs, respectively. It suggests that the estimated b_1 is sufficiently large in magnitude to induce habit persistence after 1998. In figure 5.1b, pork demand is plotted against its own lagged demand holding lagged beef and poultry demands constant at 15 lbs and 22.167 lbs, respectively. Although less apparent visually, the pork curve slopes downward indicating a mild degree of inventory behavior. Finally, figure 5.1c depicts the relation between poultry demand and its lagged demand while

[1]In general, λ_t depends on current wealth, expected future income, prices, food safety events and interest rates; however, presumably, even a permanent change in food safety or price for a meat species will have little effect on λ_t at least for consumers in a developed economy.

the lagged demands for beef and pork are 15 lbs and 12.5 lbs, respectively. The downward-sloping curve indicates that inventory effect dominates habit persistence in poultry demand at quarterly frequencies. These results are consistent with *a priori* expectations.

It is difficult to evaluate exactly how much the simulated quantities over- or under-estimate meat demands, because 1) the simulated demands are free of seasonality while the observed quantities are not, 2) the "true" expectations of the household are not known by econometricians. Of course, the former will not be a problem if one is willing to de-seasonalize the data prior to GMM estimation.

Next, demand responses to unexpected price and food safety shocks that are *expected* to be transitory or permanent are simulated following the $(T+1)$-step procedure described in 5.1.2. A transitory price or food safety shock is defined as a change in price or food safety only at t, while a permanent shock refers to a change in price or food safety $\forall \tau \geq t$. After experimenting with several values of T, it was determined that $T = 4$ is sufficient to capture the full long-run effects of permanent shocks on demand. In the simulation, an unexpected price or food safety shock that is expected to be transitory is represented by a 2% increase in price or food safety index at t while holding prices and food safety indices in other periods constant at their 2004(4) levels. Similarly, a permanent shock is simulated by increasing price or food safety index of interest by 2% for all periods. Price and food safety elasticities of demand were computed at all interpolation nodes at $t, t+1, ..., t+4$ and the averages are reported in table 5.1 and 5.2. These elasticities are income-compensated to hold the marginal utility of wealth constant over time.

The own-price and own-food safety elasticities for beef demand are consistent with the theoretical predictions in chapter 3. The immediate response elasticity (at t) of beef demand to a price increase that is expected to be permanent is -0.63, while in contrast this elasticity drops to -0.25 when the price increase is expected to be transitory. The long-run own-price elasticity of beef demand is around -0.81 and is achieved approximately three quarters after the price increase. For goods that display inventory effects, the immediate demand response to an own-price increase should be larger in absolute value when the price hike is expected to be transitory than when the price increase is expected to be permanent. The reason is that a temporary price increase can always be accommodated by depleting the inventory. The simulated elasticities reported in table 5.1 support this theory. The immediate response elasticities for pork and poultry demands to a transitory own-price increase are -0.73 and -0.98, respectively, whereas these elasticities to a permanent own-price increase are -0.70 and -0.83, respectively. Differences between these elasticities are relatively small because the estimated b_2 and b_3 in table 4.2 are small in magnitude when compared to the b_{ij}'s, the effects of contemporaneous consumption on current utility. The long-run own-price elasticities for pork and poultry demand to a permanent price change are -0.81 and -0.84, slightly higher than their short-run counterparts in magnitude. Since inventory behavior implies higher short-run responses than long-run responses, the higher long-run pork and poultry own-price elasticities are likely results of substitution away from pork and poultry and toward beef in the long run. To offer some information on how the present elasticity estimates compare with estimates of previous static meat demand studies, the ranges of own-price elasticities surveyed by the U.S. Environmental Protection Agency (EPA) (table 3-2) are (-2.590, -0.150), (-1.234, -0.070), (-1.250, -0.104), and (-0.680, -0.372) for beef, pork, broilers, and turkey demands, respectively.

Table 5.2 indicates that the long-run own-food safety elasticities to a permanent increase in food safety index are negative for all meats, consistent with intuition. All long-run cross-effects of food safety are negative except for the positive effects of poultry food safety on beef and pork demands. Interestingly, Piggott and Marsh also find positive cross-effects of poultry safety on beef and pork demands. Because food safety information in the previous period is found to statistically affect current consumption, whether the short-run own-safety elasticity of beef demand is lower (in absolute value) for a transitory food safety change than for a permanent food safety change is an empirical question. It hinges upon the weight on contemporaneous relative to lagged food safety information in explaining current consumption. In this application, the short-run responses to transitory and permanent food safety changes are the same for all meats.

The magnitudes of most of the long-run food safety elasticities are in the order of 1×10^{-3}. Beef demand is the most elastic to food safety shocks with the immediate response elasticity to a transitory own-safety change being -1.17E-2 and the long-run elasticity to a permanent own-safety shock around -1.55E-2. Inspection of figure 4.1 suggests that it is not uncommon to have a food safety index jump by 100% in certain quarters. Under these circumstances, the economic significance of a major food scare may no longer be trivial even if the incidence is expected to be transitory. For comparison, the average own-food safety elasticities for their most preferred model in Piggott and Marsh are 1.33E-3, -5.51E-3, and -2.04E-2 for beef, pork, and poultry, respectively.

Finally, to examine how the simulation performs when the Piggott and Marsh indexes are used, price and food safety elasticities of demand are computed using parameter estimates of model 3 in table 4.3. The price and food safety elasticities, with 2004(4) prices and food safety levels as baseline (pre-shock) values, are reported in table 5.3 and 5.4, respectively. Due to the larger estimated value of the coefficient on the beef habit, the wedges implied by model 3 between short-run and long-run responses are greater than those implied by model 2. For example, the long-run price elasticity of beef demand to a permanent price change (-1.5) is more than twice of the size of its short-run counterpart (-0.6). However, the simulated current (short-run) elasticity of beef demand to a transitory beef price increase is positive, a counterintuitive result. Unlike model 2, the simulated short-run own-food safety elasticities for transitory and permanent food safety shocks are positive for poultry demand, although the long-run elasticity for a permanent food safety change is negative, as expected. The own-effects of beef safety index are larger in model 3 than in model 2, depending on which period one is looking at, these elasticities in model 3 can be 3 to 5 times greater than those in model 2. Both model 2 and 3 suggest that it takes about 1 year for the demand system to reach its long-run equilibrium. Overall, in my judgment, model 2 provides better estimates of U.S. meat demand elasticities.

5.3 Concluding Remarks

The objective of this chapter has been to evaluate the economic significance of modeling time-nonseparability in meat demand under rational expectations. A comparison of the short-run and long-run elasticities indicates that habit persistence is quantitatively important in U.S. meat demand. The distinct short-run elasticities for shocks that are expected to be transitory or permanent implies that modeling rational expectations in meat demand can be a fruitful exercise.

If one is only interested in testing habit persistence, there exist simpler ways to do this without performing the often sophisticated numerical simulations. One of such methods is to include past consumption as part of current subsistence level of consumption. A positive coefficient on the habit term indicates that past demand contributes positively to the present level of subsistence consumption. Becker (1996, p. 122) showed that habit persistence is guaranteed in this case regardless of the values of other parameters. But the interests of many economic investigations go beyond this. Economists are interested in quantifying the magnitudes of various price and food safety changes under different expectations schemes. In these situations, it is likely to be inevitable to perform simulation studies similar to the one conducted here, unless a functional form, such as the linear-quadratic utility function, that yields linear first-order conditions is specified. Most of the empirical studies of rational addictions are based on the linear-quadratic preferences specification for the ease of being able to compute demand elasticities analytically. This study appears to be the first effort to compute demand elasticities in a nonlinear dynamic rational expectations model.

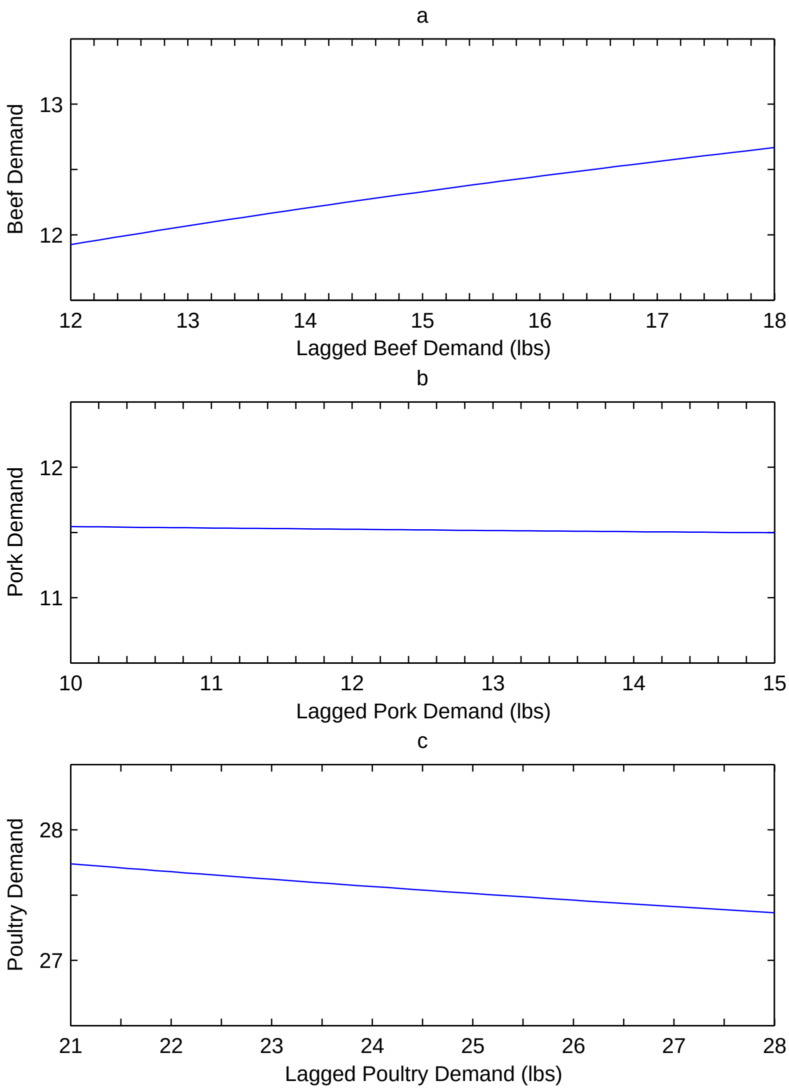

Figure 5.1: Relations between contemporary demands and lagged demands near a steady state

Table 5.1: Simulated demand elasticities for transitory and permanent price shocks (1)

	Response by quarter to a transitory or permanent price increase				
	0	1	2	3	4
			a transitory increase in beef price		
Beef	-0.247	-0.034	-0.005	-6.40E-4	-8.80E-5
Pork	0.194	0.028	0.004	5.13E-4	7.05E-5
Poultry	0.186	0.019	0.003	3.88E-4	5.38E-5
			a permanent increase in beef price		
Beef	-0.633	-0.795	-0.815	-0.816	-0.807
Pork	0.499	0.629	0.643	0.644	0.638
Poultry	0.479	0.567	0.578	0.579	0.574
			a transitory increase in pork price		
Beef	0.316	0.046	0.006	8.53E-4	1.17E-4
Pork	-0.727	-0.029	-0.005	-6.73E-4	-9.42E-6
Poultry	0.102	-0.041	-0.003	-5.40E-4	-7.06E-5
			a permanent increase in pork price		
Beef	0.305	0.428	0.447	0.448	0.439
Pork	-0.702	-0.789	-0.805	-0.806	-0.798
Poultry	0.099	4E-4	-0.010	-0.011	-0.006
			a transitory increase in poultry price		
Beef	0.308	0.032	0.005	6.40E-4	8.87E-5
Pork	0.104	-0.041	-0.003	-5.35E-4	-7.01E-5
Poultry	-0.978	0.012	-0.004	-3.42E-4	-5.59E-5
			a permanent increase in poultry price		
Beef	0.260	0.339	0.352	0.353	0.346
Pork	0.088	4E-4	-0.009	-0.010	-0.005
Poultry	-0.829	-0.830	-0.841	-0.841	-0.836

Note: [a] Quarter "0" corresponds to period t = 2004(4).
[b] A price is increased by 2% over its actual 2004(4) value to simulate a price shock.
[c] Preference parameters are those of model 2 in table 4.2

Table 5.2: Simulated demand elasticities for transitory and permanent food safety shocks (1)

	Response by quarter to a transitory or permanent increase in food safety index				
	0	1	2	3	4
	a transitory increase in beef safety index				
Beef	-1.17E-2	-4.00E-4	5.10E-6	-1.51E-6	-1.22E-7
Pork	-1.00E-2	-1.00E-3	7.00E-5	-1.89E-6	2.16E-7
Poultry	-8.50E-3	4.30E-3	-1.61E-4	6.90E-6	-1.59E-7
	a permanent increase in beef safety index				
Beef	-1.17E-2	-1.51E-2	-1.56E-2	-1.57E-2	-1.53E-2
Pork	-1.00E-2	-8.50E-3	-8.00E-3	-8.00E-3	-8.30E-3
Poultry	-8.50E-3	-1.90E-3	-1.80E-3	-1.70E-3	-1.90E-3
	a transitory increase in pork safety index				
Beef	2.80E-3	-6.50E-3	-1.10E-3	1.49E-4	-2.07E-5
Pork	3.50E-3	-5.40E-3	8.00E-4	1.26E-4	1.63E-5
Poultry	3.00E-3	-6.70E-3	1.00E-3	7.67E-5	1.31E-5
	a permanent increase in pork safety index				
Beef	2.80E-3	-4.20E-3	-5.40E-3	-5.60E-3	-5.40E-3
Pork	3.50E-3	-1.60E-3	-8.00E-4	-6.00E-4	-7.00E-4
Poultry	3.00E-3	-3.30E-3	-2.20E-3	-2.10E-3	-2.20E-3
	a transitory increase in poultry safety index				
Beef	3.60E-3	1.10E-3	1.48E-4	2.09E-5	2.85E-6
Pork	3.10E-3	2.70E-3	-1.55E-4	-1.58E-5	-2.32E-6
Poultry	-1.10E-3	-1.50E-3	-4.47E-5	-1.47E-5	-1.66E-6
	a permanent increase in poultry safety index				
Beef	3.60E-3	5.70E-3	6.00E-3	6.10E-3	5.90E-3
Pork	3.10E-3	4.80E-3	4.50E-3	4.50E-3	4.60E-3
Poultry	-1.10E-3	-3.20E-3	-3.30E-3	-3.40E-3	-3.30E-3

Note: [a] Quarter "0" corresponds to period t = 2004(4).
[b] A negative food safety index (NIDX) is increased by 2% over its actual 2004(4) value to simulate a food safety shock. [c] Preference parameters are those of model 2 in table 4.2

Table 5.3: Simulated demand elasticities for transitory and permanent price shocks (2)

	Response by quarter to a transitory or permanent price increase				
	0	1	2	3	4
			a transitory increase in beef price		
Beef	0.126	0.048	0.019	0.007	0.003
Pork	-0.111	-0.050	-0.020	-0.008	-0.003
Poultry	-0.087	-0.027	-0.011	-0.004	-0.002
			a permanent increase in beef price		
Beef	-0.621	-1.25	-1.464	-1.502	-1.404
Pork	0.556	1.231	1.448	1.485	1.388
Poultry	0.435	0.790	0.918	0.942	0.882
			a transitory increase in pork price		
Beef	0.196	0.090	0.036	0.014	0.005
Pork	-0.444	-0.108	-0.038	-0.015	-0.006
Poultry	0.040	-0.042	-0.020	-0.008	-0.003
			a permanent increase in pork price		
Beef	0.316	0.842	1.053	1.095	0.997
Pork	-0.713	-1.299	-1.506	-1.546	-1.452
Poultry	0.065	-0.198	-0.315	-0.339	-0.284
			a transitory increase in poultry price		
Beef	0.214	0.067	0.026	0.010	0.004
Pork	0.056	-0.057	-0.026	-0.010	-0.004
Poultry	-0.722	-0.046	-0.015	-0.006	-0.002
			a permanent increase in poultry price		
Beef	0.212	0.464	0.564	0.585	0.537
Pork	0.056	-0.171	-0.268	-0.288	-0.243
Poultry	-0.717	-0.886	-0.946	-0.958	-0.929

Note: [a] Quarter "0" corresponds to period t = 2004(4).
[b] A price is increased by 2% over its actual 2004(4) value to simulate a price shock.
[c] Preference parameters are those of model 3 in table 4.3

Table 5.4: Simulated demand elasticities for transitory and permanent food safety shocks (2)

	Response by quarter to a transitory or permanent increase in food safety index				
	0	1	2	3	4
			a transitory increase in beef safety index		
Beef	-3.43E-2	-4.70E-3	-2.10E-3	-8.30E-4	-3.20E-4
Pork	-2.45E-2	9.40E-3	2.40E-3	8.80E-4	3.40E-4
Poultry	-3.08E-2	1.25E-2	1.00E-3	4.63E-4	1.79E-4
			a permanent increase in beef safety index		
Beef	-3.43E-2	-6.53E-2	-7.83E-2	-8.08E-2	-7.42E-2
Pork	-2.45E-2	9.30E-3	2.25E-2	2.50E-2	1.86E-2
Poultry	-3.08E-2	-2.00E-4	7.40E-3	8.80E-3	4.90E-3
			a transitory increase in pork safety index		
Beef	1.28E-2	1.50E-2	5.30E-3	2.19E-3	7.84E-4
Pork	5.00E-4	-5.20E-3	-5.00E-3	-2.10E-3	-8.21E-4
Poultry	4.90E-3	1.00E-3	-3.30E-3	-1.20E-3	-4.40E-4
			a permanent increase in pork safety index		
Beef	1.28E-2	4.47E-2	5.68E-2	5.95E-2	5.50E-2
Pork	5.00E-4	-2.10E-2	-3.24E-2	-3.51E-2	-3.08E-2
Poultry	4.90E-3	-4.80E-3	-1.22E-2	-1.39E-2	-1.11E-2
			a transitory increase in poultry safety index		
Beef	3.99E-2	-1.58E-2	-4.50E-3	-1.70E-3	-6.44E-4
Pork	2.97E-2	-1.31E-2	3.20E-3	1.70E-3	6.71E-4
Poultry	3.36E-2	-2.23E-2	3.50E-3	1.00E-3	3.64E-4
			a permanent increase in poultry safety index		
Beef	3.99E-2	4.35E-2	4.71E-2	4.72E-2	4.29E-2
Pork	2.97E-2	-1.30E-3	-6.30E-3	-6.40E-3	-2.10E-3
Poultry	3.36E-2	-2.60E-3	-3.80E-3	-3.80E-3	-1.20E-3

Note: [a] Quarter "0" corresponds to period $t = 2004(4)$. [b] A food safety index of Piggott and Marsh (2004) is increased by 2% over its actual 2004(4) value to simulate a food safety shock. [c] Preference parameters are those of model 3 in table 4.3

Chapter 6

Conclusion

This dissertation concerns the theoretical and empirical implications of a rational expectations model with habits on the economics of food safety. This approach appears to be a unique and viable application of the rational habit formation model that has been frequently used to solve, with some success, the equity premium puzzle and to explain demands for addictive drugs. The Lucas critique of macroeconometric evaluation of policies argues that it is misdirected to simulate economic agents' consumption decisions independent of their expectations of the decision *rules* of policy-makers. Translating this argument into food safety economics suggests that food demand may be a function of consumers' expectations on future occurrences of food safety events and how transitory or permanent they will be. It is demonstrated in chapter 3 that expectations are most relevant for demand analysis when preferences are not time-separable. If household preferences are temporally separable, expectations are useful to rational households for equating current marginal utility of wealth to its discounted future values. Since food expenditures account for a relatively small portion of the total disposable income for developed economies, the impact of food prices on the marginal utility of wealth seems to be minimal. Chapter 4 provides empirical evidence that U.S. consumer preferences for beef, pork, and poultry are time-nonseparable. However, to justify that efforts spent on the rational expectations approach is worthwhile, it is paramount to quantify effects of expectations on consumption. Using the recursive dynamic programming technique, chapter 5 simulates the short- and long-run demand responses to price and food safety changes that are expected to be transitory or permanent. The simulation results indicate that expectations are quantitatively important in modeling U.S. meat demand. The simulated short-run decline in U.S. per capita beef consumption in response to a beef price increase that is expected to be permanent is more than twice the size of the drop in per capita beef consumption when the price increase is expected to be short-lived.

Coffey et al. (2005) reported results from a survey targeting residents in California, Kansas, and New York following the discovery of the first U.S. case of BSE in Washington state in December, 2003. The results indicate that 77% of the respondents did not change consumption habits as a result of the first U.S. BSE case. However, the survey results also suggest that one additional BSE case in a indigenous cow[1] or 20 additional cases of BSE in different parts of the country would have substantial adverse effect on U.S. beef consumption. This observation may be interpreted along two complementary lines of argument. First and most obvious, an indigenous BSE case or 20 cases across the country would cause consumers' confidence in the safety of U.S. beef to plummet and therefore reduce aggregate demand. Second, additional BSE cases may be perceived as an indication that the U.S. livestock system is more deeply troubled; thereby uprooting these problems is expected to be much more time-consuming than an isolated BSE case would otherwise suggest. In the presence of consumption habits and rational expectations, consumers would respond more both in the short run and long run to the negative news of indigenous or multiple BSE cases. This example strikes the importance of developing a rational expectations model with habits in answering the type of questions that Coffey et al.'s consumer survey attempts to address.

The present research suggests several avenues for future research. First, the econometric model was applied to the U.S. data partly because these data are readily available. However, both the breadth and depth of the food safety incidences occurred in the United States have been much less severe than some other developed economies. While U.S. consumers may have perceived food safety incidences in North America as largely transitory so far, consumers in the U.K. and some other European countries could have experienced changes in food safety perception that were more or less permanent. The United Kingdom is a prominent example where consumer, the meat industry, and policy makers have been confronted with a continuum of food safety crises, among which BSE incidences are the most notable. Although BSE and its (uncertain) infectivity emerged as a food safety issue as early as late 1980s, prior to 1996, BSE was considered by many to be a veterinary disease, not much

[1]The infected cow in Washington state was found to be of Canadian origin, sending a weaker signal that the U.S. herd is at great risk than would have been if the cow was born and raised in the U.S.

different from scrapie—a disease of sheep that does not spread to humans. The British government repeatedly tried to assure the public that beef was safe by mandating that all infected cattle be slaughtered, by introducing a feed ban that prevents all bovine products from going to cattle feed in 1988, by specifying that specific offals should be discarded in 1989, by initiating a computer identification system that was supposedly capable of tracing the origin of a cow in 1993, and by denying that cattle could be endemically infected in 1994[2]. In March 1996, the government admitted that a new variant form of CJD is possibly due to the consumption of BSE infected beef, and eight people had died from it. This announcement effectively discredited the Ministry of Agriculture, Fisheries and Food (MAFF) in disseminating trustworthy food safety information in the future[3]. Now it became clear that BSE would not be eradicated in Great Britain for many years to come. From an economic viewpoint, a potentially testable hypothesis is that U.K. consumers' perception of beef safety permanently changed in 1996 or earlier[4]. In this example, any economic/econometric evaluation of food safety policies may have to take into account the damaged credibility of government agencies in informing the public about how desperate the situation is and how long the crisis is expected to last.

Second, GMM estimator is a limited information estimator. It is frequently implemented to estimate nonlinear rational expectations models, because it does not require explicit solution of the Euler equation. However, Tauchen (1986) showed that GMM estimator can create severe bias in small samples. Fuhrer, Moore, and Schuh (1995), using the extensively studied linear-quadratic inventory model, provided empirical evidence supporting Tauchen's results. However, to estimate a rational expectations model with maximum likelihood estimator (MLE), how expectations are formed needs to be specified, which requires knowledge of the complete economic environment by the econometricians. Obviously, it is hardly the case that an econometrician can specify the entire economic environment without invoking strong and implausible assumptions. Besides, computing MLE for the nonlinear rational expectations model calls for re-solving the Euler equation every time the optimization rou-

[2]A chronological account of the British BSE events can be found at: http://bse.airtime.co.uk/hist.htm.

[3]The mishandling of the BSE crisis and later the foot and mouth disease epidemic in 2001 led to the transfer of MAFF functions to the new Department for Environment, Food and Rural Affairs (DEFRA) in 2001.

[4]It is plausible that certain demographic groups, such as medical professionals, recognized, earlier than the rest of the public, the true nature of the disease and how permanent the crisis was going to be.

tine perturbs the model parameters. Due to the computational complexity involved, the nonlinear model is often linearized before being estimated with MLE (e.g., Fuhrer, 2000). Applications of MLE to nonlinear rational expectations models are few, but Miranda and Glauber (1993) and Miranda and Rui (1997) are two notable exceptions.

This said, computing MLE for the meat demand model with potential rational habit persistence appears to be less rewarding than the other avenues for future research. The reason is two-fold: 1) dynamic simulations in chapter 5 generate intertemporal demand responses that are not unreasonable, 2) presumably, prices and quantities of meat consumption in U.S. are measured with less errors than those of the more aggregated goods and services to which dynamic rational expectations models are often applied. Since dynamic instability (e.g., Fuhrer, Moore, and Schuh) and measurement errors (e.g., Miranda and Rui) are among the symptoms and causes quoted for poor performance of GMM, implementing GMM in the present model should be less susceptible to these criticisms.

Third, in some of the specifications, GMM estimates of b_2 and b_3 indicate that inventory behavior may be the dominating factor in pork and poultry demands. It does not suggest that habit persistence is not important in the demand of the two meats, but that at quarterly frequencies inventory behavior is manifested over habits. In this case, the point estimates of habit persistence may be biased downward. Because the estimated magnitude of habit terms affects the simulated difference between short-run and long-run demand responses, and the time needed for the household to converge to a long-run equilibrium, for future work, it would be interesting to allow more general dynamics where consumption is substitutable in the short run and complementary in the long run. This appears to be a potentially rewarding exercise, because Allais (2004) finds this more general specification of dynamics to be an important feature of U.S. per capita consumption of non-durables and services even at annual frequencies. The econometric challenge is that GMM is not feasible anymore because of the complicated dynamics. In this case, the expectation function will have to be numerically approximated at the estimation stage.

Fourth, due to the lack of micro data, most past studies of time-nonseparable preferences are based on aggregate data. A common problem inherited by all studies of habit persistence using aggregate data is that the conclusion is dependent upon the serial correlation of the aggregate consumption. This may lead to spurious evidence of habit persistence when the serial correlation is not a result of intertemporally dependent preferences. The advent of scanner panel data is likely to alleviate this problem. Nevertheless, testing habit persistence with micro data does not necessarily reduce the odds of finding evidence of time-nonseparable preferences. In fact, to my knowledge, only two out of the eight panel data studies of household consumption of goods other than addictive substances failed to reject the null hypothesis of time-separable preferences[5].

Last, farmers and policy-makers are often faced with the decision of allocating limited funds between R&D and promotion. Wohlgenant (1993) argues that "...an upward shift in retail demand will generate returns to producers that are generally smaller than returns generated through shifting the producer supply curve downward by the same amount. ...producers would generally prefer activities that reduce production costs by an equal amount compared to marketing cost reductions and promotional activities" (p. 642-643). This argument has partially motivated subsequent economic research into the marginal effectiveness of generic advertising expenditures in affecting consumer demands (e.g., Brester and Schroeder, 1995; Alston, Chalfant, and Piggott, 2000). Drawing an analogy to this literature, in the context of food safety, policy-makers have the option of allocating funds among commodity promotion and veterinary and food science research and risk-reduction activities such as extending the scope of animal testings. An efficient distribution of funds requires a comprehensive assessment of the relative marginal effectiveness of these funding alternatives. This dissertation studies the impacts of consumers' quality perception of food safety as measured by media indices on retail meat demand. Future research is needed to investigate, *inter alia*, how risk reduction is transformed into consumers' perception of food safety and how (un)biased of a role the media plays in this transformation.

[5]These studies are Meghir and Weber (1996), Naik and Moore (1996), Dynan (2000), Guariglia and Rossi (2002), Browning and Collado (2004), Ravina (2004), Richards, Patterson, and Tegene (2004), Carrasco, Labeaga and López-Salido (2005).

Bibliography

Abel, Andrew B., 1982, Dynamic effects of permanent and temporary tax policies in a q model of investment, *Journal of Monetary Economics* 9, 353-373.

Adda, Jérôme, 2001, Behavior torwards health risks: an empirical study using the "mad cow" crisis as an experiment, Department of Economics, University College London.

Allais, Olivier, 2004, Local substitution and habit persistence: matching the moments of the equity premium and the risk-free rate, *Review of Economic Dynamics* 7, 265-296.

Alston, Julian M., James A. Chalfant and Nicholas E. Piggott, 2000, The incidences of the costs and benefits of generic advertising, *American Journal of Agricultural Economics* 82, 665-671.

Becker, Gary S., 1996, *Accounting for Tastes* (Harvard University Press, Cambridge, MA).

Becker, Gary S. and Kevin M. Murphy, 1988, A theory of rational addiction, *Journal of Political Economy* 96, 675-700.

Becker, Gary S., Michael Grossman and Kevin M. Murphy, 1994, An empirical analysis of cigarette addiction, *American Economic Review* 84, 396-418.

Bockstael, Nancy E. and Kenneth E. McConnell, 1993, Public goods as characteristics of non-market commodities, *Economic Journal 103*, 1244-1257.

Boyer, Marcel, 1978, A habit forming optimal growth model, *International Economic Review* 19, 585-609.

_______, 1983, Rational demand and expenditures patterns under habit formation, *Journal of Economic Theory* 31, 27-53.

Brester, Gary W. and Ted C. Schroeder, 1995, The impacts of brand and generic advertising on meat demand, *American Journal of Agricultural Economics* 77, 969-979.

Browning, Martin and M. Dolores Collado, 2004, Habits and heterogeneity in demands: a panel data analysis, Centre for Applied Microeconometrics, Institute of Economics, University of Copenhagen.

Burton, Micheal and Trevor Young, 1996, The impact of BSE on the demand for beef and other meats in Great Britain, *Applied Economics* 28, 687-693.

Carrasco, Raquel, José M. Labeaga and J. David López-Salido, 2005, Consumption and habits: Evidence from panel data, *Economic Journal* 115, 144-165.

Chalfant, James A. and Julian M. Alston, 1988, Accounting for changes in tastes, *Journal of Political Economy* 96, 391-410.

Chaloupka, Frank, 1991, Rational addictive behavior and cigarette smoking, *Journal of Political Economy* 99, 722-42.

Chavas, Jean-Paul, 1983, Structural change in the demand for meat, *American Journal of Agricultural Economics* 65, 148-153.

Christensen, Laurits R. and Marilyn E. Manser, 1977, Estimating U.S. consumer preferences for meat with a flexible utility function, *Journal of Econometrics* 5, 37-53.

Coffey, Brian, James Mintert, Sean Fox, Ted C. Schroeder and Luc Valentin, 2005, The economic impact of BSE on the U.S. beef industry: product value losses, regulatory costs, and consumer reactions, Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.

Constantinides, George M., 1990, Habit formation: a resolution of the equity premium puzzle, *Journal of Political Economy* 98, 519-543.

Dahlgran, Roger A. and Dean G. Fairchild, 2002, The demand impacts of chicken contamination publicity—a case study, *Agribusiness* 18, 459-474.

Diebold, Francis X., 1987, Testing for serial correlation in the presence of ARCH, Proceedings of the American Statistical Association, business and economic statistics section, 1986, 323-328. Washington, DC: American Statistical Association.

Dynan, Karen E., 2000, Habit formation in consumer preferences: evidence from panel data, *American Economic Review* 90, 391-406.

Eales, James S. and Laurian J. Unnevehr, 1988, Demand for beef and chicken products: separability and structural change, *American Journal of Agricultural Economics* 70, 521-532.

Ferguson, Brian S., 2000, Interpreting the rational addiction model, *Health Economics* 9, 587-598.

Flake, Oliver L. and Paul M. Patterson, 1999, Health, food safety and meat demand, Paper presented at AAEA Annual Meetings, Nashville, TN.

Fuhrer, Jeffrey C., 2000, Habit formation in consumption and its implications for monetary-policy models, *American Economic Review* 90, 367-390.

Fuhrer, Jeffrey C., George R. Moore, and Scott D. Schuh, 1995, Estimating the linear-quadratic inventory model: Maximum likelihood versus generalized method of moments, *Journal of Monetary Economics* 35, 115-157.

Guariglia, Alessandra and Mariacristina Rossi, 2002, Consumption, habit formation, and precautionary saving: evidence from the British Household Panel Survey, *Oxford Economic Papers* 54, 1-19.

Grossman, Michael, 1972, On the concept of health capital and the demand for health, *Journal of Political Economy* 80, 223-255.

Gruber, Jonathan and Botond Köszegi, 2001, Is addiction "rational"? theory and evidence, *Quarterly Journal of Economics* 116, 1261-1303.

Hansen, Lars P., 1982, Large sample properties of generalized method of moments estimators, *Econometrica* 50, 1029-1055.

Heaton, John, 1995, An empirical investigation of asset pricing with temporally dependent preference specifications, *Econometrica* 63, 681-717.

Heien, Dale and Cathy Durham, 1991, A test of habit formation hypothesis using household data, *Review of Economics and Statistics* 73, 189-199.

Henson, Spencer and Mario Mazzocchi, 2002, Impact of bovine spongiform encephalopathy on agribusiness in the United Kingdom: results of an event study of equity prices, *American Journal of Agricultural Economics* 84, 370-386.

Holt, Matthew T. and Barry K. Goodwin, 1997, Generalized habit formation in an Inverse Almost Ideal Demand System: an application to meat expenditures in the U.S., *Empirical Economics* 22, 293-320.

Houthakker, Hendrik S. and Lester D. Taylor, 1970, *Consumer Demand in the United States: Analyses and Projections* (Harvard University Press, Cambridge, MA).

Kinnucan, Henry W., Hui Xiao, Chung-Jen Hsia and John D. Jackson, 1997, Effects of health information and generic advertising on U.S. meat demand, *American Journal of Agricultural Economics* 79, 13-23.

Lucas, Robert E., 1976, Econometric policy evaluation: a critique, in K. Brunner and A. Metzler (eds), *The Phillips Curve and Labour Market*, Carnegie-Rochester Conference Series on Public Policy (North-Holland, Amsterdam).

Marsh, Thomas L., Ted C. Schroeder and James Mintert, 2004, Impacts of meat product recalls on consumer demand in the USA, *Applied Economics* 36, 897-909.

McGuirk, Anya, Paul Driscoll, Jeffrey Alwang and Huilin Huang, 1995, System misspecification testing and structural change in the demand for meats, *Journal of Agricultural and Resource Economics* 20, 1-21.

Meghir, Costas and Guglielmo Weber, 1996, Intertemporal nonseparability or borrowing restrictions? A disaggregate analysis using a U.S. consumption panel, *Econometrica* 64, 1151-1181.

Mehra, Rajnish and Edward C. Prescott, 1985, The equity premium: A puzzle, *Journal of*

Monetary Economics 15, 145-161.

Miranda, Mario J. and Paul L. Fackler, 2002, *Applied Computational Economics and Finance* (MIT Press, Cambridge, MA).

Miranda, Mario J. and Xiongwen Rui, 1997, Maximum likelihood estimation of the nonlinear rational expectations asset pricing model, *Journal of Economic Dynamics and Control* 21, 1493-1510.

Miranda, Mario J. and Joseph W. Glauber, 1993, Estimation of dynamic nonlinear rational expectations models of primary commodity markets with private and government stockholding, *Review of Economics and Statistics* 75, 463-470.

Muellbauer, John, 1988, Habits, rationality and myopia in the life cycle consumption function, *Annales d'Economie et de Statistique* 9, 47-70.

Naik, Narayan Y. and Michael J. Moore, 1996, Habit formation and intertemporal substitution in individual food consumption, *Review of Economics and Statistics* 78, 321-328.

Newey, Whitney K. and Kenneth D. West, 1987, A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix, *Econometrica* 55, 703-708.

_______, 1994, Automatic lag selection in covariance matrix estimation, *Review of Economic Studies* 61, 631-653.

Nishiyama, Shin-Ichi, 2005, The cross-Euler equation approach to intertemporal substitution in import demand, *Journal of Applied Econometrics* 20, 841-872.

Olekalns, Nilss and Peter Bardsley, 1996, Rational addiction to caffeine: an analysis of coffee consumption, *Journal of Political Economy* 104, 1100-1104.

Phlips, Louis, 1983, *Applied Consumption Analysis*, North-Holland Publishing Company.

Piggott, Nicholas E. and Thomas L. Marsh, 2004, Does food safety information impact U.S. meat demand, *American Journal of Agricultural Economics* 86, 154-174.

Pollak, Robert A., 1970, Habit formation and dynamic demand functions, *Journal of Political Economy* 78, 745-763.

Pollak, Robert A. and Terence Wales, 1969, Estimation of the linear expenditure system, *Econometrica* 37, 611-628.

Pope, Rulon, Richard Green and Jim Eales, 1980, Testing for homogeneity and habit formation in a flexible demand specification of U.S. meat consumption, *American Journal of Agricultural Economics* 62, 778-784.

Ravina, Enrichetta, 2004, Keeping up with the Joneses: evidence from micro data, Department of Economics, Northwestern University.

Richards, Timothy J., Paul M. Patterson and Abe Tegene, 2004, Obesity and nutrient consumption: a rational addiction? Paper presented at AAEA Annual Meeting, Denver, Co.

Robenstein, Rodney G. and Walter N. Thurman, 1996, Health risk and the demand for red meat: Evidence from futures markets, *Review of Agricultural Economics* 18, 629-641.

Ryder, Harl E. and Geoffrey M. Heal, 1973, Optimum growth with intertemporally dependent preferences, *Review of Economic Studies* 40, 1-33.

Sakong, Young and Dermot Hayes, 1993, Testing the stability of preferences: a nonparametric approach, *American Journal of Agricultural Economics* 75, 269-277

Sargent, Thomas J., 1987, *Macroeconomic Theory* (Academic Press, New York).

Sarmiento, Camilo, 2005, A varying coefficient approach to global flexibility in demand analysis: a semiparametric approximation, *American Journal of Agricultural Economics* 87, 38-47.

Silberberg, Eugene, 1985, Nutrition and the demand for tastes, *Journal of Political Economy* 93, 881-900.

Smith, Mark E., Eileen O. van Ravenswaay, and Stanley R. Thompson, 1988, Sales loss determination in food contamination incidents: an application to milk bans in Hawaii, *American Journal of Agricultural Economics* 70, 513-520.

Stigler, George J., 1945, The cost of subsistence, *Journal of Farm Economics* 27, 303-314.

Stigler, George J. and Gary S. Becker, 1977, De gustibus non est disputandum, *American Economic Review* 67, 76-90.

Tauchen, George, 1986, Statistical properties of generalized method-of-moments estimators of structural parameters obtained from financial data, *Journal of Business and Economic Statistics* 4, 397-425.

Thomsen, Michael R. and Andrew M. McKenzie, 2001, Market incentives for safe foods: an examination of shareholder losses from meat and poultry recalls, *American Journal of Agricultural Economics* 82, 526-538.

Thurman, Walter N., 1987, The poultry market: demand stability and industry structure, *American Journal of Agricultural Economics* 69, 30-37.

United States Department of Agriculture. Economics of foodborne disease. http://www.ers.usda.gov/Briefing/FoodborneDisease/ 2000.

United States Department of Environmental Protection Agency, Office of Science and Technology, 2002, *Economic analysis of proposed effluent limitations guidelines and standards for the meat and poultry products industry*, EPA-821-B-01-006, Washington DC.

Verbeke, Wim and Ronald W. Ward, 2001, A fresh meat almost ideal demand system incorporating negative TV press and advertising impact, *Agricultural Economics* 25, 359-374.

Wang Gene-Jack, Nora D. Volkow, Frank Telang, Millard Jayne, Jim Ma, Manlong Rao, Wei Zhu, Christopher T. Wong, Naomi R. Pappas, Allan Geliebter and Joanna S. Fowler, 2004, Exposure to appetitive food stimuli markedly activates the human brain, *NeuroImage* 21, 1790-1797.

Wohlgenant, Michael K. and William F. Hahn, 1982, Dynamic adjustment in monthly consumer demands for meats, *American Journal of Agricultural Economics* 64, 553-557.

Wohlgenant, Michael K., 1993, Distribution of gains from research and promotion in multistage production systems: the case of the U.S. beef and pork industries, *American Journal of Agricultural Economics* 75, 642-651.