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Demand for risky foods and food safety

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Demand for risky foods and food safety

by

Kung-Cheng Lin

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GENERAL INTRODUCTION:

AN OVERVIEW OF FOOD SAFETY PROBLEMS

Americans have spent on average more than fifteen percent of their total expenditures on food at home and away from home yearly since 1986 (CES 1992). Are food supplies safe? Kramer (1990) listed eight major food safety incidents[1] in the 1980s. These incidents involved a wide range of food items[2] and have caused substantial economic losses such as illness or death to individuals and sale losses to food industries. How do consumers react to food safety accidents? Do they care about food safety problems? This general introduction first explains the dissertation format and then describes three economic issues in food safety problems: the costs incurred in the food safety incidents, consumers' attitudes to the risks in foods, and the importance of uncertainties involved in food safety problems. Finally, we discuss what economists can do for these problems.

An Explanation of the Dissertation Organization

Following the general introduction are three separate papers which relate to issues in food safety. The format in each paper is self-contained with its own introduction, model, summary conclusion, references, tables, and figures. Paper I constructs a basic model for the analysis of demand for two risky foods. Both of the cases of exogenous and endogenous safety levels are considered. Paper II applies the model in section I to derive the measure of the consumer's willingness to pay for the food safety improvement and the marginal willingness to pay for the risky food. Paper III considers the issue of whether the perfectly competitive market would provide the socially optimal safety level and implications for the government's regulation of the food supply. Following Paper III is a general conclusion.

References cited in the general introduction and conclusion sections are included in the literature cited section.

The Costs of Food Safety Accidents

Food safety accidents cause economic losses either for consumers or producers, or both. These costs may include medical costs, productivity loss, values associated with consumer deaths[3] and sales losses for producers. For consumers, the "cost of illness" (COI) approach is the traditional way used to estimate the loss due to the foodborne diseases. COI measures the resources that the economy would save if the accident did not occur. Based on 1987 values, for example, Roberts (1989) estimated the human illness costs (including only medical costs and productivity losses) at $4.8 billion annually caused by all foodborne bacterial diseases. Recent estimates give the range of COI for U.S. microbial foodborne diseases is between $4 and $8 billion annually (Roberts and Marks 1993). Listeria, a microbial organism which might cause serious health problems, has been found in prepared sandwiches and fresh vegetables; and caused 400-500 deaths out of an average 1600 cases of infection reported each year (Kramer 1990)[4].

Producer losses in sales have been estimated in several studies. Smith et al. (1989), for example, studied the effects of the announcement of the pesticide heptachlor contamination of fresh fluid milk in Oahu of Hawaii in 1982. Although a considerable amount of suspicious milk was recalled or dumped, the continuous media reports were found to affect the demand for milk in Oahu. The total estimated sales loss of $422,000 amounted to over $26,000 per producer in Oahu. Another example concerns the estimated sales losses from the publicity concerning Alar use on apples, which amounted to $194.8 million (in 1983 dollars) during the July 1984 to July 1989 periods (van Ravenswaay and Hoehn 1991). In addition to the sales losses such as these due to the announcement of risky contamination in foods, food producers may also suffer losses of sales or market share from the competition of other food producers in producing differentiation foods (Caswell and Johnson 1991).

These examples provide some idea of what types of costs may occur to consumers and producers, and how serious the accidents may be. The range of estimates indicates the inherent difficulty in estimation of consumers' illness costs and that consumer's perceived risk is likely to have an important effect on changes in the demand for risky foods.

Consumers' Attitudes Toward the Food Safety Problems

Faced with possible losses from consuming risky foods, what is the consumer response to the potential food safety hazard[5]? The following lists some of observations based on recent surveys. A survey by the Food Marketing Institute (FMI) in 1991 showed that an average of more than 75% of respondents considered residues (such as pesticides and herbicides) as a serious hazard during the period of 1985 to 1991; this number reached 80% in 1991 (FMI 1991). Other surveys also have reported similar results (van Ravenswaay 1988). When people have been asked "how confident are they about the safety of foods in the supermarket" in the January 1989 FMI's annual survey, 81% of respondents felt strongly confident (Senauer et al. 1991). This figure had dropped to 67% in a follow-up FMI's survey after the Alar issue and the grape tampering episode in the early of 1989. However, this confidence figure recovered to 79% and 82% in the January 1990 and 1991 FMI's surveys, respectively.

Consumers appear to be concerned about food safety issues but the structure of their concern is changing. The continuous surveys by FMI indicate consumers' increased concerns about nutritional issues instead of foodborne diseases through an open-ended question. This result may imply the consumers are more educated about nutritional issues or consumers are changing their concerns about food safety issues through time (van Ravenswaay 1988).

An important feature of food safety is that the ranking of food safety issues by consumers is different from the ranking of scientific experts. In rating the consumers' concerns about food safety issues, pesticide residues and environmental contaminants appear to be of greatest concern in many surveys (Jones 1992). These surveys also indicate that disease or bacterial contamination are the next greatest concern, followed by preservatives and artificial colors, irradiation and artificial sweeteners. However, this ranking is opposite to that of scientific experts. The Food and Drug Administration (FDA) has considered diseases caused by microorganisms as the most serious foodborne health risk for many years. Incidences of reported foodborne diseases due to bacterial diseases surpass those caused by chemical, parasitic and viral diseases (Kramer 1990). In fact, the FDA also considers malnutrition and nutritional imbalance as the second most serious food safety problem.

In sum, most consumers show great concern about food safety issues but they appear confident in the safety of food supplies. Second, consumers' concerns have switched from ranking foodborne diseases to nutritional issues in the last five years. Finally, the ranking of consumers' concern about the types of risk runs counter to experts' concern. These observations about consumers' attitudes and the information about the risk in foods point out inherent uncertainty in the risky effects of foods and asymmetric information about food safety.

Risks and the Problems of Uncertainty

In considering food safety, risky food is one that contains hazardous ingredients such as excessive pesticides, or microbial contamination; and the consumption of the risky food may cause some degree of loss. In this section, a summary about the definition of risk, the types of risk, and the risky effects is given first. Then the potential uncertainties surrounding the risk and the risky effects are identified.

The meaning of risk is often confused between scientists and consumers (Kendall 1990). In science, risk is usually defined as "the probability of loss or injury." More precisely, risk is the probability that an adverse effect of some kind of loss will occur (Wilkinson 1990). However, in forming perceptions about risk, consumers are affected both by the announcement of "the probability of loss" from experts as well as other factors such as mass reports of media on particular food accidents.

The types of food safety risk can be grouped as the following: (1) chemical or pesticides in agricultural products, (2) pathogenic microorganisms, and (3) naturally occurring toxins, such as aflatoxin which is exhibited by a mold contained in corn or peanuts (Kramer 1990). Sometimes, the concerns of nutritional health, the effects of cigarette smoking and alcohol drinking are also considered as food safety issues (Jones 1992).

The hazardous or toxic effects in consuming risky foods are generally divided into two categories: acute and chronic effects (Wilkinson 1990). Acute effects usually occur within a short period of time (say 24 - 48 hours) after exposure, for example, from exposure to E-coli in meats or fruits. Acute effects are considered to be more easily evaluated than chronic effects which are often cumulative in nature. The chronic effect may be delayed for years after exposure, for instance, illness caused by long-term exposure to carcinogenic agents applied as pesticides to foods.

All sorts of uncertainties arise in food safety problems: uncertainties about identification and characterization of food safety hazards, the effect of hazards on the public health, and interaction of various types of hazards in the human body. Scientific experts sometimes have different opinions on the identification of risky effects. For example, contradictory evidence about the effect of livestock hormones residues on humans has confused consumers about the safety of the meat products and has been used by the European Community (EC) as a rationale to protect meat consumers (and, of course, producers at the same time) in the EC countries (Krissoff 1989). The scientific controversy about mixed evidence also tends to decrease consumers' confidence in the experts' opinions, making consumers even more likely to be misled by media reports.

Uncertainty which arises from how foods are processed is another important issue. In the case of pesticide residues, the potential risk to human health is a function of the toxicity of the pesticide residues in foods and the level of exposure. Some risks can be avoided by consumers in selecting foods grown without pesticide application or by washing and/or peeling food in home preparation. However, consumers have less control over the quality of commercially processed foods. Without further searching or obtaining information about the process used in producing food (or source of agricultural product ingredients), consumers are uncertain to what levels of the risk they are being exposed. Another uncertainty is about to what degree exposure to residues may adversely affect health, which is likely to depend on many individual characteristics.

What Can Economists Do?

The fact that consumers often distort the scientific risks in foods, and under or over estimate dietary hazards indicates the need for better understanding of what factors affect consumers' risk perception. Given the importance of encouraging the private sector to improve food safety levels (Kramer 1990), it is of prime importance to provide information which can guide resource allocation to achieve aggregate safety improvements. Information on consumers' willingness to pay (WTP) will be important to food industries in making decisions about production technologies. Explaining consumer perception of risk related to food safety issues and obtaining a reasonable estimate of consumers' valuation of food safety are two important tasks for economists. In this section, the first issue considered is consumers' risk perception. Then a review of estimates of individuals' WTP for food safety is presented.

Explaining the Consumers' Risk Perception

Changes in consumers' perception of risk and reaction to the controversies about the health risk of certain hazardous contaminants in foods can cause significant sales losses (Swartz and Strand 1981; Smith et al. 1988; van Ravenswaay and Hoehn 1991). The study of what factors affect consumers' risk perception, and by what process, has become an important issue for food producers and the government.

The psychometric paradigm, one of the traditional ways of research on consumer perception of risk about consuming goods or activities, focuses on the explanation of how the consumer's perceptions vary given the different characteristics of each type of risk (van Ravenswaay 1991). Slovic (1986) gave a list of factors[6] that affect the individual's perceived risk. For example, the individual may consider the "not memorable" event being "less risky" and the "memorable" event being "more risky." Analogous to Slovic's observations, people are more concerned about the effect of pesticide residues than bacterial-causing disease because the former is frequently covered by the media (memorably) by the consumers. Another example is that individuals increase their concern about nutritional aspects of foods while having less concerns about diseases caused by bacteria in foods because the former is considered being more "controllable"[7] by consumers than the latter.

For economists in regard to the consumers' risk perception, the task is to provide a better understanding of what factors determine the consumers' acquisition of information and what are efficient ways of providing information to narrow the gap in the differing risk assessments of food experts, food industries, and consumers. Putler and Frazao (1991), for example, looked at how the consumption level of total fat intakes in foods varied with women's characteristics and awareness of health information. Their study tried to explain what are the factors in determining the demand for risky food (determined relative to fat intake). Further research on investigating the determinants of efficiently providing information is needed.

The Estimation of the Consumer's WTP

One of the important tasks that economists can do for food safety problems is to provide guidance for determining consumers' value (willingness to pay) for safety when markets do not work properly in providing the information about safety value. There are several methods by which to estimate the individual's WTP for the reduction of risk in foods: (1) the contingent valuation method (CVM), (2) the laboratory simulation, or experimental methods, and (3) the hedonic pricing method (observed market behavior) and the input resource method (nonmarket behavior) which examines individuals' willingness to spend more time (i.e., time resources) in providing safer food at home.

The common method by which to evaluate WTP is to use a contingent valuation method by surveying consumers directly. The advantages of CVM are the ability to examine a considerable subset of the population and the opportunity to compare the consumer's preferences for different processing technologies (Roberts and Marks, 1993). For instance, Misra, et al. (1991) used CVM to measure individuals' WTP for the differentials between pesticide free (organic food) and pesticide treated produce in the Georgia area, and concluded that the individual's risk attitude was an important factor in determining the magnitude of WTP for organic food.

The major disadvantage of CVM is that the respondents are considered to answer any question in a "hypothetical" situation (what they think) rather than in a real situation (what they actually do). The laboratory simulation method is one method which tries to overcome this disadvantage. Based on a laboratory experiment, for example, Shin (1991) used nonhypothetical experimental methods to evaluate participant response, when informed about the probabilities of getting a microbial foodborne disease in a meal, to estimate the individual's WTP for a safer meal. There were several limitations to his study, however, and care needs to be taken in designing what is the "realistic" situation in this method. The small sample problem and nonrepresentative sample problem are likely to be shortcomings of this method.

Another way of measuring WTP is the hedonic pricing method. This method looks at the existing market for goods to evaluate the price difference for a particular product when the safety level (or perceived risk) changes. The study of van Ravenswaay and Hoehn (1991) is one application of this method to food safety. They analyzed welfare implications due to the announcement of Alar exposure in apples during the period 1984-89; and measured consumers' WTP for Alar free apples, by estimating a value, (or price), ascribed to the value of apples with and without Alar risk. The hedonic method is restricted in two ways: first, the equilibrium price change may be caused both by changes in safety (risk perception) as well as other factors, such as changes in income and prices of substitutes; second, it is difficult to derive the social aggregate WTP from this method.

The relation among alternative valuation methods (COI, self-protective expenditures, and WTP) has been a focus of study in evaluating specific health risk (Berger et al. 1987; Shogren and Crocker 1991; Quiggin 1992). COI and self-protective expenditures are often considered as the lower bound of WTP in estimating the individual's valuation of health risk change (Berger et al. 1987). For valuing demand for food safety, self-protective behavior in food safety, such as time resources used in searching for a safer food or carefully preparing foods, could be used to value the WTP for improvement of food safety. However, lack of data in this area leaves the study of using this technique in estimating WTP still in its beginning.

This review has summarized methodologies used and selected empirical studies for estimating WTP for safer food. Continuing research on the estimation of WTP for food safety will be useful for food industries and policy makers. As indicated by Kramer (1988), economists can make an important contribution to public policy related to the food safety problem by providing a better understanding of consumers' valuation of food safety or safety information.

NOTES

1 These accidents are: (1) Alar contamination in apples, (2) Chilean grape poisoning, (3) seafood safety, (4) poultry, livestock products and salmonella, (5) Listeria in dairy products and vegetables, (6) hormone use in livestock, (7) aflatoxin in peanuts and corn, and (8) saturated fat in "Tropical" oils.

2 These foods included apples, grapes, corn, peanuts, vegetables, poultry, livestock products, dairy products, seafood, sandwiches, and palm kernel oils, etc.

3 A reasonable estimation of consumers' losses should also try to cover the following: leisure time losses, pain and suffering, child care costs, risk aversion costs, travel costs, averting behavior costs, home modifications, and vocational and physical rehabilitation costs (Roberts 1989). However, some of these costs are difficult to estimate in practice.

4 A summary of the death rates and estimated COI of various foodborne bacterial diseases could be found in Roberts and Foegeding (1991), page 121.

5 Jones (1992) considers food safety issues to include foods which involve the following: additives, colors, and flavors; antibiotics and other food additive; fertilizers and other growing aids; irradiation; microbiological contamination; naturally occurring food toxicant; nutrition; pesticides; pollutants; processing, package and labeling; or tampering. However, some researchers do not consider the nutritional issues as food safety problems.

6 These factors are:

<u>Less Risky</u>	<u>More Risky</u>
Voluntary	Involuntary
Familiar	Unfamiliar
Controllable	Uncontrollable
Controlled by Self	Controlled by others
Fair	Unfair
Not memorable	Memorable
Not dread	Dread
Chronic	Acute
Diffuse in time and space	Focused in time and space
Not fatal	Fatal
Immediate	Delayed
Natural	Artificial
Individual mitigation possible	Individual mitigation impossible

Detectable	Undetectable
Old risk	New risk
Known to science	Unknown to science
Easily reduced	Not easily reduced
Individual	Catastrophic
Does not affect me	Affects me
Not in my back yard	In my back yard

7 Slovic considered the "controllable" behavior being "more risky" and the "uncontrollable" behavior being "less risky."

PAPER I.

SAFETY AND DEMAND FOR RISKY FOODS

INTRODUCTION

Food safety issues have become a major concern for consumers in recent years. Concern about chemical contaminants in foods that present a potential hazard for human health led to the creation of a food contamination monitoring program in 1976, which was sponsored by the United Nations, World Health Organization (WHO), and the Food and Agricultural Organization (FAO). A US. survey by Food Marketing Institute showed that an average above 75 percent of respondents considered pesticide residues in food as a serious hazard between 1984 and 1989 (Senauer et al. 1991). Economic theory predicts that the perception of the risky content in food by consumers will have an adverse effect on the demand for the food. Recent examples include the decrease in the consumption of fresh apples in response to the announcement of Alar residues in apples (van Ravenswaay and Hoehn 1991), and the European Community's ban of beef imports on the basis of hormone use in production.

There has been little theoretical work on the theory of demand for foods in the presence of risk. Two studies which incorporate the aspects of risk in consumption are Ippolito (1981), and Choi and Jensen (1991). They focused on demand for one risky good. However, consumers have imperfect information about product characteristics. Continued scientific research may reveal hitherto unknown hazards of a consumption good that was considered safe in the past. Thus, it is more realistic to suppose that most consumption goods (more than one) are risky. For instance, it is difficult to find a food without hazards. High intake of saturated fat and relatively high cumulative cholesterol levels from red meat have been linked to heart disease. A switch in diet from red meat to more vegetables may considerably reduce levels of cholesterol in the body, but pesticide residues have been found on vegetables. Thus, it is important to understand how a consumer chooses among risky consumption goods.

This paper analyzes the demand for two risky foods. While the theory can be extended to n risky foods, the basic framework is developed for two risky foods. The consumer derives some utility directly from the consumption of the risky foods. However, unlike pure consumption goods in conventional demand theory, a risky food has a side effect; a risky food contains an ingredient which reduces the probability of survival of the consumer[1].

The paper is organized as follows. Section 2 investigates demand for two risky foods over two periods when the hazard contents of the risky foods are fixed. Section 3 considers demands for safety and quantities when safety levels are chosen by the consumer. Section 4 contains concluding remarks.

DEMAND FOR RISKY FOODS WHEN HAZARD LEVELS ARE FIXED

In conventional demand theory consumption goods are assumed to increase utility without side effects and will be called pure foods here. Foods with negative side effects will be called impure or "risky" foods[2]. To analyze demand for risky foods which contain hazardous ingredients, it is important to specify whether consumers are capable of choosing the level of hazards embodied in the product. In this section, we investigate demand for foods whose hazards levels can not be changed by the consumer.

A risky food contains a potentially hazardous ingredient such as a toxin, pathogen, or carcinogen. Assume that the hazard cannot economically be separated by the consumer. When a commodity bundle contains an impure consumption good, the consumer has to weigh the direct utility gains versus potential health risks. Consequently, a von Neumann-Morgenstern utility function is used to derive demand functions for risky foods.

For simplicity, assume that the consumer spends income on two risky foods each period. Consumer preferences in each period can be represented by a monotone increasing and concave von Neumann-Morgenstern utility function

$$u_t = u(X_{1t}, X_{2t}),$$

where X_{it} is the quantity of the risky food X_i in period t, i = 1,2. Total utility of the consumer is

$$U = \sum_{t=1}^{T} \delta^{t-1} u(X_{1t}, X_{2t}) \tag{1}$$

where T is the terminal period, and δ is a discount factor, $0 < \delta \leq 1$.

Equation (1) yields total utility when the survival into the terminal period T is certain. When the probability of survival into the second period is uncertain, however, the utility in each period must be further weighed by the probability of survival. Obviously, in a multiperiod model with T > 2, the probability of survival continually declines until the terminal period is reached.

To get insights on the demand for risky foods when survival is uncertain in the least complicated way, we use a two period model (T = 2). Consider a representative individual who lives for two periods with time-invariant utility functions over the two risky foods, X_1 and X_2. We assume that the hazard content of these foods cannot be detected by visual inspection and that the harmful effects of the risky foods are realized after a time lag, as in the case of many carcinogens. Thus, the hazards do not affect consumer's utility in the current period, but affect the consumer's chance of survival in good "health" into the next period. Thus, the consumer faces uncertainty regarding survival into the next period.

Assume that the probability of survival is less than one and known by the consumer. Let π be the probability of survival into the second period, $0 \leq \pi < 1$. The budget constraint in each period is given by

$$p_{1t}X_{1t} + p_{2t}X_{2t} = I_t, \quad t = 1,2.$$

where p_{it} and I_t are the price of the risky good X_i and income in period t, respectively. If the consumer survives, he maximizes $u(X_{12}, X_{22})$ subject to the budget constraint in the second period. Let $X_1[p_{12}, p_{22}, I_2]$ and $X_2[p_{12}, p_{22}, I_2]$ denote the second period demand functions. The indirect utility in the second period is then

$$v(p_{12}, p_{22}, I_2) \equiv u[X_1(p_{12}, p_{22}, I_2), X_2(p_{12}, p_{22}, I_2)].$$

It should be noted that the individual receives no income if he does not survive. Without loss of generality, we assume that the utility level in the second period is zero if the consumer fails to survive ($u_2 = 0$). Assume further that the utility function in each period is normalized so that the utility in the second period when the consumer survives is unity, i.e., $u_2 = v = 1$. Then the second period utility can be written as a random variable,

$$u_2 = \begin{cases} 0, \text{with probability } (1-\pi), \\ 1, \text{with probability } \pi. \end{cases}$$

The expected utility of the consumer is

$$J = u(X_1, X_2) + \delta\pi \quad (2)$$

where the subscript t = 1 is suppressed (i.e., $X_1 = X_{11}$ and $X_2 = X_{21}$).

Let α_i denote the amount of impurity per unit of the risky foods X_i consumed. For simplicity, the hazard content in each food is assumed to be constant and is normalized so that $0 \le \alpha_1, \alpha_2 \le 1$.[3] Then the amounts of impurity absorbed, C_i, are defined as

$$C_i = \alpha_i X_i = (1-\beta_i)X_i, \quad i = 1,2. \quad (3)$$

where $\beta_i \equiv 1-\alpha_i$ is a measure of the safety level of X_i; an increase in β_i indicates increased safety of X_i.

The probability of survival is written as

$$\pi = \pi(C_1, C_2). \quad (4)$$

Assume that the probability of survival is decreasing in C_i, i.e., $\pi_i < 0$, where $\pi_i \equiv \dfrac{\partial \pi}{\partial C_i}$, $i = 1,2$. Assume further that the probability of survival function is constantly equal to one when there is no impurity, i.e., $\pi(0,0) = 1$.

The consumer's problem is to maximize the expected utility, $J = u(X_1, X_2) + \delta\pi$ subject to the budget constraint, $I = p_1 X_1 + p_2 X_2$. The Lagrangian function associated with this problem can be written as

$$L = u(X_1 X_2) + \delta\pi + \lambda(I - p_1 X_1 - p_2 X_2) \quad (5)$$

The first order conditions are

$$\frac{\partial L}{\partial X_1} = u_1 + \delta\alpha_1\pi_1 - \lambda p_1 = 0, \tag{6a}$$

$$\frac{\partial L}{\partial X_2} = u_2 + \delta\alpha_2\pi_2 - \lambda p_2 = 0, \tag{6b}$$

$$\frac{\partial L}{\partial \lambda} = I - p_1X_1 - p_2X_2 = 0, \tag{6c}$$

where $u_i \equiv \frac{\partial u}{\partial X_i}$. The solutions to (6a), (6b), and (6c) yield the following demand functions:

$$X_1 = X_1[p_1, p_2, I; \beta_1, \beta_2, \delta], \quad X_2 = X_2[p_1, p_2, I; \beta_1, \beta_2, \delta]. \tag{7}$$

Equations in (7) imply that demand functions are conditioned on safety levels or hazards, as well as by prices and income.

Information and Demand for Risky Foods

We first consider the role of safety information on the demand for risk foods. Equations (6a) and (6b) yield the equilibrium condition,

$$\frac{J_1}{J_2} = \frac{p_1}{p_2}, \tag{8}$$

where $J_i \equiv \left[u_i(X_1^*, X_2^*) + \delta\alpha_i\pi_i(\alpha_1X_1^*, \alpha_2X_2^*)\right]$ is the expected marginal utility of X_i.

Recall that the hazards in risky goods cannot be detected by visual inspection. If the consumer ignores the hazards in the consumption goods, he would behave as does the consumer in conventional demand theory. But, how does the consumer who is informed about the hazard behave relative to the uninformed consumer? If the hazards contained in X_1 and X_2 are ignored, then the resulting equilibrium may not be optimal, depending on the magnitude of $\alpha_1\pi_1$ and $\alpha_2\pi_2$.

To illustrate the impacts of ignorance of risk on the choice between risky foods, consider the case in Figure 1. In Figure 1, the optimal consumption occurs at point E, where the indifference curve J is tangent to the budget line, AB. If the consumer ignores the hazard in X_1, then $-\frac{u_1}{J_2}$ (the slope of U in Figure 1) is equated to $-\frac{p_1}{p_2}$ at a point F, which causes over-consumption of X_1, i.e. $X_1^* < X_1^\circ$.[4] This implies that *the consumer buys less of the risky food, X_1, when he correctly knows the hazard in the risky food* than when the hazard is ignored. In other words, when the hazard in X_2 is ignored, the individual consumes too much X_2.

PROPOSITION 1: Assume that one good is safe and the other is risky. Then lack of information about hazards in the risky good (i.e. the individual mistakenly assumes the risky food is safe) results in over-consumption of the risky good.

How does the consumer behave when the hazards in both foods are ignored? The consumer equates $\frac{u_1}{u_2}$ (instead of $\frac{J_1}{J_2}$) to the price ratio when the hazards in both goods are ignored. Note that the indifference curve $\frac{J_1}{J_2}$ is steeper (flatter) than the indifference curve $\frac{u_1}{u_2}$ if $\frac{J_1}{J_2}-\frac{u_1}{u_2} > (<)\ 0$, which holds if and only if $\frac{\alpha_1\pi_1}{\alpha_2\pi_2} < (>) \frac{u_1}{u_2}$. If $\frac{\alpha_1\pi_1}{\alpha_2\pi_2} < \frac{u_1}{u_2}$, X_1 can be viewed as safer than X_2. In this case, ignorance of hazards in both goods results in under-consumption of X_1. On the other hand, if $\frac{\alpha_1\pi_1}{\alpha_2\pi_2} > \frac{u_1}{u_2}$, then X_1 is riskier than X_2, and lack of information results in over-consumption of X_1.

The Effect of a Change in Income

First, consider the effect of a change in income on demand. Differentiating (6a) -(6c) with respect to I gives

$$\frac{\partial X_1}{\partial I} = \frac{(p_2 J_{12} - p_1 J_{22})}{H}, \tag{9a}$$

$$\frac{\partial X_2}{\partial I} = \frac{(p_1 J_{21} - p_2 J_{11})}{H}, \tag{9b}$$

$$\frac{\partial \lambda}{\partial I} = \frac{(J_{12}^2 - J_{11} J_{22})}{H}, \tag{9c}$$

where

$$J_{ij} = \frac{\partial^2 J}{\partial X_i \partial X_j} = u_{ij} + \delta \alpha_i \alpha_j \pi_{ij},$$

and H is the determinant of the bordered Hessian matrix

$$[H] = \begin{bmatrix} J_{11} & J_{12} & -p_1 \\ J_{21} & J_{22} & -p_2 \\ -p_1 & -p_2 & 0 \end{bmatrix}.$$

By the second order conditions, the bordered Hessian, $H = -p_1^2 J_{22} - p_2^2 J_{11} + 2p_1 p_2 J_{12}$, is positive. From (9a) and (9b), the sign of $\frac{\partial X_i}{\partial I}$ is generally indeterminate. The risky good X_i can be said to be normal if $\frac{\partial X_i}{\partial I} \geq 0$.

Change in the Price of a Risky Food

As in the conventional case with riskless foods, the effect of a price change can be decomposed into the substitution and income effects. Differentiating the first order conditions (6a) - (6c) with respect to p_1 yields

$$\frac{\partial X_1}{\partial p_1} = \frac{-p_2^2\lambda}{H} - X_1\left(\frac{\partial X_1}{\partial I}\right), \tag{10a}$$

$$\frac{\partial X_2}{\partial p_1} = \frac{p_1 p_2 \lambda}{H} - X_1\left(\frac{\partial X_2}{\partial I}\right). \tag{10b}$$

Although the expressions of the total effects in (10a) and (10b) are the same as those in the conventional case in the absence of risk, their values will be affected - although the direction is unclear - by the probability of survival, the discount rate and amount of hazards, α_1 and α_2, all of which are embedded in H. As in the conventional case, the first term $\frac{-p_2^2\lambda}{H}$ in (10a) can be viewed as the substitution effect, whereas the second term, $-X_1\left(\frac{\partial X_1}{\partial I}\right)$, is the income effect from a price change.

In general, the sign of $\frac{\partial X_1}{\partial p_1}$ or $\frac{\partial X_2}{\partial p_1}$ cannot be determined. Note that the substitution effect $\frac{-p_2^2\lambda}{H}$ in (10a) is negative. If X_1 is a normal good, then an increase in the price of X_1 will reduce the demand for X_1. If X_2 is a normal good, then an increase of the price of X_1 will have an ambiguous effect on the sign of X_2 and the sign of $\frac{\partial X_2}{\partial p_1}$ will depend on the magnitude of two positive terms, $\frac{p_1 p_2 \lambda}{H}$ and $X_1\left(\frac{\partial X_2}{\partial I}\right)$.

Hazard Aversion and Change in Risk

To investigate the effects of a change in hazard content, it is useful to introduce the notion of hazard aversion. The Arrow-Pratt measures of absolute risk aversion

$A(I) = -\frac{u''(I)}{u'(I)}$ and relative risk aversion $R(I) = -\frac{Iu''(I)}{u'(I)}$ have been widely used, where u(I) is the utility of income function. To investigate consumption decisions on risky goods, we similarly define *absolute hazard aversion* in hazard C_i,[5]

$$A_i(C_1, C_2) = \frac{\pi_{ii}}{\pi_i} > 0,$$

and *relative hazard aversion* in hazard C_i,

$$R_i(C_1, C_2) = \frac{C_i \pi_{ii}}{\pi_i} > 0.$$

Observe that $\pi_{ii} < 0$ implies that the probability of survival decreases at *an increasing rate.* Further, $\pi_{ii} < 0$ also implies that the individual who reveals hazard aversion considers that the initial level of toxin may not have a serious effect on survival. When the level of toxin continues to accumulate and exceeds some certain amount or level, the probability of survival drops rapidly.

An example of constant hazard aversion can be considered as follows. Consider the probability of survival function as

$$\pi(C_1, C_2) = \begin{cases} \dfrac{e^{\gamma\overline{C}_1} - e^{\gamma C_1} + e^{\gamma\overline{C}_2} - e^{\gamma C_2}}{e^{\gamma\overline{C}_1} + e^{\gamma\overline{C}_2} - 2}, & \text{if } 0 \le C_i \le \overline{C}_i \\ 0, & \text{otherwise} \end{cases},$$

where e is the exponential function; $\overline{C}_i$ is the maximum amount of hazard content for C_i; and γ is a positive parameter. Note that $e^{\gamma\overline{C}_1} + e^{\gamma\overline{C}_2} - 2 > 0$ for positive values of γ and $\overline{C}_i$, i = 1,2. This survival function satisfies the following conditions:

$$\pi(C_1 = 0, C_2 = 0) = 1,$$
$$\pi(C_1 = \overline{C}_1, C_2 = \overline{C}_2) = 0,$$

$$\frac{\partial \pi}{\partial C_i} = \frac{-\gamma e^{\gamma C_i}}{e^{\gamma \bar{C}_1} + e^{\gamma \bar{C}_2} - 2} < 0,$$

$$\frac{\partial^2 \pi}{\partial C_i^2} = \frac{-\gamma^2 e^{\gamma C_i}}{e^{\gamma \bar{C}_1} + e^{\gamma \bar{C}_2} - 2} < 0, \text{ and}$$

$$\frac{\partial^2 \pi}{\partial C_i \partial C_j} = 0,$$

for i, j = 1, 2 and $i \neq j$. In this case, the absolute hazard aversion $A_i(C_1, C_2) = \frac{\pi_{ii}}{\pi_i} = \gamma$ is constant. Therefore, γ can be considered as the *constant absolute hazard aversion* (CAHA) coefficient.

We now consider the effect of a change in hazard content on the demand for the risky foods. Differentiating (6a) - (6c) with respect to β_1 gives

$$\frac{\partial X_1}{\partial \beta_1} = \frac{-p_2\delta[p_2(\pi_1 + \alpha_1\pi_{11}X_1) - p_1\alpha_2X_1\pi_{21}]}{H}, \tag{11a}$$

$$\frac{\partial X_2}{\partial \beta_1} = \frac{p_1\delta[p_2(\pi_1 + \alpha_1\pi_{11}X_1) - p_1\alpha_2X_1\pi_{21}]}{H}. \tag{11b}$$

Generally, an increase in the safety level of one food will have an ambiguous effect on the demand for its own or the other food, i.e., $\frac{\partial X_i}{\partial \beta_j}$ may be positive or negative, $i, j = 1, 2$.

First, consider the case of risk independence ($\pi_{21} = 0$). Intuitively, $\pi_{21} = 0$ implies that the marginal toxicity of C_2 ($\frac{\partial \pi}{\partial C_2}$, which is negative) is independent of an increase of the other toxin C_1. Hazard aversion ($\pi_{11} < 0$) then implies $\frac{\partial X_1}{\partial \beta_1} > 0$, and that an improvement of the safety level of food i increases the demand for food i and decreases the demand for the other food. Further, when $\pi_{21} = 0$, (11a) and (11b) can be written as

$$\frac{\partial X_1}{\partial \beta_1} = \frac{-p_2^2 \delta \pi_1 (1 + C_1 A_1)}{H}, \tag{11a'}$$

$$\frac{\partial X_2}{\partial \beta_1} = \frac{p_1 p_2 \delta \pi_1 (1 + C_1 A_1)}{H}, \tag{11b'}$$

where A_1 is the measure of absolute hazard aversion in C_1. Note that if the consumer exhibits CAHA, A_1 can be replaced a CAHA coefficient γ. Although we can not determine the sign impact of γ on $\frac{\partial X_1}{\partial \beta_1}$ and $\frac{\partial X_2}{\partial \beta_1}$, we show that the CAHA coefficient γ plays an important role in determining the results of these comparative statics.

If $\pi_{21} > 0$, the marginal toxicity of C_2 is lessened (i.e., $\frac{\partial \pi}{\partial C_2}$ is increased and is less negative) as the other toxin C_1 increases. Then the two types of hazards tend to offset the negative impacts of each other on the survival probability. In this case, an increase in the level of safety β_1 will increase the demand for X_1 and decrease the demand for X_2. If $\pi_{21} < 0$, the marginal toxicity of C_2 is enhanced as the other hazard is added. In this case, the effects of an increase in the safety level β_1 on demands for risky foods are ambiguous.

Discount Rate

Recall that the individual can only live for two periods at most. How does change in the subjective discount rate, δ, affect the demand for risky foods? Differentiating the first order conditions (6a) - (6c) with respect to δ and rearranging terms, we have

$$\frac{\partial X_1}{\partial \delta} = \frac{p_1 p_2^2 \left(\frac{\alpha_1 \pi_1}{p_1} - \frac{\alpha_2 \pi_2}{p_2} \right)}{H}, \tag{12a}$$

$$\frac{\partial X_2}{\partial \delta} = \frac{-p_1^2 p_2 \left(\frac{\alpha_1 \pi_1}{p_1} - \frac{\alpha_2 \pi_2}{p_2} \right)}{H}. \qquad (12b)$$

Recall that $\pi_1 < 0$ for $i = 1,2$. Generally, the signs of $\frac{\partial X_1}{\partial \delta}$ or $\frac{\partial X_2}{\partial \delta}$ are ambiguous and depend on the magnitude of $\frac{\alpha_1 \pi_1}{p_1}$ and $\frac{\alpha_2 \pi_2}{p_2}$. If X_1 is relatively less hazardous ($\frac{\alpha_1 \pi_1}{p_1} - \frac{\alpha_2 \pi_2}{p_2} > 0$), then an increase of the discount rate δ increases the demand for X_1 and decreases the demand for X_2. Intuitively, an increase in δ means that as the importance of the future increases, the consumer increases the consumption of the less risky good X_i. Further, this result could imply that age distribution of the population would be important to the demand for risky foods. Suppose an elder person gives more weight to the future than a younger one does, then the former would be more cautious about the choice of foods. If this is the case, then a society with a high percentage of old population would be more concerned about the consumption of risky foods.

DEMAND FOR FOOD SAFETY

In recent years consumers have become increasingly more aware of various food hazards. In response to these changes, manufacturers have begun to market goods with different levels of hazard. For instance, some manufacturers differentiate low salt products from their regular products or "green" products grown under "natural" process from the products grown with pesticides or herbicides. In the food processing sector, manufacturers have also marketed cholesterol-free products to attract cholesterol conscious consumers.

We now relax the assumption that good safety is exogenously given. The consumer is assumed to choose both the quantity and the safety level of each food he or she purchases. Let $p_i(\beta_i)$ be the price of X_i with impurity level $\alpha_i = 1-\beta_i$. In general, a reduction of the impurity in the food raises the production cost. Thus, $p_i(\beta_i)$ is assumed to increase as β_i increases. For simplicity, we assume a linear price schedule, $p_i(\beta_i) = p_i^\circ + q_i\beta_i$, where q_i is the price of safety for food i.

The individual's problem is to maximize the expected utility,

$$J \equiv u(X_1, X_2) + \delta\pi[(1-\beta_1)X_1, (1-\beta_2)X_2],$$

subject to the budget constraint,

$$I = (p_1^\circ + q_1\beta_1)X_1 + (p_2^\circ + q_2\beta_2)X_2.$$

The Lagrangian function for this problem can be expressed as

$$J \equiv u(X_1, X_2) + \delta\pi[(1-\beta_1)X_1, (1-\beta_2)X_2] + \lambda[I - (p_1^\circ + q_1\beta_1)X_1 - (p_2^\circ + q_2\beta_2)X_2].$$

The first order conditions are:

$$\frac{\partial L}{\partial X_1} = u_1 + \delta\pi_1\alpha_1 - \lambda(p_1^\circ + q_1\beta_1) = 0 \tag{13a}$$

$$\frac{\partial L}{\partial X_2} = u_2 + \delta\pi_2\alpha_2 - \lambda(p_2^o + q_2\beta_2) = 0 \tag{13b}$$

$$\frac{\partial L}{\partial \beta_1} = -X_1(\delta\pi_1 + \lambda q_1) = 0 \tag{13c}$$

$$\frac{\partial L}{\partial \beta_2} = -X_2(\delta\pi_2 + \lambda q_2) = 0 \tag{13d}$$

$$\frac{\partial L}{\partial \lambda} = I - (p_1^o + q_1\beta_1)X_1 - (p_2^o + q_2\beta_2)X_2 = 0. \tag{13e}$$

The solution to (13a) - (13e) yields demands for X_1, X_2, β_1, β_2:

$$X_1 = X_1(p_1^o, p_2^o, q_1, q_2, I, \delta), \qquad X_2 = X_2(p_1^o, p_2^o, q_1, q_2, I, \delta)$$

$$\beta_1 = \beta_1(p_1^o, p_2^o, q_1, q_2, I, \delta), \qquad \beta_2 = \beta_2(p_1^o, p_2^o, q_1, q_2, I, \delta).$$

Observe that $\lambda = \frac{dJ}{dI}$ by the envelope theorem. Intuitively, λ is the expected marginal utility of income. If $\beta_1 = \beta_2 = 1$ (i.e., perfect safety), then we have $\frac{\partial L}{\partial \beta_1} = -X_1\lambda q_1 < 0$, and $\frac{\partial L}{\partial \beta_2} = -X_2\lambda q_2 < 0$ from (13c) and (13d) since $\pi_1(0,0) = \pi_2(0,0) = 0$ by assumption and λ (marginal utility of income) is positive if an interior solutions exists.

PROPOSITION 2: If the consumer chooses the level of safety, then perfect safety is not optimal.

Two Stage Maximization

Assume the interior solutions exist. The first order conditions (13a) to (13d) can be stated as

$$u_1 = -\delta\pi_1\alpha_1 + \lambda(p_1^o + q_1\beta_1), \tag{13a'}$$

$$u_2 = -\delta\pi_2\alpha_2 + \lambda(p_2^o + q_2\beta_2), \tag{13b'}$$

$$\delta\pi_1 = -\lambda q_1, \tag{13c'}$$

$$\delta\pi_2 = -\lambda q_2. \tag{13d'}$$

Substituting (13c') into (13a') and (13d') into (13b'), respectively, we obtain

$$u_1 = \lambda(p_1^o + q_1), \tag{13a''}$$

$$u_2 = \lambda(p_2^o + q_2). \tag{13b''}$$

Denote X_i^* to be the optimal consumption of food i, for i = 1, 2. Equations (13a") and (13b") give the following condition

$$\frac{u_1(X_1^*, X_2^*)}{u_2(X_1^*, X_2^*)} = \frac{(p_1^o + q_1)}{(p_2^o + q_2)} \equiv \frac{p_1^*}{p_2^*}. \tag{14}$$

Equation (14) suggests that MRS (i.e. $\frac{u_1}{u_2}$) between two risky foods is equal to their price ratio when both goods are perfectly safe. That is, in equilibrium, MRS between the two risky foods is independent of the level of food safety or riskiness, and is equated to the price of the risky good when risk is totally eradicated. Furthermore, from (13c) and (13d), we have

$$\frac{\pi_1}{\pi_2} = \frac{q_1}{q_2} \tag{15}$$

Note that π_1 measures the marginal rate of change in the probability of survival resulting from a change in impurity C_1. Equation (15) implies that the marginal rate of hazard substitution (MRHS), $\frac{\pi_1}{\pi_2}$, must be equal to the safety price ratio, $\frac{q_1}{q_2}$. Equations (14) and

(15) imply that demands for quantity and safety can be determined in two stages. In the first stage, the joint consumption path (X_1,X_2) is completely determined by ordinal preferences. In the second stage, the levels of quantity (X_1,X_2) and safety (β_1,β_2) are determined based on the riskiness.

In order to get more insight about the two stage maximization process, we may image that the consumer decompose his choice problem into two stages. In the first stage the consumer decides the quantities of the consumption bundle of (X_1, X_2) and an amount of money B that will be used to allocate the safety levels of β_1 and β_2 in the second stage. In the second stage the consumer chooses the safety levels by given the budget B and the quantities of the foods to maximize the utility function.

In the second stage, the budget allocated for the choice of safety is given and the budget constraint B for the safety levels is

$$B = q_1\beta_1X_1 + q_2\beta X_2,$$

where the quantities of X_1 and X_2 are the solutions from the first stage and hence they are fixed in the second stage. The Lagrangian function of the second stage can be written as

$$J \equiv u(X_1, X_2) + \delta\pi[(1-\beta_1)X_1, (1-\beta_2)X_2] + \mu[B - q_1\beta_1X_1 - q_2\beta X_2].$$

The first order conditions for this problem are

$$\delta\pi_1 = -\mu q_1, \tag{16a}$$

$$\delta\pi_2 = -\mu q_2, \tag{16b}$$

$$B - q_1\beta_1X_1 - q_2\beta_2X_2 = 0. \tag{16c}$$

Evaluating (16a) and (16b), we have $\frac{\pi_1}{\pi_2} = \frac{q_1}{q_2}$ which is the condition of (15). That is, in the second stage, the consumer chooses β_1 and β_2 by equating the marginal rate of hazard substitution to the safety price ratio by given the solutions of X_1 and X_2 from the first stage maximization.

The first order conditions of (16a)-(16c) can be solved to derive the demand functions for the safety β_1 and β_2:

$$\beta_1^*(B,X_1,X_2), \qquad \beta_2^*(B,X_1,X_2),$$

where the pure quantity prices p_i^o and the pure safety price q_i are omitted from the demand functions.

In the first stage, the consumer allocates the income I to purchase the consumption goods X_1 and X_2; and to the budget B which will be used in the second stage. The budget constraint for the first stage is

$$I = p_1^o X_1 + p_2^o X_2 + B.$$

The Lagrangian function can be written

$$J \equiv u(X_1,X_2) + \delta\pi\left[(1-\beta_1^*)X_1,(1-\beta_2^*)X_2\right] + \lambda\left[I - p_1^o X_1 - p_2^o X_2 - B\right].$$

The first order conditions for this problem are

$$u_1 + \delta\pi_1\alpha_1 - \delta\pi_1 X_1 \frac{\partial\beta_1^*}{\partial X_1} - \delta\pi_2 X_2 \frac{\partial\beta_2^*}{\partial X_1} - \lambda p_1^o = 0, \tag{16d}$$

$$u_2 + \delta\pi_2\alpha_2 - \delta\pi_1 X_1 \frac{\partial\beta_1^*}{\partial X_2} - \delta\pi_2 X_2 \frac{\partial\beta_2^*}{\partial X_2} - \lambda p_2^o = 0, \tag{16e}$$

$$-\delta\pi_1 X_1 \frac{\partial\beta_1^*}{\partial B} - \delta\pi_2 X_2 \frac{\partial\beta_2^*}{\partial B} - \lambda = 0, \tag{16f}$$

$$I - p_1^o X_1 - p_2^o X_2 - B = 0. \tag{16g}$$

From the second budget constraint $B - q_1\beta_1 X_1 - q_2\beta_2 X_2 = 0$, we get

$$1 - q_1 X_1 \frac{\partial \beta_1^*}{\partial B} - q_2 X_2 \frac{\partial \beta_2^*}{\partial B} = 0, \tag{17a}$$

$$-q_1\beta_1 - q_1 X_1 \frac{\partial \beta_1^*}{\partial X_1} - q_2 X_2 \frac{\partial \beta_2^*}{\partial X_1} = 0, \tag{17b}$$

$$-q_2\beta_2 - q_1 X_1 \frac{\partial \beta_1^*}{\partial X_2} - q_2 X_2 \frac{\partial \beta_2^*}{\partial X_2} = 0. \tag{17c}$$

Substituting (16a) and (16b) into (16f), we have

$$\mu\left(q_1 X_1 \frac{\partial \beta_1^*}{\partial B} + q_2 X_2 \frac{\partial \beta_2^*}{\partial B}\right) - \lambda = 0. \tag{18}$$

Evaluating (17a) and (18), we have $\mu = \lambda$. Further, substituting (16a), (16b), and (17b) into (16d), we have

$$u_1 - \lambda p_1^{\circ} - \mu q_1 = 0. \tag{19a}$$

Similarly, substituting (16a), (16b), and (17c) into (16e), we have

$$u_2 - \lambda p_2^{\circ} - \mu q_2 = 0. \tag{19b}$$

Since $\mu = \lambda$, equations (19a) and (19b) become

$$u_1 = \lambda(p_1^{\circ} + q_1), \tag{19a'}$$

$$u_2 = \lambda(p_2^{\circ} + q_2). \tag{19b'}$$

By evaluating (19a') and (19b'), we obtain

$$\frac{u_1(X_1^*, X_2^*)}{u_2(X_1^*, X_2^*)} = \frac{(p_1^{\circ} + q_1)}{(p_2^{\circ} + q_2)} \equiv \frac{p_1^*}{p_2^*}$$

which is exactly the condition of equation (14). That is, in equilibrium of the first stage, MRS between the two risky foods is independent of the level of food safety or riskiness, and is equated to the price of the risky good when risk is totally eradicated. This analysis demonstrates that the two stage maximization process could shed more insight about the consumer's decision problem while the results still yield the same demand functions.

Demand for Food Safety and Willingness to Pay for Safety

To get a meaningful interpretation of equation (13c), express the equation (13c) as $q_1 = \frac{-\delta\pi_1}{\lambda}$ when the equilibrium X_1 is non zero. Consider the maximum amount the consumer is willing to pay for safety β_1 as the following way. Let $w(\beta_1)$ be the maximum amount that the consumer is willing to pay for safety β_1 per unit of X_1. Substituting $X_2 = \frac{I-(p_1^o+q_1\beta_1)X_1}{p_2^o+q_2\beta_2}$ from budget constraint into the expected utility function, we have the expected utility

$$J = \left[X_1, \frac{I-(p_1^o+q_1\beta_1)X_1}{p_2^o+q_2\beta_2}\right] + \delta\pi\left[(1-\beta_1)X_1, (1-\beta_2)\frac{I-(p_1^o+q_1\beta_1)X_1}{p_2^o+q_2\beta_2}\right].$$

Then w is implicitly defined by

$$u\left[X_1, \frac{I-(p_1^o+w)X_1}{p_2^o+q_2\beta_2}\right] + \delta\pi\left[(1-\beta_1)X_1, (1-\beta_2)\frac{I-(p_1^o+w)X_1}{p_2^o+q_2\beta_2}\right] - \bar{J} = 0, \qquad (20)$$

where $\bar{J}$ is a fixed level of expected utility. By differentiating (20) with respect to β_1 and holding X_1, X_2, and β_2 constant, we obtain the marginal willingness to pay for safety per unit of X_1

$$\left.\frac{dw}{d\beta_1}\right|_{J} = \frac{-\delta\pi_1}{u_2 + \delta\alpha_2\pi_2 \Big/ p_2^{\circ} + q_1\beta_2}. \tag{21}$$

Since $\lambda = \frac{u_2 + \delta\alpha_2\pi_2}{p_2^{\circ} + q_1\beta_2}$ from (13b), equation (21) becomes $\left.\frac{dw}{d\beta_1}\right|_{J} = \frac{-\delta\pi_1}{\lambda}$. Then we may consider $D(\beta_1) \equiv \left.\frac{dw}{d\beta_1}\right|_{J} = \frac{-\delta\pi_1}{\lambda}$ (marginal rate of substitution of the income for safety β_1 per unit of X_1) as the conditional demand curve for β_1 while X_1, X_2, and β_2 are held constant. Note that the demand curve is negatively sloped since $\frac{\partial D(\beta_1)}{\partial \beta_1} = \frac{\delta X_1 \pi_{11}}{\lambda} < 0$ for a hazard averse consumer. The intersection of the safety price q_1 (a horizontal price line) and the demand curve of safety β_1 determines the optimal level of safety β_1 as shown in Figure 2. However, the above analysis only captures the partial effect of a change in the safety price q_1. It should be noted that a change in q_1 affects the levels of X_1, X_2, and β_2 as well. The optimal levels of X_1, X_2, β_1, and β_2 should be solved simultaneously from equations (13a) to (13d). To get the total effect on β_1 by allowing X_1, X_2, and β_2 to respond, it is necessary to differentiate equations (13a) to (13d) simultaneously.

To illustrate the maximum amount the consumer is willing to pay for the optimal level of safety in a graph alternatively, consider the case where only X_1 is risky (i.e., $\beta_2 = 1$). In Figure 3, the quantities of X_1 and X_2 are measured on the horizontal and vertical axes, respectively. If the consumer demand for safety is zero ($\beta_1 = 0$), the budget line is represented by I^oI'. Then the consumer chooses point C', where the indifference curve $u(X_1', X_2')$ (not drawn) is tangent to the budget line I^oI'. If the impurity level in X_1 is eliminated ($\beta_1 = 1$), the budget line is represented by I^oI''. In this case, the consumer chooses C'', where $u(X_1'', X_2'')$ (not drawn) is tangent to the budget line I^oI''. Given the prices p_1°, p_2°,

q_1, and q_2, the horizontal difference, $I' - I''$, measures an upper limit to consumer's willingness to pay for safety in term of X_1. However, as shown in Proposition 2, paying this amount to eliminate risk is suboptimal.

As β_1 changes from 0 to 1 the budget line rotates clockwise around I^o, and the equilibrium consumption bundle is along the price consumption curve I^oO. The equilibrium in (14) indicates that the optimal consumption occurs along I^oO, somewhere between C' and C''. The optimal level of β_1 determines the location of the actual budget line, I^oI^*, and optimal consumption occurs at C^*, where I^oI^* is tangent to U^*.

CONCLUSION

Conventional demand theory based on ordinal preferences is inadequate to analyze demand for risky goods. Consumption of an impure good not only increases utility in the current period, but also decreases the probability of survival into the next period. A two-period von Neumann-Morgenstern utility function was used in this paper to derive demand functions for quantity and safety for two risky foods.

When hazard content is exogenously fixed, ignoring the hazard in a risky good results in over-consumption of that food. Conversely, informing the consumer about the hazard in the food will lead to a decrease in consumption of the food. However, when both goods are risky, a rise in the safety level of one good generally has an ambiguous effect on the demands.

For some products consumers may be able to choose the safety levels of consumption foods, such as low sodium products, fat-free products, etc. In this case, the consumer will in general accept some risks and perfect safety is not optimal. The joint consumption path of the two risky goods, X_1, and X_2, is determined by the ordinal preference over the two foods when the hazards in both risky foods are totally eliminated. Moreover, the optimal safety levels, β_1 and β_2, are solely determined by the safety price.

This paper has an important implication for the development of public policies on safety in consumer goods. Since perfect safety is not an interior solution, policies directed at eliminating risks are generally wasteful. This result is consistent with recommendations on fixing minimum acceptable contaminant levels (as with pesticide residues; Bockstael 1984). Currently, the levels of safety are not infinitely divisible and for most products consumers can choose among products with different levels of safety. Thus, the resolution of correctly modeling risk in foods will have implications for evaluation of demand and development of appropriate regulations.

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NOTES

1 An alternative approach is to assume that consumption of a risky good such as cigarettes increases utility by increasing pleasure but also decreases it via its adverse effect on health. See Dardanoni and Wagstaff (1990), Berger et al. (1987), and Falconi and Roe (1991).

2 In science, risk is defined as "the probability of loss" (Kendall 1990).

3 Alternatively, we could consider $-1 \le \alpha_1, \alpha_2 \le 1$, where negative α_i implies that X_i is a health promoting food. For example, some foods, such as milk for children, may add more nutrition to improve the health of children. However, this assumption would not alter the basic results in the paper.

4 Let U_0 denote the curve of $-\frac{u_1}{J_2}$ passing through the point E in Figure 1. When evaluated at (X_1^*, X_2^*), U_0 is steeper than J $(\frac{u_1}{J_2} > \frac{J_1}{J_2})$. When the consumer is not informed, an equilibrium occurs at F, where $-\frac{u_1}{J_2} = -\frac{p_1}{p_2}$. Since F is to the right of E, lack of information results in over-consumption of the risky good.

5 In a different context, Shogren (1991) used $\Gamma(x) = -\frac{p''(x)}{p'(x)}$ as a measure of aversion, where x is an endogenous asset and $p(\cdot)$ is the probability function.

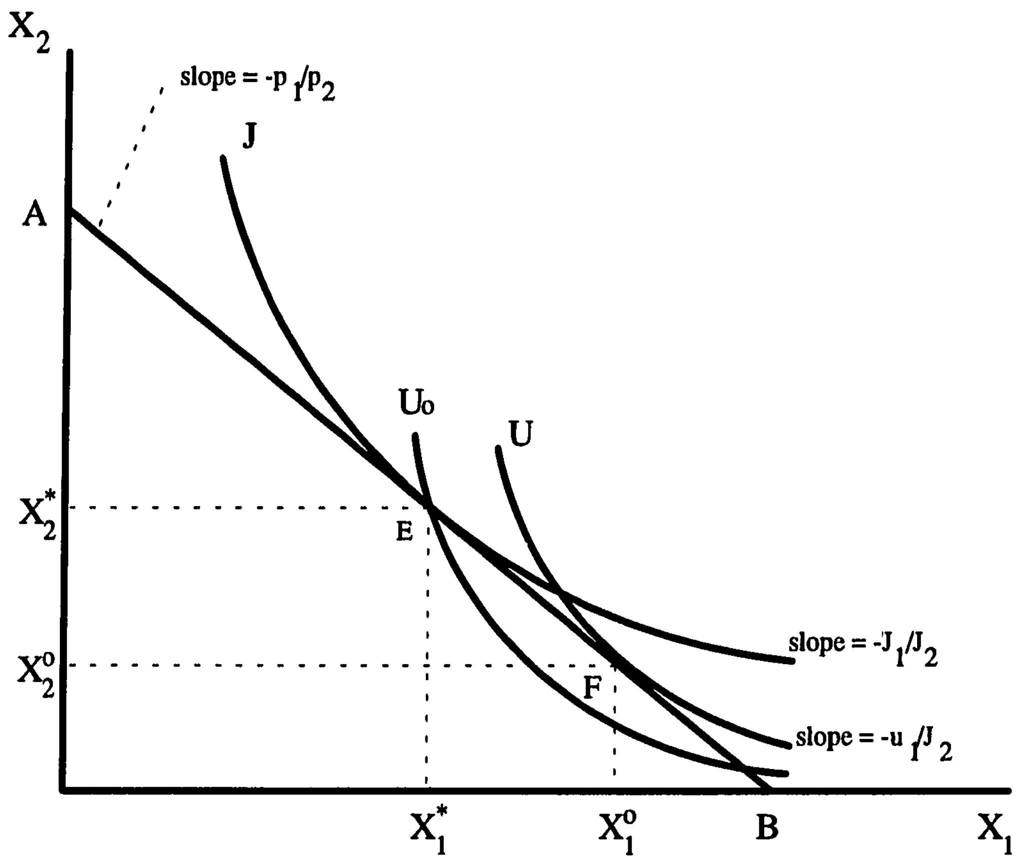

Figure 1. Over-consumption of X_1

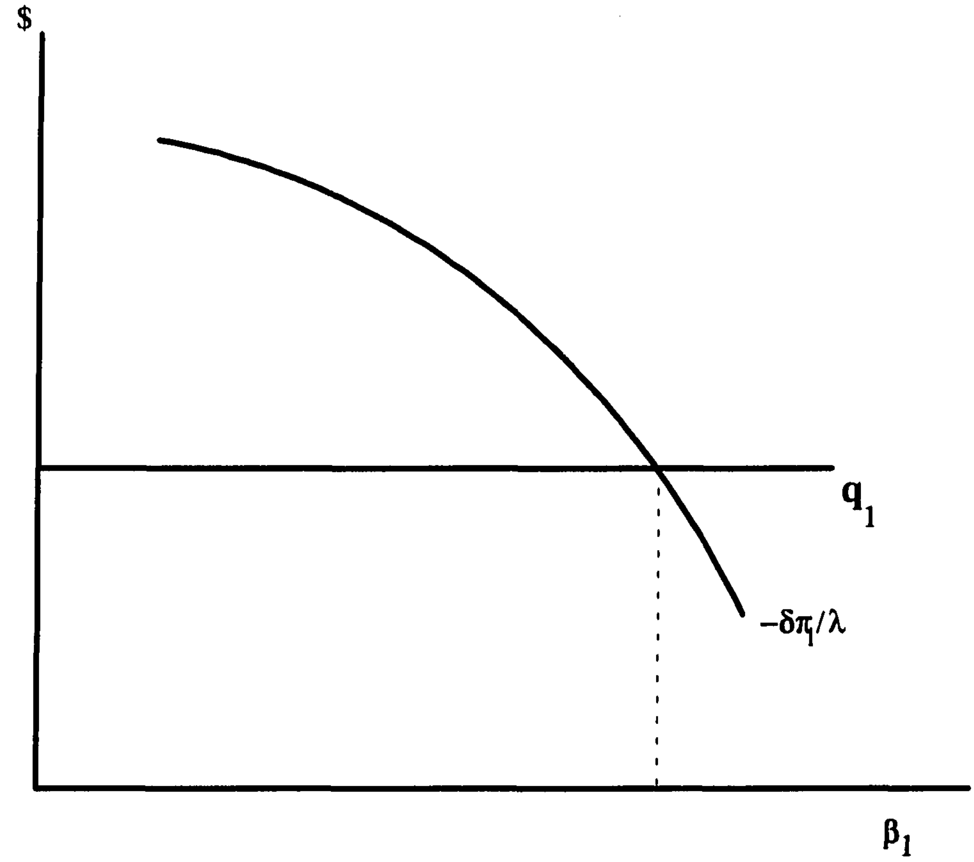

Figure 2. Conditional Demand for Food Safety β_1

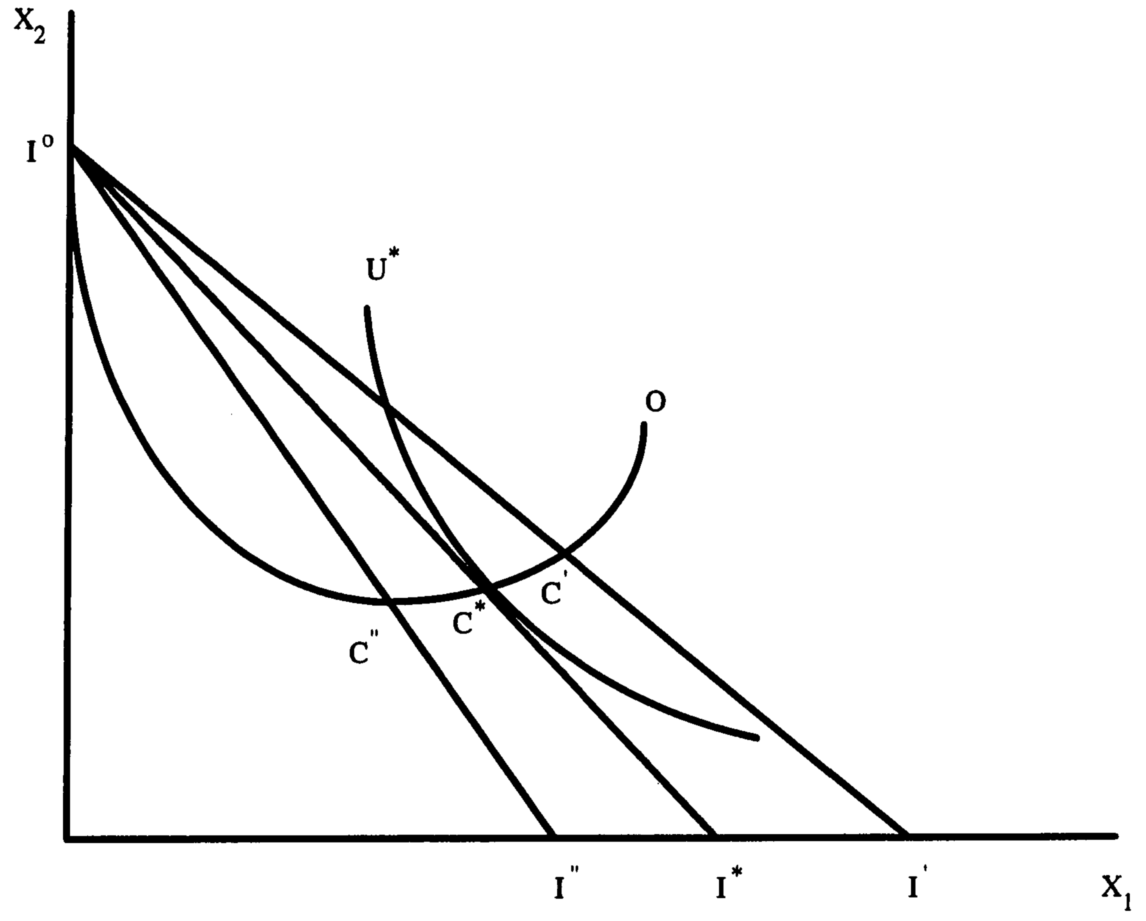

Figure 3. Willingness to Pay for Safety β_1

PAPER II.

MEASURING THE WILLINGNESS TO PAY FOR FOOD SAFETY

INTRODUCTION

The valuation of food safety improvement is an important issue in the study of risky foods. Food industries require good measures of consumers' willingness to pay (WTP) for reductions in the perceived risks from substances in foods to provide the information for production decisions. Policy makers rely on accurate measurement of the value of food safety to guide legislative decisions on regulating food contamination and sanitation. van Ravenswaay (1988) emphasized the need for economists to provide accurate valuation of food safety for both food industries and policy makers.

The problem is that there exits no market for food safety. This issue is similar to that of measuring the WTP for environmental amenities (McConnell 1990; Loehman and Park 1993). For valuing environmental amenities, the WTP is commonly measured as a function of determining variables. In the case of food safety where the hazards levels in foods can not be changed by the consumer, the measure of marginal WTP for safety improvement and the functional relationship between this WTP and the explanatory variables are of primary interest to researchers and policy makers. For an empirical example, see Misra et al. (1991), who examined the impacts of various exogenous variables on the consumer's WTP for pesticide-free products given a number of alternative price premia. Their study incorporates an individual risk perception index as well as demographic characteristics such as race sex, age, education, and income as the explanatory variables. One of their results is that respondents who are older or have a higher income have higher probability of being willing to pay a higher price premium than the ones who are younger or have lower income. Lin and Milon (1993), for another example, regressed the WTP more for safer shellfish on a set explanatory variables such as a risk perception index, experience of consumption, income, age, etc. The estimated coefficients indicated a positive effect of income and negative effect of age, although neither of these coefficients was statistically significant. Both studies have not explained the underlying theoretical relationships in determining the change in food safety.

Because the safety level is embodied in the food, another interesting aspect of food safety is: what is the consumer's total amount of WTP for the risky food when the safety level of the food is increased? This aspect has received only little attention.

The objective of this paper is to derive measures of the consumer's marginal WTP for food safety in a demand model for risky foods. Also the relationships of the WTP measure and its explanatory variables, such as income, prices, and related safety levels, are carefully examined. In the absence of theoretical derivations in the marginal WTP for food safety measure, the properties derived from this analysis can help to evaluate the consistency of the estimated empirical parameters with theory.

This paper is organized as follows. Section 2 constructs a demand model for the risky foods and states the comparative statics results. Section 3 derives the measure of the marginal WTP for safety and explains the properties of this measure in section 4. Section 5 derives and briefly discusses the measure of marginal WTP for the risky food when the safety of that food increases. Then, the implications for empirical studies of estimating WTP for safety and the risky food are addressed. Finally, a summary is presented.

THE DEMAND MODEL WHEN SAFETY IS FIXED

In conventional demand theory consumption goods are assumed to increase utility without side effects and will be called pure foods here. Foods with negative side effects will be called impure or "risky" foods. Consider a risky food which contains a potentially hazardous ingredient such as a toxin, pathogen, or carcinogen. Assume that the hazard cannot economically be separated by the consumer. When a commodity bundle contains an impure consumption food, the consumer has to weigh the direct utility gains versus potential health risks. Consequently, a von Neumann-Morgenstern utility function is used to derive demand functions for risky foods.

For simplicity, assume that the consumer spends income on two risky foods each period. Consumer preferences in each period can be represented by a monotone increasing and concave von Neumann-Morgenstern utility function

$$u_t = u(X_{1t}, X_{2t}),$$

where X_{it} is the quantity of the risky good X_i in period t, i = 1,2. For simplicity, we consider a two period utility function of the consumer as

$$U = \sum_{t=1}^{2} u(X_{1t}, X_{2t}) \tag{1}$$

where δ is a discount factor, $0 < \delta \leq 1$.

Equation (1) yields total utility when the survival into the second period is certain. Consider a representative individual who lives for two periods with time-invariant utility functions over the two risky foods, X_1 and X_2. We assume that the hazards do not affect consumer's utility in the current period, but affect the consumer's chance of survival in good "health" into the next period. Thus, the consumer faces uncertainty regarding survival into the next period.

Assume that the probability of survival is less than one and known by the consumer. Let π be the probability of survival into the second period, $0 \leq \pi < 1$. The budget constraint in each period is given by

$$p_{1t}X_{1t} + p_{2t}X_{2t} = I_t, \quad t = 1,2.$$

where p_{it} and I_t are the price of the risky good X_i and income in period t, respectively. If the consumer survives, he maximizes $u(X_{12}, X_{22})$ subject to the budget constraint in the second period. Let $X_1[p_{12}, p_{22}, I_2]$ and $X_2[p_{12}, p_{22}, I_2]$ denote the second period demand functions. The indirect utility in the second period is then

$$v(p_{12}, p_{22}, I_2) \equiv u[X_1(p_{12}, p_{22}, I_2), X_2(p_{12}, p_{22}, I_2)]$$

It should be noted that the individual receives no income if he does not survive. Without loss of generality, we assume that the utility level in the second period is zero if the consumer fails to survive ($u_2 = 0$). Assume further that the utility function in each period is normalized so that the utility in the second period when the consumer survives is unity, i.e., $u_2 = v = 1$. Then the second period utility can be written as a random variable,

$$u_2 = \begin{cases} 0, \text{with probability } (1-\pi), \\ 1, \text{with probability } \pi. \end{cases}$$

The expected utility of the consumer is

$$J = u(X_1, X_2) + \delta\pi \tag{2}$$

where the subscript $t = 1$ is suppressed (i.e., $X_1 = X_{11}$ and $X_2 = X_{21}$) and δ is the time discount rate.

Let α_i denote the amount of impurity per unit of the risky goods X_i consumed. For simplicity, the hazard content in each food is assumed to be constant and is normalized so that $0 \leq \alpha_1, \alpha_2 \leq 1$. Then the amounts of impurity absorbed, C_i, are defined as

$$C_i = \alpha_i X_i = (1-\beta_i)X_i, \quad i = 1,2. \tag{3}$$

where $\beta_i \equiv 1-\alpha_i$ is a measure of the safety level of X_i; an increase in β_i indicates increased safety of X_i. The probability of survival is written as

$$\pi = \pi(C_1, C_2). \tag{4}$$

Assume that the probability of survival is decreasing in C_i, i.e., $\pi_i < 0$, where $\pi_i \equiv \frac{\partial \pi}{\partial C_i}$, $i = 1,2$.

The consumer's problem is to maximize the expected utility, $J = u(X_1, X_2) + \delta\pi$ subject to the budget constraint, $I = p_1X_1 + p_2X_2$. The Lagrangian function associated with this problem can be written as

$$L = u(X_1, X_2) + \delta\pi[(1-\beta_1)X_1, (1-\beta_2)X_2] + \lambda(I - p_1X_1 - p_2X_2). \tag{5}$$

The first order conditions are

$$\frac{\partial L}{\partial X_1} = u_1 + \delta\alpha_1\pi_1 - \lambda p_1 = 0, \tag{6a}$$

$$\frac{\partial L}{\partial X_2} = u_2 + \delta\alpha_2\pi_2 - \lambda p_2 = 0, \tag{6b}$$

$$\frac{\partial L}{\partial \lambda} = I - p_1X_1 - p_2X_2 = 0, \tag{6c}$$

where $u_i \equiv \frac{\partial u}{\partial X_i}$. The solutions to (6a), (6b), and (6c) yield the following demand functions:

$$X_1 = X_1[p_1, p_2, I; \beta_1, \beta_2, \delta], \quad X_2 = X_2[p_1, p_2, I; \beta_1, \beta_2, \delta]. \tag{7}$$

Equations in (7) imply that demand functions are conditioned on safety levels or hazards, as well as by prices and income.

Hazard Aversion and Change in Risk

To investigate the effects of a change in hazard content, it is useful to introduce the notion of hazard aversion. The Arrow-Pratt measures of absolute risk aversion $A(I) = -\frac{u''(I)}{u'(I)}$ and relative risk aversion $R(I) = -\frac{Iu''(I)}{u'(I)}$ have been widely used, where u(I) is the utility of income function. To investigate consumption decisions on risky goods, we similarly define *absolute hazard aversion* in hazard C_i,[1]

$$A_i(C_1, C_2) = \frac{\pi_{ii}}{\pi_i} > 0,$$

and *relative hazard aversion* in hazard C_i,

$$R_i(C_1, C_2) = \frac{C_i \pi_{ii}}{\pi_i} > 0.$$

Observe that $\pi_{ii} < 0$ implies that the individual who reveals hazard aversion considers that the initial level of toxin may not have a serious effect on survival. When the level of toxin continues to accumulate and exceeds some certain amount or level, the probability of survival drops rapidly.

The Effect of Change in Income

Consider the effect of a change in income on demand. Differentiating (6a) -(6c) with respect to I gives

$$\frac{\partial X_1}{\partial I} = \frac{(p_2 J_{12} - p_1 J_{22})}{H}, \tag{8a}$$

$$\frac{\partial X_2}{\partial I} = \frac{(p_1 J_{21} - p_2 J_{11})}{H}, \tag{8b}$$

$$\frac{\partial \lambda}{\partial I} = \frac{(J_{12}^2 - J_{11} J_{22})}{H}, \tag{8c}$$

where

$$J_{ij} = \frac{\partial^2 J}{\partial X_i \partial X_j} = u_{ij} + \delta \alpha_i \alpha_j \pi_{ij},$$

and H is the determinant of the bordered Hessian matrix

$$[H] = \begin{bmatrix} J_{11} & J_{12} & -p_1 \\ J_{21} & J_{22} & -p_2 \\ -p_1 & -p_2 & 0 \end{bmatrix}.$$

By the second order conditions, the bordered Hessian, $H = -p_1^2 J_{22} - p_2^2 J_{11} + 2p_1 p_2 J_{12}$, is positive. From (8a) and (8b), the sign of $\frac{\partial X_i}{\partial I}$ is generally indeterminate. The risky good X_i can be said to be normal if $\frac{\partial X_i}{\partial I} \geq 0$.

<u>Change in the Price of a Risky Food</u>

As in the conventional case with riskless foods, the effect of a price change can be decomposed into the substitution and income effects. Differentiating the first order conditions (6a) - (6c) with respect to p_1 yields

$$\frac{\partial X_1}{\partial p_1} = \frac{-p_2^2 \lambda}{H} - X_1 \left(\frac{\partial X_1}{\partial I} \right), \tag{9a}$$

$$\frac{\partial X_2}{\partial p_1} = \frac{p_1 p_2 \lambda}{H} - X_1 \left(\frac{\partial X_2}{\partial I} \right). \tag{9b}$$

As in the conventional case, the first term $\frac{-p_2^2\lambda}{H}$ in (9a) can be viewed as the substitution effect, whereas the second term, $-X_1\left(\frac{\partial X_1}{\partial I}\right)$, is the income effect from a price change. In general, the sign of $\frac{\partial X_1}{\partial p_1}$ or $\frac{\partial X_2}{\partial p_1}$ cannot be determined. However, note that the substitution effect $\frac{-p_2^2\lambda}{H}$ in (9a) is negative. If X_1 is a normal good, then an increase in the price of X_1 will reduce the demand for X_1.

<u>Change in Safety of the Risky Food</u>

Consider the effect of a change in hazard content on the demand for the risky goods. Differentiating (6a) - (6c) with respect to β_1 gives

$$\frac{\partial X_1}{\partial \beta_1} = \frac{-p_2\delta\left[p_2(\pi_1 + \alpha_1\pi_{11}X_1) - p_1\alpha_2X_1\pi_{21}\right]}{H}, \tag{10a}$$

$$\frac{\partial X_2}{\partial \beta_1} = \frac{p_1\delta\left[p_2(\pi_1 + \alpha_1\pi_{11}X_1) - p_1\alpha_2X_1\pi_{21}\right]}{H}. \tag{10b}$$

Note that if $\pi_{21} = 0$ (defined as the situation of risk independence), then equations (10a) and (10b) can be written as

$$\frac{\partial X_1}{\partial \beta_1} = \frac{-p_2^2\delta\pi_1(1+R_1)}{H}, \tag{10a'}$$

$$\frac{\partial X_2}{\partial \beta_1} = \frac{p_1p_2\delta\pi_1(1+R_1)}{H}, \tag{10b'}$$

where R_1 is the measure of relative hazard aversion in C_1. Equation (10a') implies that an increase in safety of X_1 increases the demand for X_1 for a hazard averse consumer when $\pi_{21} = 0$.

Change in the Discount Rate

Differentiating the first order conditions (6a) - (6c) with respect to δ and rearranging terms, we have

$$\frac{\partial X_1}{\partial \delta} = \frac{p_1 p_2^2\left(\frac{\alpha_1\pi_1}{p_1} - \frac{\alpha_2\pi_2}{p_2}\right)}{H}, \tag{11a}$$

$$\frac{\partial X_2}{\partial \delta} = \frac{-p_1^2 p_2\left(\frac{\alpha_1\pi_1}{p_1} - \frac{\alpha_2\pi_2}{p_2}\right)}{H}. \tag{11b}$$

Define X_1 to be relatively less hazardous if $\left(\frac{\alpha_1\pi_1}{p_1} - \frac{\alpha_2\pi_2}{p_2}\right) > 0$. Therefore, an increase of the discount rate δ increases the demand for X_1 and decreases the demand for X_2 if X_1 is relatively less hazardous.

THE MEASURE OF THE MARGINAL WTP FOR SAFETY

Based on the demand model in (2), what is the measure of marginal WTP for food safety improvement? Substituting (7) into (1), we have the indirect utility function

$$V(p_1,p_2,I,\beta_1,\beta_2,\delta)$$
$$\equiv u[X_1(p_1,p_2,I,\beta_1,\beta_2,\delta),X_2(p_1,p_2,I,\beta_1,\beta_2,\delta)]$$
$$+\delta\pi[(1-\beta_1)X_1(p_1,p_2,I,\beta_1,\beta_2,\delta),(1-\beta_2)X_2(p_1,p_2,I,\beta_1,\beta_2,\delta)]. \quad (12)$$

In order to focus on the WTP for the increment of safety in X_1, ignore p_2 and β_2 in (12). Further, for notational simplicity we denote the indirect utility function in (12) as $V(I,\beta,p,\delta)$, where β and p are the safety level and the price of X_1, respectively. Consider an improvement in the safety level from β° to β^1 in X_1. The compensating variation $\rho(\beta^\circ,\beta^1)$, which is the maximum amount an individual would be willing to pay to insure this change, is implicitly defined by

$$V(I,\beta^0,p,\delta)=V(I-\rho,\beta^1,p,\delta). \quad (13)$$

Differentiating both sides of (13) with respect to β^1 and setting $\frac{\partial V(I,\beta^\circ,p,\delta)}{\partial\beta^1}=0$, we have

$$V_I(-\rho_\beta)+V_\beta=0, \quad (14)$$

where and the superscript in β^1 is omitted. Rearranging the terms in (14), we get the marginal WTP for safety

$$\rho_\beta=\frac{V_\beta}{V_I}. \quad (15)$$

Note that V_I is the marginal utility of income λ (see Appendix A for the derivation of V_I). For the positive V_I, we observe that the marginal WTP for safety ρ_β is positive since $V_\beta = -\delta X_1 \pi_1 > 0$ (see Appendix B for the derivation of V_β). Further, note that the marginal WTP for a change in safety is equal to the marginal rate of substitution between income and safety. More specifically, the right hand side of (15) expresses the marginal WTP for a safety improvement as a tradeoff between the value of safety improvement (e.g., the value of an increase in the probability of survival) and the value of monetary income.

In order to get more insight about the marginal WTP for safety, consider equation (15) as a conditional demand for the food safety. Differentiating (15) with respect to β and holding the demand for X_1 and X_2, and the marginal utility of income V_I constant, we have $\rho_{\beta\beta} = \frac{\delta X_1^2 \pi_{11}}{V_I}$, which is negative for a hazard averse consumer. That is the marginal WTP for safety decreases as the safety increases by holding X_1, X_2, and V_I constant[2]. The downward-sloping conditional demand for safety is depicted in Figure 1. In Figure 1, the vertical axis represents the value of the marginal WTP for safety and the horizontal axis is the amount of safety. When the safety increases, the marginal WTP for safety decreases along the curve $\frac{-\delta X_1 \pi_1}{V_I}$. The purpose of this analysis is to illustrate how the conditional demand for safety might be examined as a case analogous to the conventional downward-sloping demand for good. It should be noted, however, that a change in safety will affect the choices of X_1, X_2, and V_I. A formal treatment of this comparative static is examined in the next section.

PROPERTIES OF THE MARGINAL WTP FOR SAFETY

Several properties of the marginal WTP measure for safety follow from (15).

(i) The measure of marginal WTP for safety in (15) is positive by the assumption $\pi_1 < 0$. That is the WTP for safety increases as the safety level increases.

(ii) Studies which have valued the reduction of environmental hazards are concerned particularly with whether the expression of marginal WTP includes the nonobservable utility terms or not (Berger et al. 1987; Shogren and Crocker 1991). Only when the utility terms are absent from the marginal WTP, it is possible to use observed behavioral data to aggregate the marginal WTP across individuals, and avoid the problem of interpersonal utility comparisons. Berger, et al., for example, expressed the marginal WTP for an exogenous reduction in health risks to be dependent upon a "health risk function" alone. In our case, the marginal WTP for food safety, which can be rewritten as $\rho_\beta = \frac{-\delta X_1 \pi_1}{\lambda}$ from (15), is independent of the measurement of the utility function. Therefore, the use of ρ_β from (15) can avoid the problem of interpersonal utility comparison.

(iii) *The marginal WTP for safety is downward sloping if* $V(I,\beta,p,\delta)$ *is concave on* (I,β).

In general, we do not know whether the marginal WTP for safety decreases as the safety level increases (i.e., the sign of $\rho_{\beta\beta}$ cannot be determined a priori). Differentiating (14) with respect to β, we have

$$V_{II}(-\rho_\beta)^2 + V_{I\beta}(-\rho_\beta) + V_I(-\rho_{\beta\beta}) + V_{\beta I}(-\rho_\beta) + V_{\beta\beta} = 0. \qquad (16)$$

Rearranging terms in (16), we get

$$\rho_{\beta\beta} = \frac{\rho_\beta^2 V_{II} - 2\rho_\beta V_{\beta I} + V_{\beta\beta}}{V_I}. \qquad (17)$$

Is the marginal WTP for safety, ρ_β, downward sloping? The marginal WTP for safety is downward sloping if the right hand side of (17) is negative. Since the marginal utility of income in the denominator of (17) is positive, $\rho_{\beta\beta}$ is negative if the numerator of (17) is negative. Observe that the numerator of (17), $\left(\rho_\beta^2 V_{II} - 2\rho_\beta V_{\beta I} + V_{\beta\beta}\right)$, is negative if $V(I, \beta, p, \delta)$ is concave on (I, β). Therefore, the marginal WTP for safety is downward sloping if $V(I, \beta, p, \delta)$ is concave on (I, β).

Alternatively, without making the assumption that $V(I, \beta, p, \delta)$ is concave on (I, β), what are the conditions which can also result in a decreasing marginal WTP for safety? Express $V_{\beta I}$ and $V_{\beta\beta}$ as

$$V_{\beta I} = -\delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial I}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial I}\right), \tag{18}$$

$$V_{\beta\beta} = \delta X_1^2 \pi_{11} - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial \beta}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial \beta}\right), \tag{19}$$

where R_1 is the relative hazard aversion (see Appendix C for the derivations of $V_{\beta I}$ and $V_{\beta\beta}$). In order to determine the signs of $V_{\beta I}$ and $V_{\beta\beta}$, consider the case of hazard independence $\pi_{12} = 0$. When $\pi_{12} = 0$ and X_1 is normal, $V_{\beta I}$ is positive for a hazard averse individual in (18). However, the sign of $V_{\beta\beta}$ in (19) can not be determined for a hazard averse individual even when $\pi_{12} = 0$ and X_1 is normal. If $\delta X_1^2 \pi_{11} - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial \beta}\right) < 0$ in (19), then $V_{\beta\beta}$ is negative for $\pi_{12} = 0$. Therefore, we observe that the marginal WTP for safety ρ_β decreases as the safety increases if the hazards are independent $\pi_{12} = 0$, the marginal utility of income is nonincreasing $V_{II} \leq 0$, and $\delta X_1^2 \pi_{11} - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial \beta}\right) < 0$ for a hazard averse individual.

This discussion illustrates the alternative conditions which could also result in a decreasing marginal WTP for safety.

(iv) *If two hazards are independent ($\pi_{12} = 0$), the marginal WTP for an safety increment increases as income increases for an individual revealing aversion in both income risk and hazard (i.e.,* $V_{II} < 0$ *and* $R_1 < 0$*).*

How does a change in income affect the marginal WTP for safety? Differentiating (14) with respect to I, we have

$$V_{II}(-\rho_\beta) + V_I(-\rho_{\beta I}) + V_{\beta I} = 0. \tag{20}$$

Rearranging (20) yields

$$\rho_{\beta I} = \frac{-\rho_\beta V_{II} + V_{\beta I}}{V_I}. \tag{21}$$

The sign of $\rho_{\beta I}$ depends on the sign of numerator in the right hand side of (21). Define $V_{II} = (<) 0$ for an individual who reveals income risk neutrality (aversion). Further, note that $V_{\beta I}$ is positive when two hazards are independent ($\pi_{12} = 0$) for a hazard averse consumer ($R_1 < 0$) from (18). Hence, when the individual exhibits aversion in both hazard and income risk for two independent hazards, the marginal WTP for safety increases as income increases. This property clearly illustrates the sufficient conditions for the common hypothesis in empirical studies that there exists an increasing marginal WTP for an increase in income .

(v) *If the two hazards are independent, the marginal WTP for an improvement of safety in a normal food* X_1 *decreases as the price of* X_1 *increases for an individual exhibiting income risk neutrality and hazard aversion.*

What is the effect of a change of price in food X_1 on the marginal WTP for safety? Differentiating (14) with respect to p, we have

$$V_{Ip}\left(-\rho_{\beta}\right)+V_{I}\left(-\rho_{\beta p}\right)+V_{\beta p}=0. \tag{22}$$

Rearranging terms in (22) yields

$$\rho_{\beta p}=\frac{-\rho_{\beta}V_{Ip}+V_{\beta p}}{V_{I}}. \tag{23}$$

The sign effect of a change in price on the marginal WTP for safety depends upon $-\rho_{\beta}V_{Ip}+V_{\beta p}$, the numerator of the right hand side of (23). Note that $V_{Ip}=0$ for a risk neutral individual. Therefore the sign of $\rho_{\beta p}$ depends on $V_{\beta p}$ for a risk neutral individual. Further it can be shown that

$$V_{\beta p}=-\delta\pi_{1}\left(1+R_{1}\right)\left(\frac{\partial X_{1}}{\partial p}\right)-\delta\alpha_{2}X_{1}\pi_{12}\left(\frac{\partial X_{2}}{\partial p}\right). \tag{24}$$

See Appendix C for the derivation of (24). Since $\frac{\partial X_1}{\partial p}<0$ for a normal good X_1, $V_{\beta p}$ is negative if two hazards are independent ($\pi_{12}=0$) and the individual exhibits hazard aversion ($R_1<0$). Therefore we observe that an increase in the food price decreases the marginal WTP for safety in that food when the individual reveals hazard aversion and income risk neutrality for two independent hazards.

In a study of estimating WTP for a safety improvement in shell fish, Lin and Milon (1993) hypothesized that consumers are not willing to pay more for the improvement of safety for a relatively high priced food when compared to their WTP for a relatively low priced food. Their empirical results show a negative relationship between the marginal WTP and the price of shell fish, although the estimated coefficient is not statistically significant. Our analytics identify the underlying assumptions implicitly made for a decreasing marginal WTP with respect to the risky food price. That is, the hypothesis of Lin and Milon is consistent with the assumptions that the individual reveals hazard aversion and has a constant marginal utility of income.

(vi) *When the individual reveals hazard aversion and income risk neutrality, an increase valuation on the future (i.e., an increase of* δ *) increases the marginal WTP for the safety level in* X_1 *if* X_1 *is relatively less hazardous than* X_2 $\left(\text{i.e.,} \frac{\alpha_1\pi_1}{p_1} > \frac{\alpha_2\pi_2}{p_2}\right)$.

What is the effect of a change in the discount rate δ on the marginal WTP for safety? Differentiating (14) with respect to δ, we have

$$V_{I\delta}(-\rho_\beta) + V_I(-\rho_{\beta\delta}) + V_{\beta\delta} = 0. \tag{25}$$

Rearranging terms in (25), we get

$$\rho_{\beta\delta} = \frac{-\rho_\beta V_{I\delta} + V_{\beta\delta}}{V_I}. \tag{26}$$

Note that the sign of $\rho_{\beta\delta}$ depends on the sign of $(-\rho_\beta V_{I\delta} + V_{\beta\delta})$, the numerator of the right hand side of (26). Again, if the individual exhibits income risk neutrality, then $V_{I\delta} = 0$. Further, we can derive $V_{\beta\delta}$ as

$$V_{\beta\delta} = -X_1\pi_1 - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial \delta}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial \delta}\right). \tag{27}$$

See Appendix C for the derivation of (27). Note that $\frac{\partial X_1}{\partial \delta}$ is positive if X_1 is relatively less risky than X_2 (i.e., $\frac{\alpha_1\pi_1}{p_1} > \frac{\alpha_2\pi_2}{p_2}$). Therefore we can observe that $V_{\beta\delta}$ is positive if two hazards are independent ($\pi_{12} = 0$) and X_1 is relatively less risky than X_2. Hence, the marginal WTP for safety in X_1 increases for a rise in the discount rate when the individual reveals hazard aversion and income risk neutrality for a relatively less risky food X_1. The meaning of the positive sign in (27) is straightforward. That is, an increase in the valuation of future for a hazard averse individual increases the marginal WTP for the safety increment in X_1 when X_1 is relatively less hazardous than X_2. In the case where there is only one risky food X_1 (then $\frac{\alpha_1 \pi_1}{p_1} < 0$), an increase of the future valuation of life has an ambiguous effect on the marginal WTP for the safety improvement in X_1 since the term $\frac{\partial X_1}{\partial \delta}$ is negative in (27) and the sign of $V_{\beta\delta}$ is ambiguous.

THE MEASURE OF MARGINAL WTP FOR THE RISKY FOOD

What is the consumer's maximum willingness to pay for the risky food when the safety is improved? Substituting the budget constraint $X_2 = \frac{I - p_1 X_1}{p_2}$ into the expected utility $J = u(X_1, X_2) + \delta\pi(\alpha_1 X_1, \alpha_2 X_2)$ in (2), the expected utility function can be expressed as

$$J = u\left(X_1, \frac{I - p_1 X_1}{p_2}\right) + \delta\pi\left(\alpha_1 X_1, \alpha_2\left(\frac{I - p_1 X_1}{p_2}\right)\right). \tag{28}$$

The maximum amount of the consumer's willingness to pay for the safer food X_1, ω, is implicitly defined as

$$u\left(X_1, \frac{I - \omega}{p_2}\right) + \delta\pi\left(\alpha_1 X_1, \alpha_2\left(\frac{I - \omega}{p_2}\right)\right) - \bar{J} = 0, \tag{29}$$

where $\bar{J}$ is a fixed amount of utility level. Totally differentiating equation (29) with respect to ω and β (note that we denote β as the safety level of X_1 for notational simplicity), we have

$$\left.\frac{d\omega}{d\beta}\right|_J = -\frac{\delta X_1 \pi_1}{\frac{1}{p_2}(u_2 + \delta\alpha_2\pi_2)}. \tag{30}$$

Since $(u_2 + \delta\alpha_2\pi_2) = \lambda p_2$ from the first order condition, equation (30) can be written as

$$\left.\frac{d\omega}{d\beta}\right|_J = -\frac{\delta X_1 \pi_1}{\lambda}. \tag{31}$$

Note that the sign of $\left.\frac{d\omega}{d\beta}\right|_{T}$ in (31) is positive. Equation (31) says the total amount that the consumer is willing to pay for the risky food increases as the safety level increases.

Note that since $\lambda = V_I$, the right hand side of (31) is exactly the same as the marginal WTP for safety in (15). The comparative statics results follow the discussion of properties (iii) to (vi) in the section of properties of the marginal WTP for safety.

IMPLICATION FOR EMPIRICAL SPECIFICATIONS

In this section we focus on the discussion of empirical studies in estimating the marginal WTP for food safety. Empirical methods used to elicit the WTP measures for safety improvement include a wide range of approaches, such as the contingent valuation method (Misra et al. 1991; Lin and Milon 1991), laboratory experimental approach (Shin et al. 1992; Fox et al. 1993), and market-based studies (van Ravenswaay and Hoehn 1991). Can these expressed WTP measures be directly applied in food policy analysis? Despite the valuation methods being used, researchers, particularly those who use contingent valuation methods, usually collect data on the WTP measures as well as respondent's income and demographic characteristics. Then, they seek to explain how the magnitude in the WTP measures varies among different explanatory variables. The examination of the functional relationship between the marginal WTP measures and the independent variables in the previous section can provide useful tests for verifying the validity of applying the estimated WTP in policy analysis.

Note that the marginal WTP for food safety, which is implicitly defined by equation (15), is a function of prices, income, change in safety levels, and the future discount rate. In the case of many risky foods, the marginal WTP for the food safety improvement can be expressed as a function of the form $f(p, I, \Delta\beta, \delta)$, where p is a vector of prices, I is the income, $\Delta\beta$ is a vector of change in safety, and δ is the time discount rate. For empirical studies, the measure of marginal WTP may be specified as the following

$$\text{Marginal WTP} = f(p, I, \Delta\beta, \delta; D) + \varepsilon,$$

where D is a vector of demographic characteristics and ε is the disturbance term. The properties of the marginal WTP, as discussed in the previous section, may be evaluated by decomposing the marginal WTP into several components for each explanatory variable.

Without decomposition, the hypothesized signs of coefficients are often undetermined. In the following we review the recent empirical studies in examining the relationship between the marginal WTP for safety improvement and the explanatory variables of prices and income, and relate these empirical results with the properties of the marginal WTP for safety discussed in the previous section. Then we focus on the issue of measuring the variable of safety or change in safety in empirical applications.

Surveys designed to elicit individuals' WTP for safety improvement usually do not have data on food prices. Hence, when researchers use cross section survey data, the food prices are assumed to be the same across respondents and are commonly omitted in the regression analysis of WTP. Evidence shows that the individual's consumption decision is often based on the multiattribute context of food related decisions (Halbrendt et al. 1993; Lin and Milon 1993). That is, the decision for the consumer to respond to a change in WTP for the safety improvement is likely to depend upon not only the change in safety but also the resulting change in prices of foods and other attributes. Therefore, incorporating the change in prices into consumers' decision of WTP will lead us to greater insight about the variation in consumers' responses to changes in the marginal WTP for safety.

Recall that equation (21) implies that when income increases, an increasing marginal WTP for safety exists for a hazard averse consumer with the nonincreasing marginal utility of income. Empirical studies, such as Buzby et al. (1993), Lin and Milon (1993), Misra et al. (1991), and Underhill and Figueroa (1993), all showed a positive relationship between income and the consumer's value of safer food. This evidence is consistent with property (iv) in section of properties of the marginal WTP for safety. That is, the marginal WTP for safety will increase as income increases when the individual reveals hazard aversion as well as income risk aversion (or income risk neutrality).

The measure of the safety index β or change in safety level is the most troublesome variable in empirical studies. A distinction of whether the safety index is directly observed or not is a caution here. The ideal measure of the safety index perceived by the consumers should be objectively measured in technological improvement of the safety of food. However, even where such measures exist, scientific information may not be fully understood by the consumers. While news reports are a major source of information to consumers, Maney and Plutzer (1993) found evidence that journalists might report the effects of using irradiation in cleaning livestock with their own political ideology. Therefore, the scientific measures of safety perceived by the consumers are not directly observable.

In practice, methods used to elicit WTP for safer food usually provide respondents with information on mortality or morbidity risk reduction. Then the interviewers may ask the question "how much do you want to pay for this risk reduction?" Since the human ability to correctly perceive information is complex and sensitive to the way information is presented, it is important to note that the results of such surveys or experiments may be sensitive to the type and manner in which information is provided. Studies on how to design appropriate surveys have been reviewed in the areas of evaluating risk reduction in life (such as Jones-Lee et al. 1985) and valuation of the environmental amenities (see Choices, second quarter 1993 for a review). As mentioned by Belzer and Therous (1993), these criteria for appropriately eliciting the value of WTP for environmental amenities should be carried on to the methodology in valuing safer food.

One point related to the functional specification of WTP should be mentioned here. Among empirical estimations of WTP for valuing food safety on the basis of surveys, the change in safety level is usually omitted in the specification equation since all respondents are given the same information about the risk reduction. Evidence has shown that consumers form their own perceptions about the safety improvement information given by the interviewers, despite how the safety information is given. That is, the consumers value WTP based on their own perception of the risk reduction provided by the interviewers. The consumer's *attitude* toward the risk information is the direct factor that affects the measure of WTP. In this sense, the level of safety perceived by the consumers is not directly observed.

Latent variables models are commonly used to find the approximation index for the unobservable explanatory variables in studies which examine the impact of consumers' attitudes or awareness on demand for goods (Train et al. 1987; Jensen et al. 1992). We may consider using the methodology in the latent variables model as one of the approaches to recover the unobserved variable of the consumers' attitudes in food safety studies.

SUMMARY

This paper derives theoretical measures of the marginal WTP for safety. The marginal WTP measure for safety is independent of the utility function. All the properties of marginal WTP for safety are addressed. These properties illustrate how the marginal WTP for safety is affected by a change in explanatory variables such as the safety level, income, and prices. All of the results of comparative statics results regarding to the marginal WTP for safety are summarized in Table 1. Table 1 clearly indicates the sufficient conditions which result in determining the signs of the impacts of exogenous variables on the marginal WTP for safety. For example, if two hazards are independent ($\pi_{12} = 0$) and the marginal utility of income is constant, then an increase in the price of food decreases the marginal WTP for safety. The discussion of these properties could shed more insight for understanding the signs of estimated coefficients in empirical studies. For instance, the common hypothesis that marginal WTP for safety increases when income increases should be contingent on the assumptions that the consumers reveal hazard aversion and income risk aversion (or income risk neutrality).

Further, we review some of the studies in empirical specification of WTP for food safety. The food prices were commonly omitted in the marginal WTP equation and most of empirical results suggested a positive relation between income and the marginal WTP. Finally, we pointed out the problems of measuring the variable of safety level and suggested that one way to recover the unobserved variables is to apply the latent variables models.

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NOTES

1 In a different context, Shogren (1991) used $\Gamma(x) = -\frac{p''(x)}{p'(x)}$ as a measure of aversion, where x is an endogenous asset and $p(\cdot)$ is the probability function.

2 An alternative way to explain equation (15) is to examine how the risk premium changes as the hazard increases. The risk premium here is defined as the amount of money that the consumer is willing to give up in order to insure the certainty. Let us consider the case of one risky food (i.e., $\beta_2 = 1$) and the price of X_2 is normalized as one. Therefore, the risk premium, η, is implicitly defined as

$$u(X_1, I - p_1X_1 - \eta) + \delta \cdot 1 = u(X_1, I - p_1X_1) + \delta\pi[(1-\beta_1)X_1]$$

Taking a Taylor's series expansion around $(X_1, I - p_1X_1)$ for both sides of the above equation, we have the left hand side

$$\begin{aligned} u(X_1, I - p_1X_1 - \eta) + \delta \cdot 1 \cong\; & u(X_1, I - p_1X_1) + \delta + (X_1 - X_1)u_1(X_1, I - p_1X_1) \\ & + [(I - p_1X_1) - \eta - (I - p_1X_1)]u_2(X_1, I - p_1X_1) + O^2(\cdot), \end{aligned}$$

and the right hand side

$$u(X_1, I - p_1X_1) + \delta\pi[(1-\beta_1)X_1] \cong u(X_1, I - p_1X_1) + \delta\pi[(1-\beta_1)X_1] + O^3(\cdot)$$

where $O^2(\cdot)$ and $O^3(\cdot)$ are the second and third orders of the remainders. Equating both sides of the expansion and setting the remainders equal to zero, we have the risk premium

$$\eta = \frac{\delta(1-\pi)}{u_2}.$$

Note that since the budget constraint is linear in X_2 and the price of X_2 is normalized at one the risk premium can be expressed as $\eta = \frac{\delta(1-\pi)}{\lambda}$ where λ is the marginal utility of income. The meaning of this risk premium is straightforward. The amount of money that the individual is willing to give up to insure the certainty of survival is equal to the discounted value of non survival weighted by the marginal utility of income. How much is the individual willing to give up for an additional unit of increased risk? Differentiating the risk premium with respect to α_1, we have

$$\frac{\partial \eta}{\partial \alpha_1} = \frac{-\delta X_1 \pi_1}{\lambda}.$$

Note that since $\lambda = V_I$, the right hand side of the above equation has the same expression as that appears in equation (15).

Table 1. The comparative statics for the marginal WTP for safety[1]

sign	$\pi_{12}=0$	$V(I,\beta,p,\delta)$ is concave on (I,β)	$\pi_{12}=0$, and $V_{II}\le 0$	$\pi_{12}=0$, and $V_{II}=0$	$\pi_{12}=0$, $V_{II}=0$, and $\frac{\alpha_1\pi_1}{p_1}>\frac{\alpha_2\pi_2}{p_2}$
$\rho_{\beta\beta}$	?	-	nr	nr	nr
$\rho_{\beta I}$	?	nr[2]	+	nr	nr
$\rho_{\beta p}$	?	nr	nr	-	nr
$\rho_{\beta\delta}$	?	nr	nr	nr	+

1 Assume X_1 and X_2 are normal, and the consumer reveals hazard aversion ($R_1 > 0$).
2 "nr" indicates that the sign is irrelevant to the assumption made in that column.

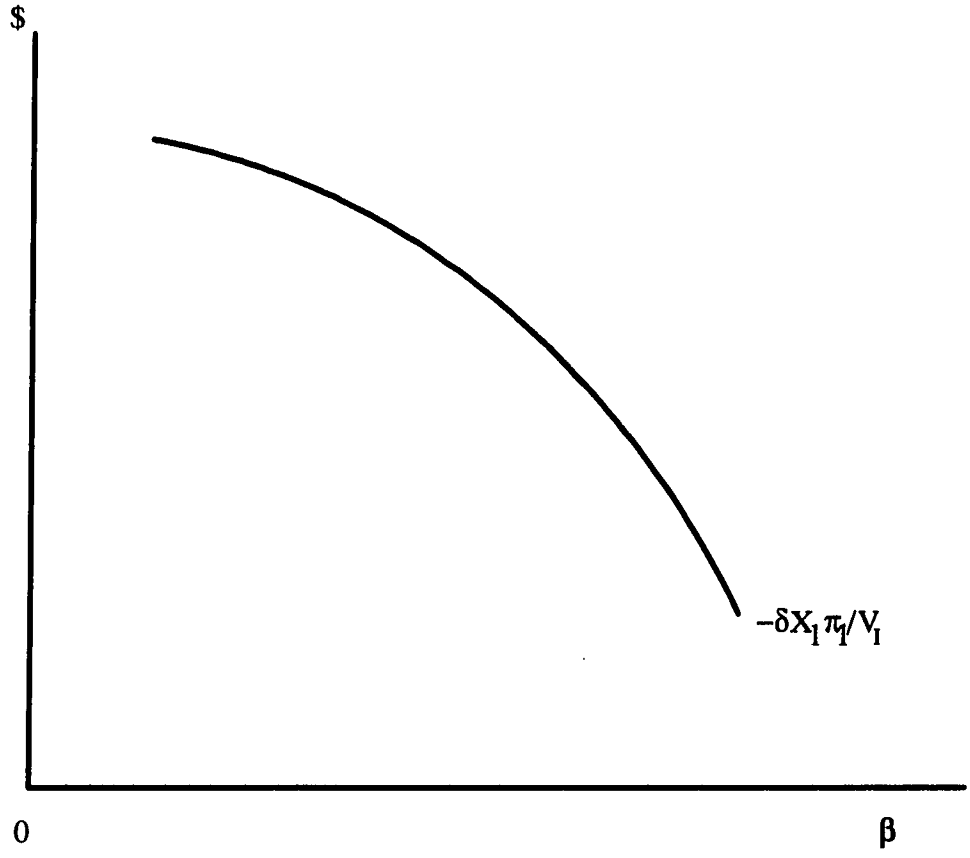

Figure 1. The Conditional Demand for Food Safety β

APPENDIX

A. Derivation of V_I:

Differentiating (12) with respect to I yields

$$V_I = u_1\left(\frac{\partial X_1}{\partial I}\right) + u_2\left(\frac{\partial X_2}{\partial I}\right) + \delta\alpha_1\pi_1\left(\frac{\partial X_1}{\partial I}\right) + \delta\alpha_2\pi_2\left(\frac{\partial X_2}{\partial I}\right)$$

$$= (u_1 + \delta\alpha_1\pi_1)\left(\frac{\partial X_1}{\partial I}\right) + (u_2 + \delta\alpha_2\pi_2)\left(\frac{\partial X_2}{\partial I}\right). \quad \text{(A1)}$$

Since $u_1 + \delta\alpha_1\pi_1 = \lambda p_1$ and $u_2 + \delta\alpha_2\pi_2 = \lambda p_2$ from the first order conditions, we have

$$V_I = \lambda\left[p_1\left(\frac{\partial X_1}{\partial I}\right) + p_2\left(\frac{\partial X_2}{\partial I}\right)\right]. \quad \text{(A2)}$$

Further, since $p_1\left(\frac{\partial X_1}{\partial I}\right) + p_2\left(\frac{\partial X_2}{\partial I}\right) = 1$ from the budget constraint, we have $V_I = \lambda$, the marginal utility of income.

B. Derivation of V_β:

Differentiating (12) with respect to β, we have

$$V_\beta = u_1\left(\frac{\partial X_1}{\partial \beta}\right) + u_2\left(\frac{\partial X_2}{\partial \beta}\right) + \delta\alpha_1\pi_1\left(\frac{\partial X_1}{\partial \beta}\right) + \delta\alpha_2\pi_2\left(\frac{\partial X_2}{\partial \beta}\right) - \delta X_1\pi_1. \quad \text{(B1)}$$

Rearranging terms in (B1) yields

$$V_\beta = (u_1 + \delta\alpha_1\pi_1)\left(\frac{\partial X_1}{\partial \beta}\right) + (u_2 + \delta\alpha_2\pi_2)\left(\frac{\partial X_2}{\partial \beta}\right) - \delta X_1\pi_1. \quad \text{(B2)}$$

Again, since $u_1 + \delta\alpha_1\pi_1 = \lambda p_1$ and $u_2 + \delta\alpha_2\pi_2 = \lambda p_2$ from the first order conditions, equation (B2) becomes

$$V_\beta = \lambda\left[p_1\left(\frac{\partial X_1}{\partial\beta}\right) + p_2\left(\frac{\partial X_2}{\partial\beta}\right)\right] - \delta X_1\pi_1. \tag{B3}$$

Since $p_1\left(\frac{\partial X_1}{\partial\beta}\right) + p_2\left(\frac{\partial X_2}{\partial\beta}\right) = 0$ from equations (9a) and (9b), we have

$$V_\beta = -\delta X_1\pi_1. \tag{B4}$$

C. Derivations of $V_{\beta I}, V_{\beta\beta}, V_{\beta p}$, and $V_{\beta\delta}$:

Derivation of $V_{\beta I}$:

Since $V_\beta = -\delta X_1\pi_1$ in (B4), we have

$$V_{\beta I} = -\delta\pi_1\left(\frac{\partial X_1}{\partial I}\right) - \delta\alpha_1 X_1\pi_{11}\left(\frac{\partial X_1}{\partial I}\right) - \delta\alpha_2 X_1\pi_{12}\left(\frac{\partial X_2}{\partial I}\right). \tag{C1}$$

Substituting the relative hazard aversion $R_1 = \frac{\alpha_1 X_1\pi_{11}}{\pi_1}$ into (C1), we have $V_{\beta I}$ as

$$V_{\beta I} = -\delta\pi_1(1 + R_1)\left(\frac{\partial X_1}{\partial I}\right) - \delta\alpha_2 X_1\pi_{12}\left(\frac{\partial X_2}{\partial I}\right). \tag{C2}$$

Derivation of $V_{\beta\beta}$:

Again, differentiating (B4) with respect to β, we have

$$V_{\beta\beta} = -\delta\pi_1\left(\frac{\partial X_1}{\partial\beta}\right) - \delta\alpha_1 X_1\pi_{11}\left(\frac{\partial X_1}{\partial\beta}\right) - \delta\alpha_2 X_1\pi_{12}\left(\frac{\partial X_2}{\partial\beta}\right) + \delta X_1^2\pi_{11}. \tag{C3}$$

Substituting $R_1 = \dfrac{\alpha_1 X_1 \pi_{11}}{\pi_1}$ into (C3) and rearranging terms yields

$$V_{\beta\beta} = \delta X_1^2 \pi_{11} - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial\beta}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial\beta}\right). \tag{C4}$$

Derivation of $V_{\beta p}$:

Differentiating (B4) with respect to p, we have

$$V_{\beta p} = -\delta\pi_1\left(\frac{\partial X_1}{\partial p}\right) - \delta\alpha_1 X_1 \pi_{11}\left(\frac{\partial X_1}{\partial p}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial p}\right). \tag{C5}$$

Substituting $R_1 = \dfrac{\alpha_1 X_1 \pi_{11}}{\pi_1}$ into (C5), we get $V_{\beta p}$ as

$$V_{\beta p} = -\delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial p}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial p}\right). \tag{C6}$$

Derivation of $V_{\beta\delta}$:

Differentiating (B4) with respect to δ, we have

$$V_{\beta\delta} = -\delta\pi_1\left(\frac{\partial X_1}{\partial\delta}\right) - \delta\alpha_1 X_1 \pi_{11}\left(\frac{\partial X_1}{\partial\delta}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial\delta}\right) - X_1\pi_1. \tag{C7}$$

Substituting $R_1 = \dfrac{\alpha_1 X_1 \pi_{11}}{\pi_1}$ into (C7) and rearranging terms, we have

$$V_{\beta\delta} = -X_1\pi_1 - \delta\pi_1(1+R_1)\left(\frac{\partial X_1}{\partial\delta}\right) - \delta\alpha_2 X_1 \pi_{12}\left(\frac{\partial X_2}{\partial\delta}\right). \tag{C8}$$

PAPER III.

EQUILIBRIUM ANALYSIS AND IMPLICATIONS FOR REGULATION OF RISKY FOODS

INTRODUCTION

Food safety cases and increased scientific evidence on food related diseases have resulted in increasing attention by media, consumers, and policy makers to food consumption choices and posed new demands for public involvement. This attention has been reflected in the concerns of Congress. In 1989, 16 food safety bills were introduced into Congress. These legislative proposals addressed a variety of considerations related to regulating food safety problems, such as banning particular pesticides, offering financial incentives to use substitute chemicals in production, and regulating food labeling to improve consumers' information (Kramer 1990). During the period of 1990 to 1992, several legislative proposals concerning food safety were continuously introduced to Congress (Food Review). Most of them focused on the establishment of a standard level on food sanitation during processing or delivery. And currently there is public debate about the appropriate organization of food safety regulation within the federal government.

So far, only a few economic studies have focused on the welfare implications of the food safety policies. For examples, Morales and Thurman (1993) evaluated the resulting benefits and costs caused by a regulation policy to control salmonella enteritis on shell and breaker markets. Huang (1993) developed a framework to examine the ex ante welfare costs for producers and consumers in response to a pesticide reduction regulation. Among these studies, an underline presumption is that the initial levels of safety and quantity are optimal. Hence the analysis is taken to compare the initial levels and the resulting equilibria changes brought about by a policy change. The difference between the initial welfare and the resulting welfare by regulation is referred to the welfare losses.

An interesting question arises from these studies in regulating food safety. If the initial equilibria in markets are optimal, then any policy which distorts the market will result in a welfare loss. Therefore, we return to a natural question of whether or not it is necessary for the government to intervene in markets when the food safety level is of concern. If the market fails to provide the optimal safety level, what are the implications for the government to choose efficient policies to improve social welfare. When the market fails to provide the desirable safety level, the government in general may take the following ways to reduce the welfare losses (Choi and Jensen 1991). First, the government may require producers to disseminate the necessary information about the risk characteristics into the product label or it may provide necessary information directly to the consumers. Second, it can use a tax (subsidy) to restrict the outputs or inputs in order to reduce hazards to the public. Third, it may set the level of food safety or maximum tolerance levels for risky inputs used in producing foods directly to avoid the possible consumers' losses.

The purpose of this study is to investigate whether the equilibrium levels of quantity and safety in the perfectly competitive markets are socially optimal levels. Is there a need for the government to intervene in perfectly competitive markets? We examine this question in the following way. First, we define and establish the conditions for determining the socially optimal quantities and safety levels. Then we compare these conditions with the equilibrium conditions under perfectly competitive markets. The observation is that the perfectly competitive markets would provide the socially desirable safety levels when the safety information is fully perceived by the consumer. However, when the consumer forms subjective beliefs about the safety level or there exists uncertainty about the impact of hazard on survival, will the competition in markets still lead to socially optimal levels of safety? Although this question has not been further analyzed, we suggest that it is unlikely that competitive markets would yield socially desirable levels of safety and quantity when safety is perceived with uncertainty.

This paper is organized as follows. Section 2 gives the demand model for risky foods and the production structure of firms under the perfectly competitive markets. Section 3 defines the socially optimal conditions. Section 4 derives the perfectly competitive market conditions and compares these conditions with the socially optimal conditions. Finally, the implications for food safety regulations are addressed.

THE PERFECTLY COMPETITIVE MARKETS FOR RISKY FOODS

Consider the situation where there are two safety levels of a risky food available in the markets. Assume a representative consumer allocates his income on a numeraire good Z and the risky food X, where there are two safety levels of food X available for the consumer in the market. Examples are cases where there are foods with regular fat and low fat, naturally occurring level of cholesterol and cholesterol free, etc. Denote food X_1 with the safety level β_1 and X_2 with the safety level β_2. The consumer is assumed to choose a combination of X_1 and X_2, and the numeraire good Z.

In the case where a commodity bundle contains an impure consumption food, the consumer has to weigh the direct utility gains versus potential health risks. Assume X_1 and X_2 are perfect substitutes in the sense their sum enters the utility function $u(\cdot)$ directly. That is the consumer's current utility $u(\cdot)$ depends on Z and the sum of X_1 and X_2. For simplicity, let us consider a two period utility of the consumer as

$$U = \sum_{t=1}^{2} u(X_{1t} + X_{2t}, Z_t). \tag{1}$$

Equation (1) yields total utility when the survival into the second period is certain. We assume that the hazards do not affect consumer's utility in the current period, but affect the consumer's chance of survival in good "health" into the next period. Thus, the consumer faces uncertainty regarding survival into the next period.

Assume that the probability of survival is less than one and known by the consumer. Let π be the probability of survival into the second period, $0 \leq \pi < 1$. It should be noted that the individual receives no income if he does not survive. Without loss of generality, we assume that the utility level in the second period is zero if the consumer fails to survive ($u_2 = 0$). Assume further that the utility function in each period is normalized so that the utility in the second period when the consumer survives is unity, i.e., $u_2 = v_2 = 1$ where v_2 is the indirect utility function in the second period. Then the second period utility can be written as a random variable,

$$u_2 = \begin{cases} 0, \text{with probability } (1-\pi), \\ 1, \text{with probability } \pi. \end{cases}$$

The expected utility of the consumer is

$$J = u(X_1 + X_2, Z) + \delta\pi, \tag{2}$$

where the subscript $t = 1$ is suppressed (i.e., $X_1 = X_{11}$ and $X_2 = X_{21}$).

Let α_i denote the amount of impurity per unit of the risky goods X_i consumed. For simplicity, the hazard content in each food is assumed to be constant and is normalized so that $0 \le \alpha_1, \alpha_2 \le 1$. Further, the total hazards which enter the probability of survival function are assumed to be the sum of two impurities, i.e., the total hazards are $(1-\beta_1)X_1 + (1-\beta_2)X_2$ where $\alpha_i = 1 - \beta_i$. Then the probability of survival is written as

$$\pi = \pi[(1-\beta_1)X_1 + (1-\beta_2)X_2]. \tag{3}$$

Assume that the probability of survival is decreasing in $(1-\beta_1)X_1 + (1-\beta_2)X_2$, i.e., $\pi' < 0$. Therefore, the consumer's expected utility is

$$u[X_1 + X_2, Z] + \delta\pi[(1-\beta_1)X_1 + (1-\beta_2)X_2]. \tag{4}$$

Note that this model is related to the repackaging model of quality varying goods (Deaton and Muellbauer 1980) but they are not exactly the same. In considering the quality difference of a representative good, the utility function of a simple repackaging model for a good with two quality levels of concern could be considered as $u = u[\beta_1 X_1 + \beta_2 X_2, Z]$, where β_i now is referred to the quality parameter of good X_i. However, in our study, the expected utility function can be implicitly expressed as $J \equiv J[X_1 + X_2, (1-\beta_1)X_1 + (1-\beta_2)X_2, Z]$, where the hazards has an adverse effect on J.

Further, we assume the price of X_i taking a linear price schedule, $p_i(\beta_i) = p_i^o + q_i\beta_i$, where p_i^o is the "pure" quantity price and q_i is the price of safety for food X_i. This assumption is analogous to the price-quality trade-offs function suggested by Houthakker (1951-52). Houthakker considered a price-taking consumer faces a linear price function: $p_i = a_i + b_i\beta_i$, where a_i is the "pure quantity" price, b_i is the "quality" price, and β_i is the quality level associated with good i; b_i could be referred to as the cost per unit of quality associated with one unit of the good i (Hanemann 1982).

In the production side, assume X_1 and X_2 are produced by different firms. For simplicity, assume all competitive firms in market 1 for producing X_1 are identical. Also, all competitive firms in market 2 for producing X_2 are identical. Consider a representative firm in each market producing a risky product. The representative firm's profits in each market are defined, respectively, as

$$M_1 \equiv (p_1^o + q_1\beta_1)X_1 - C_1(X_1, \beta_1), \text{ and} \tag{5a}$$

$$M_2 \equiv (p_2^o + q_2\beta_2)X_2 - C_2(X_2, \beta_2), \tag{5b}$$

where $C_i(\cdot)$ is the cost function for the representative firm in market i. Assume that M_i is concave on X_i and β_i, respectively, for i = 1,2.

THE SOCIALLY OPTIMAL CONDITIONS

The individual income is assumed to be allocated among X_1, X_2, and Z. Therefore, the price-taking individual's budget constraint is

$$I = (p_1^o + q_1\beta_1)X_1 + (p_2^o + q_2\beta_2)X_2 + Z, \tag{6}$$

where the price of Z is normalized as one. The socially optimal levels of quantity and safety are obtained by solving the maximization problem of a representative consumer who receives the profits from both productions. That is the representative consumer also receives the income from producers and the consumer's budget constraint becomes

$$I + M_1 + M_2 = (p_1^o + q_1\beta_1)X_1 + (p_2^o + q_2\beta_2)X_2 + Z. \tag{7}$$

Rearranging (7), this constraint could be expressed in term of Z

$$Z = I - C_1(X_1, \beta_1) - C_2(X_2, \beta_2). \tag{8}$$

Then the socially optimal levels of quantities and safety levels are defined as the situation where the consumer chooses X_1, X_2, β_1, and β_2 to maximize the expected utility

$$u[X_1 + X_2, I - C_1(X_1, \beta_1) - C_2(X_2, \beta_2)] + \delta\pi[(1-\beta_1)X_1 + (1-\beta_2)X_2]. \tag{9}$$

Denote $X \equiv X_1 + X_2$ and $C \equiv (1-\beta_1)X_1 + (1-\beta_2)X_2$. The first order conditions for this problem are

$$\frac{u_X + \delta(1-\beta_1)\pi_C}{u_Z} = \frac{\partial C_1}{\partial X_1}, \tag{10a}$$

$$\frac{u_X + \delta(1-\beta_2)\pi_C}{u_Z} = \frac{\partial C_2}{\partial X_2}, \tag{10b}$$

$$\frac{-\delta X_1 \pi_C}{u_Z} = \frac{\partial C_1}{\partial \beta_1}, \tag{10c}$$

$$\frac{-\delta X_2 \pi_C}{u_Z} = \frac{\partial C_2}{\partial \beta_2}, \tag{10d}$$

where $u_X \equiv \frac{\partial u}{\partial X}$, $u_Z \equiv \frac{\partial u}{\partial Z}$, and $\pi_C \equiv \frac{\partial \pi}{\partial C}$. The solutions to (10a) - (10d) yield the socially optimal levels for X_1, X_2, β_1, and β_2. In this case, the representative consumer who is also the producer would choose the levels of X_i and β_i by equating the marginal benefits of the consumer to the marginal costs of the production for both X_i and β_i in each market, respectively.

THE EQUILIBRIA UNDER THE PERFECTLY COMPETITIVE MARKETS

Assume the information about the safety levels β_1, and β_2 are correctly recognized by the consumer in the perfectly competitive markets. Therefore, the representative consumer's problem is to choose X_1, X_2, and Z to maximize the expected utility,

$$u[X_1 + X_2, Z] + \delta\pi[(1-\beta_1)X_1 + (1-\beta_2)X_2], \tag{11}$$

subject to the budget constraint,

$$I = (p_1^o + q_1\beta_1)X_1 + (p_2^o + q_2\beta_2)X_2 + Z. \tag{12}$$

Substituting Z in (12) into (11), the representative consumer's problem is rewritten as to choose X_1 and X_2 to maximize the expected utility function:

$$\begin{aligned} J \equiv\ & u[X_1 + X_2, I - (p_1^o + q_1\beta_1)X_1 - (p_2^o + q_2\beta_2)X_2] + \\ & \delta\pi[(1-\beta_1)X_1 + (1-\beta_2)X_2]. \end{aligned} \tag{13}$$

The first order conditions for this problem are

$$\frac{u_X + \delta(1-\beta_1)\pi_C}{u_Z} = (p_1^o + q_1\beta_1), \tag{14a}$$

$$\frac{u_X + \delta(1-\beta_2)\pi_C}{u_Z} = (p_2^o + q_2\beta_2). \tag{14b}$$

In this case, the consumer under perfectly competitive markets chooses the equilibrium quantities of X_1 and X_2 by equating the marginal benefit of X_i to the price of X_i for i = 1,2.

What is the consumer's marginal willingness to pay for the safety β_i per unit of X_i (i.e., what is the expression for the value of q_i)? It can be shown that the consumer's marginal willingness to pay for the safety β_i (i.e., q_i) is $\frac{-\delta\pi_C}{u_Z}$ for i = 1,2.[1] These results can be expressed as

$$q_1X_1 = \frac{-\delta X_1\pi_C}{u_Z}, \tag{14c}$$

$$q_2X_2 = \frac{-\delta X_2\pi_C}{u_Z}. \tag{14d}$$

The representative firm's problem in the perfectly competitive market i is assumed to be choosing X_i and β_i to maximize the profit at given prices. Therefore, the first order conditions for (5a) and (5b) are

$$\left(p_1^o + q_1\beta_1\right) = \frac{\partial C_1}{\partial X_1}, \tag{15a}$$

$$\left(p_2^o + q_2\beta_2\right) = \frac{\partial C_2}{\partial X_2}, \tag{15b}$$

$$q_1X_1 = \frac{\partial C_1}{\partial \beta_1}, \tag{15c}$$

$$q_2X_2 = \frac{\partial C_2}{\partial \beta_2}. \tag{15d}$$

In this case, the representative firm in market X_i chooses the levels of X_i and β_i by equating the prices of X_i and β_i to the marginal cost of X_i and β_i, respectively, for i=1,2.

By examining the equations (14a)-(14d) and (15a)-(15d), we observe that the perfectly competitive equilibria of quantity and safety are obtained by equating the consumer's marginal benefits to the marginal costs in the production. This is because the consumer equates the marginal benefits to the prices and the producer equates the prices to the marginal costs. Combining the consumer's optimal condition of equations (14) and the producers' optimal condition of equations (15) yields the exact same conditions as equations (10a)-(10d), which provide the socially optimal levels of quantity and safety. That is, under perfectly competitive markets for both X_1 and X_2, the equilibria of quantity and safety are socially desirable.

The above analysis is under the assumption that the product information is accurately perceived by the consumers. If this is the case, this result implies there is no need for the government to regulate the food safety level when the market is perfectly competitive for each safety level. The role for the government in this case may be restricted only to require the producers to provide accurate information to consumers. However, if accurate information is not fully prevailing in the market, then the underling market may fail to provide the optimal levels of quantity and safety. Further, even if the product information is accurately transmitted, the consumer may have a subjective belief or distribution about the hazards in the risky foods that differs from the covered information (National Academy of Sciences 1989). Will the perfectly competitive markets still yield the socially desirable levels of safety and quantity when the consumer formulates a subjective belief about the hazards? If the market fails to provide desirable safety, what are the implications for the role of government in choosing public policies to improve the social welfare? We discuss these implications for food policies in the next section.

CONCLUSION AND IMPLICATIONS FOR GOVERNMENT POLICIES

A demand for risky food model allows examining the question of whether the competition outcomes lead to socially optimal levels. It is shown that if accurate information about the hazard content is provided, the desired levels of safety and quantity by the policy makers are the same choices that result from consumers and producers acting in competitive markets. This result implies that there is no need for the government to intervene when competitive markets prevail and information on the safety content of food is fully provided. In this case, the consumer can optimally choose the product differentiated by the safety content. Examples include choices between cholesterol free and natural cholesterol products, sugar free and regular sugar products, irradiated meat or not, meat with low fat or high fat, organic fruit or not, etc. Further, we may distinguish markets which have products of different qualities. In these markets, the role of government may be limited to the verification of label information being accurately provided.

However, the assumption that the consumer perceives perfectly the hazard content does not hold for many risky food markets. It is quite possible that asymmetric information about the hazard content prevails in risky food markets because producers have no incentive to provide accurate information if the provision of information is costly or the adverse information may affect the product sales (Choi and Jensen 1991; Falconi and Roe 1991). Furthermore, even if the information is perfectly provided, the consumer may form his or her subjective perception about the potential hazard effects on health which differs from actual levels and this difference may result in undesirable social levels of safety and quantity. Examples include the case where the consumer's belief about safety differs from objective/scientific evidence on the safety of products grown with pesticide use, grown with artificial hormone use, or treated with irradiation. In these cases, the resulting markets with random safety levels perceived by consumers are not likely to provide the socially desirable levels of safety and quantity. A single policy instrument, for example setting a higher safety standard only for one food, will not guarantee the improvement of social welfare level in the many risky foods markets. In considering all of the possible instruments like government's signaling the safety information or requiring the producers to provide necessary information, taxing the hazard inputs (or subsiding the safety improvement), and regulating the minimum standard safety levels, the government could choose the combination of these instruments by comparing the expected marginal gain of each policy to its respective marginal cost.

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NOTES

1 In this case, we derive the consumer's marginal willingness to pay for safety per unit of X_1 as the following way. Let us consider the case of safety improvement of X_1 first. The maximum amount the consumer is willing to pay for safety β_1, w_1, per unit of X_1 is implicitly defined as

$$u\left[X_1+X_2, I-p_1^{\circ}X_1-w_1X_1-\left(p_2^{\circ}+q_2\beta_2\right)X_2\right]+\delta\pi\left[(1-\beta_1)X_1+(1-\beta_2)X_2\right]-\bar{J}=0, \quad (13')$$

where is a fixed level of expected utility. Assume $w_1(\beta_1)$ is the WTP for safety per unit of X_1 satisfying (13'). Totally differentiating (13') with respect to w_1 and β_1 gives

$$\frac{dw_1}{d\beta_1}=\frac{-\delta\pi_C}{u_Z}. \quad (13'')$$

That is the consumer's marginal WTP for safety β_1 per unit of X_1 is $\frac{-\delta\pi_C}{u_Z}$. Therefore, the value of q_1 is $\frac{-\delta\pi_C}{u_Z}$. Multiplying both sides of q_1 and $\frac{-\delta\pi_C}{u_Z}$ by X_1, this relation can be expressed as $q_1X_1=\frac{-\delta X_1\pi_C}{u_Z}$. Following the same argument above for the valuation of safety β_2, we can derive the following relation: $q_2X_2=\frac{-\delta X_2\pi_C}{u_Z}$.

GENERAL CONCLUSION

A demand for risky food model is constructed to study several aspects of food safety. On the basis of a proposed demand model, several results are addressed in the following. First, when the food safety is exogenously fixed, an increase in the safety level of the risky food X_1 increases the demand for X_1 if X_1 is normal. However, when both goods are risky, a rise in the safety level of one good generally has an ambiguous effect on the demands. For the case where the safety level is endogenously chosen, the consumer will in general accept some risks and perfect safety is not optimal.

Second, in the absence of a market place for the food safety, a measure of the marginal willingness to pay for the safety improvement is derived. The expression of the marginal willingness to pay for safety is independent of the utility function. The use of this marginal willingness to pay measure can avoid the interpersonal utility comparison in the empirical studies. Although the signs of the comparative static analysis of the marginal WTP for safety are ambiguous, the conditions which result in a deterministic sign in a comparative static study are clearly shown and discussed. The discussion of these conditions could shed more insight for understanding the signs of estimated coefficients in empirical studies. For instance, the common hypothesis of the increasing marginal willingness to pay for safety with respect to income should be contingent on the assumptions that consumers reveal hazard aversion and income risk aversion (or income risk neutrality). In the recognition that food safety is embodied in the food, we also derive the measure of the marginal willingness to pay for the risky food with respect to an increase in safety.

Third, given full information about the safety content, competitive markets would yield the optimal levels of quality and quantity. This result implies that there is no need for the government to intervene when competitive markets prevail and information on the safety content of food is fully provided. However, when the safety information is perceived with uncertainty, the competitive market would not likely produce the socially desirable levels of either safety or quantity.

This study points out three important food safety issues that have not been received considerable attention. They are (1) the study of multi-risky foods case, (2) the theoretical treatment in determining the sign impacts of exogenous variables on the marginal willingness to pay for safety and the marginal willingness to pay for the risky food, and (3) the equilibrium analysis by the influence of food safety information. These three papers on food safety issues could help the future development of either theoretical or empirical studies in the demand for risky foods.

Future researches could include two aspects. First, consider to extend the demand for risky food model into more periods where we can examine the role of future income in determining the demand for risky foods. Under the multiperiod model we can incorporate the government signal in information and examine how the signal affects the demand for the risky foods in the long run. Then, we can examine the role of hazard aversion in such a multiperiod demand model. Second, consider the possibility of self-protecting behavior in reducing the risky content and hence the probability of survival function.

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