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HEALTH RISKS IN FOOD PRODUCTS, LEARNING OPPORTUNITY AND VALUES OF RISK INFORMATION: AN APPLICATION OF SELF-PROTECTION MODEL

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Health risks from food product consumption have received increased attention in recent years as a major consumer concern. Currently available empirical evidence suggests that consumers' concerns about food-related risks seem to motivate them to undertake some types of protective actions. Yet, consumers seem to have difficulty dealing with low-probability events, but are able to learn about the risks after receiving new information. This paper proposes to develop a conceptual framework integrating these three separately treated components in dealing with food safety risks — risk perceptions, learning and averting behavior — into a single and consistent model of a two-period framework of expected utility maximization. The ex ante *value of risk information derived from the theoretical analysis reflects both changes in self-protection expenditures and values of improved decision making due to learning about health risks over time.*

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I. INTRODUCTION

In recent years, consumers have become increasingly concerned about health risks they may face from food product consumption. Traditionally, economists have used observed purchase behavior and tradeoffs that consumers make in the marketplace as a basis for inferences about their preferences for and implicit values of health risks. However, health risks are only part of bundles of attributes characterizing food products. That is, health risks are nonmarket goods without directly

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observable price components. Therefore, the conventional consumer demand analysis may not directly applicable in measuring the values that consumers place on changes in health risks.

In these circumstances, a natural tendency of economic modeling strategy is to establish some linkage between the nonmarket goods to be valued and observable market goods or private actions. Indeed, currently available empirical evidence suggests that consumers' concerns about food-related risks seem to motivate them to undertake some types of protective actions to reduce health risks (Swartz and Strand (1981), Smith et al., (1988), Foster and Just (1989), Brown and Schrader (1990), Ippolito and Mathios (1990), van Ravenswaay and Hoehn (1991a), Eom (1994, 1996a)).

While these studies provide evidence on consumers' revealed or stated preferences for safer products, these early efforts failed to incorporate consumers' risk perception processes into the behavioral framework. In studies investigating consumers' aggregate responses, risk information was measured using crude proxies such as the number of news accounts appearing or dummy variables. On the other hand, in studies of individual responses, consumers were assumed to know technical risk estimates or to perceive the risks accurately in response to news coverage with the exception of van Ravenswaay and Hoehn (1991b) and Eom (1994, 1996a). Unfortunately, objective risk measures are not known exactly, even to the scientists (Kramer (1990), Talcott (1992)). Indeed, prominent psychologists such as Slovic et al., (1985) argue that there is no objective risk. In their view, all risks are subjective, whether judged by experts or lay people. In the formation of subjective risks, however, consumers often have imperfect and incorrect information about the event at risk, and seem to be influenced by factors that are different from those influencing experts' risk assessments.[1] Especially, consumers appeared to overestimate the likelihood of low-probability events, which are likely to yield health impacts that are uncertain, long-term, imposed involuntarily, and associated with "dread" outcomes (Lowrance (1976), Arrow (1982), Slovic (1987), Viscusi and Magat (1987), van Ravenswaay (1991)). Nonetheless, growing empirical evidence suggests that consumers can learn about the low-probability risks and update their risk perceptions after receiving new information (Viscusi and O'Connor (1984), Smith and Johnson (1988)).

This possible three-way connection—perception, behavior and valuation—clearly provides important implications on governmental efforts to address

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[1] For example, while food safety experts rank known food-borne diseases due to microorganisms as the most important health risk to the public, consumers perceive negligible but unknown cancer-causing chemical residuals as their most serious food safety concerns (see Roberts and van Ravenswaay (1989), Kramer (1990), Food Marketing Institute (1989-1992)). A similar tendency was found among Korean consumers. For example, a consumer survey conducted in Chon Ju, Korea by Eom (1996b) included questions probing consumers' attitudes toward six substances that may remain in food. Of 675 respondents, more than half of the consumers reported that chemical residues including pesticides would pose the most serious health hazards to their household members. On the other hand, only 7 percent of the respondents felt that microorganism pathogens would pose the most serious health hazards.

market failure associated with food product risks. However, to date, these three aspects of product safety economics have not been analyzed in an integrated manner. To address these issues systematically, I propose to develop a conceptual framework of consumers' consumption behavior incorporating their risk perception processes in response to new information. The conceptual framework will largely accept the conventional expected utility theory as a description of consumer behavior in the presence of health risks. However, the framework will modify it to incorporate such a situation when consumption decisions must be made with incomplete information about food-related risks but self-protection actions to reduce adverse health effects are available.

When we interpret consumers' protective responses to risk information, it is important to distinguish between two different perspectives of valuation measures—ex ante and ex post evaluation. Consumers' protective decisions focus on the probability distribution of health effects, not on the realization of health outcomes, arising from the consumption of certain food attributes. On the other hand, consumers' behavioral adjustments are undertaken after receiving (or acquiring) new information about product safety. Hence, the valuation measures that will be derived in this paper are ex ante measures with respect to health risks but ex post with respect to information about health risks from food products.

The section II begins by describing a self-protection model within the framework of the expected utility theory, allowing adjustments to risks through averting behavior, In the section III, I introduce a subjective self-protection model by treating the probability function as a subjective risk perception function based on available information. This formulation is static in the sense that learning is not taken into account. Finally, in the section IV, I introduce multiple time horizons into the subjective self-protection model to develop an integrated conceptual framework of risk perceptions, learning and self-protection actions. This section also illustrates how information and self-protection can be incorporated into a Bayesian learning model. The last section provides some concluding remarks.

II. SELF-PROTECTION MODEL AND EX ANTE VALUE OF RISK REDUCTIONS

Suppose a representative household allocates its given income over the primary food item(X) and in other composite goods(Y). A household's food purchasing decisions are made for all members of the household, so health risks from food consumption affect the entire household. However, following Becker's (1974) argument, we assume that a household decision process is the same as that of the household head, so that there exists a household preference that reflects all members' tastes. While the household observes some food attributes (such as color, size, shape, or freshness) prior to purchase, it does not know which particular "state of health" will actually occur from the consumption of X. For simplicity, it is assumed to face only two states of the world—either the occurrence or non-occurrence of adverse health outcomes. If it consumes the food item(X) suspected to contain h armful substances(chemical residues) over its lifetime, there is a probability π of the adverse health outcome. Because heath effects identified(for example, getting cancer or having a nervous disorder) often involve unique and irreplaceable losses, the extreme characterization of health outcome seems reasonable. In these cases, it is assumed to evaluate consumed food differently depending on the health outcome, implying state dependent preferences (Cook and Graham (1977)). Thus, the household's state-dependent utility function can be defined as $U_b(X, Y)$ if the health event occurs, and as $U_g(X, Y)$ if it does not occur. It is also assumed that $U_g(X, Y) > U_b(X, Y)$ for all X, Y.

Moreover, the situations considered in our analysis (e.g., consuming chemically contaminated food) can be viewed as a case in which a household can take actions to reduce those food risks. For example, households could change their food preparation methods (i.e., spend more time in clean-up or cooking), or could decrease the consumption of the suspected food items and eventually shift to food items that are viewed to be safer.[2] However, given the uncertainty of ultimate health effects, any actions undertaken by a household cannot yield a certainty of protection, but can only provide the reduction of the probability of the adverse health outcomes (i.e., the risk).

The recognition that risks can be affected by a household's action stimulated Ehrlich and Becker (1972) to develop the self-protection model. They argued that self-protection activities undertaken by a household would shift the whole probability distribution to the left to reduce the probability of adverse health outcome and raise the probability of favorable health outcomes. Therefore, the household risk assessment was described as a function such as $\pi = \phi(v)$, where v is a vector of self-protection actions undertaken.

Our framework analyzing product purchase decisions follows Ehrich and Becker's view and treats self-protection as a type of averting behavior. Thus, incorporating the opportunity of self-protection, the household aims to select the level of self-protection, v, as well as X and Y to maximize its expected utility as shown in (1):

$$\underset{X, Y, v}{Max}\ EU = (1-\pi)U_g(X,Y) + \pi U_b(X,Y) = (1-\phi(v))U_g(X,Y) + \phi(v)U_b(X,Y) \tag{1}$$

The health risk, π, is assumed to decrease as the household increases self-protective activities ($\partial\pi/\partial v < 0$). In addition, the household is assumed to know how its

[2] This type of switching behavior entails discrete choices, which result in corner solutions for food consumption decisions. Eom (1994) describes a discrete choice model in a situation involving risks from pesticide residues on fresh produce.

self-protection actions would affect the risk function, $\psi(v)$, as Ehrlich and Becker described. With the above assumptions, the health risk became endogenous in the household decision process but still remains "objective" information in that the functional relationship of the risk, $\psi(v)$, is known to the household.

The above description of the risk function allows the self-protection model to adopt the household production framework in the same way as the averting behavior models (see Gerking and Stanley (1986), Dickie et al. (1987), Berger et al. (1987)). Risk, π, is equivalent to a final service flow produced using a vector of self-protection, v. Self-protection(v) may be considered to be household activities combining the householder's time and other resources (for example, a change in cooking preparation practice), and the purchase of nondurable products or services as essential inputs of the production process. Self-protection is not a direct source of utility. It only serves to reduce the health risk (i.e., non-jointness in the household production).[3]

Following Becker (1965), we assume that the household faces a "full income" budget constraint, M. The full income constraint is defined as:

$$M = wT + A = (m_x + wt_x)X + Y + (m_v + wt_v)v$$
$$= p_x X + Y + p_v v \tag{2}$$

where m_x, m_v: money price of goods X and v relative to price of Y,

w: wage rate,

t_x, t_v: time spent for X and v relative to time spent on Y,

p_x, p_v: "full" price of X and relative to "full" price of Y.

T: time endowment, and

A: non-wage asset income.

The household production framework enables us to look at a household's choice problem in a two-stage decision process (see Dickie et al. (1987), Deaton and Muellbauer (1980)). In the first stage, the household is minimizing self-protection expenditures to obtain a given level of health risk such as :

$$C(p_v, \pi^0) = C = min\ p_v v$$
$$s.t.\ \pi^0 = \psi(v) \tag{3}$$

This expenditure function has properties similar to a firm's cost function. It is positive, homogeneous of degree one, and concave in p_v.

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[3] Perhaps, this non-jointness assumption in the household production framework may be equivalent to the separability assumption between exposure to pollutants and unobservable randomness affecting health, which permitted Quiggin (1992) to derive some positive results in applying self-protection models. As a result of the non-jointness assumption, our analysis excludes certain preventive health behaviors (such as regular physical exercise) that improve households' general health conditions as well as mitigating the adverse health outcomes associated with particular food contaminants.

In the second stage, the expected utility is maximized subject to the budget constraint that induces self-protection expenditures, C from the first stage. Substituting (3) into (1), the Lagrangian is defined as

$$L = [1 - \phi(C^*)]U_g(X,Y) + \phi(C^*)U_b(X,Y) + \mu[M - p_x X - Y - C^*] \quad (4)$$

The optimally chosen self-protection expenditure, C^* is to reduce risk but also to reduce income left over for the consumption. Maximizing the Lagrangian with respect to C, X and Y, and rearranging the first order conditions would yield (5).[4]

$$\frac{\partial C}{\partial \pi} = \frac{1}{\partial \pi / \partial C} = \frac{U_b - U_g}{\mu} = \frac{(U_b - U_g)}{[(1-\pi)(\partial U_g/\partial M + \pi(\partial U_b/\partial M))]} = MRS_{\pi_M} \quad (5)$$

The first term in (5) is the marginal self-protection expenditure which is observable. The last term is the ex ante marginal rate of substitution between π and M (MRS_{π_M}),[5] which is the difference between state-dependent utility functions divided by the expected marginal utility of income. This MRS_{π_M} term in (5) is indeed equal to the marginal willingness to pay($MWTP$) for the risk reductions($\partial M/\partial \pi$), which is a standard result from welfare theory under uncertainty (Viscusi(1986), Freeman(1989), Eom(1996c)). This $MWTP$ concept measures the income change that would need to be taken away from the household in response to a reduction in risk while holding the expected utility constant($dEU=0$). Moreover, it represents an ex ante trade-off between income and risk because the household must reveal its value for risk changes before it experiences the adverse health outcomes. Thus, we can obtain (6) from (5).

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[4] The second order condition to assure a maximum of expected utility requires that

$$\frac{\partial^2 \pi}{\partial C^2}(U_b - U_g) - 2\frac{\partial \pi}{\partial C}\left[\frac{\partial U_b}{\partial M} - \frac{\partial U_g}{\partial M}\right] + \left[(1-\pi)\frac{\partial^2 U_g}{\partial M^2} + \frac{\partial^2 U_b}{\partial M^2}\right] < 0$$

In addition to the assumptions made about the state-dependent utility functions, the only restriction required to guarantee inequality would be $(\partial^2\pi/\partial C^2) > 0$. It is noteworthy that derivation of the second order condition does not necessarily require risk averse preferences. Even though marginal utility of consumption is increasing (i.e., $\partial^2 U_i/\partial M^2 > 0$ $i=b,g$), there may be cases in which inequality still holds. The desire to undertake self-protection might occur for risk lovers as well as for risk averters.

[5] Because of the assumption of the linear budget constraint and the normalized price of Y, marginal utility of a composite good Y is equivalent to marginal utility of income (i.e., $\partial U_i/\partial Y = \partial U_i/\partial M$) in each state of the world($i=g,b$). Thus, the last term was obtained by sustituting MRS_{π_Y} to MRS_{π_M}. And this later term in (5) was commonly measured in job risk cases to represent the risk-dollar tradeoff selected by a worker (see Viscusi (1986)). For the case of the risk of premature death, this ex ante MRS_{π_M} represents the implicit value of one's statistical life. For the case of non-fatal injury, the rate of tradeoff represents the implicit value of per unit risk of injury.

$$\frac{\partial M}{\partial \pi} = \frac{\partial C}{\partial \pi} = \frac{\partial C(p_v,\pi^0)}{\partial \pi} = MRS_{\pi_M} \tag{6}$$

Equation (6) implies that the *ex ante* marginal willingness to pay for risk reduction is equal to the marginal self-protection expenditure of risk reduction. In other words, the marginal benefit of the reduction in risks is equal to the marginal cost of achieving the same reduction in risk through the use of v. In this framework, the estimation of marginal values of risk reductions requires only knowledge of household production technology and price of protective behavior, p_v, not of unobersavable households' preferences.[6]

III. SUBJECTIVE SELF-PROTECTION MODEL AND VALUE OF INFORMATION

In the conventional expected utility framework and self-protection model, the probability or probability function of the adverse health outcome was treated as "objective" information in that any households facing the same problem will assign the same probability. However, the uncertain situation causing the adverse health outcome is often unique and nonrepetitive. So there is little opportunity to gain the experience that is usually associated with learning. Although the risk of short-term acute health problems due to chemical poisoning is relatively well understood, the risk of health effects posed by long-term and low-level exposures to food contaminants (such as chemical residues) are not as well known. We cannot assume that any individual, whether an informed consumer or a professional toxicologist, knows the technical risk. Nonetheless, it is reasonable to expect that a household will have subjective probabilistic beliefs. Any assignment of subjective probability is permissible, in principle, provided there is coherence in a household's judgement about the relative likelihood of various values of unknown states of the world (see Winkler and Hays (1975)).

Each household may perceive a different degree of subjective risks according to its demographic background, knowledge about the event at risk, and past experiences with similar situations. These factors will serve as a set of information, I, to the household in the process of forming risk perceptions at a point in time. Thus, incorporating information, a household's subjective risk perception can be defined as (7) :

$$\pi = \psi(v, I) \tag{7}$$

where v denotes a vector of self-protection actions, and I represents available information to the household. It is assumed that information, I in (7), is exogenously

[6] see Smith (1990) for more formal discussion of the household production framework.

provided and thus is not subject to the household's choices and does not explicitly enter the budget constraint. Therefore, while risk perceptions become endogenous outcomes, information is still considered an exogenous factor in the household decision process.

At the beginning of each period, a household is assumed to make self-protection decisions and consumption plans X and Y, given a set of available information about the uncertain event. A household's objective function can be written as:

$$EU = (1 - \phi(v,I))U_g(X,Y) + \phi(v,I)U_b(X,Y) \tag{8}$$

Applying the two-stage decision process again and solving the household's constrained expected utility maximization problem given the budget constraint, (2), yield the following state-dependent indirect utility functions:

$$EV = [1 - \phi(p_s,I)]V_g(M,p_s) + \phi(p_s,I)V_b(M,p_s) \tag{9}$$

Because of the exogeneity of information at each period of consumption choice, marginal willingness to pay for additional information again can be derived by taking the total differential of the ex ante indirect utility function, (9). The change of information that we consider is not complete but partial in the sense that the information affects households' risk perceptions while still leaving some uncertainty present. By setting $dEV=0$ and holding $dp_x = dp_s = d\pi = 0$, we can solve for the income change that would be required in response to exogenous additional information to keep expected utility constant:

$$\frac{\partial M}{\partial I} = \frac{V_b - V_g}{(1-\pi)(\partial V_b/\partial M) + \pi(\partial V_b/\partial M)} * \frac{\partial \pi}{\partial I} = MRS_{\pi M}\frac{\partial \pi}{\partial I} \tag{10}$$

Compared with the valuation measure of risk reductions derived in (6), the expressions in (10)[7] measures the marginal willingness to pay for information about health risk. Consumers' risk perceptions are endogenously determined through the household health production activities in response to an exogenous change in information about the risk. In this subjective self-protection model, what consumers are evaluating is not food product attributes (such as health risks) but information about the product attributes. Thus, the valuation measure of additional information in (10) captures both the direct effect of information on risk perceptions ($\partial\pi/\partial I$) and indirect effects through marginal values of changes in risk ($MRS_{\pi M}$).

[7] In deriving (10), M and I changed while p_x and p_s remained constant. Thus the total differential reduced to a partial differential. That is, the partial derivative ($\partial M/\partial I$) in (10) is equal to (dM/dI) holding p_x and p_s constant.

Using the results of (5), which equate $MRS_{\pi M}$ to marginal self-protection expenditure, the specification of (10) can be reduced to (11):

$$\frac{\partial M}{\partial I} = \frac{\partial C}{\partial \pi}\frac{\partial \pi}{\partial I} = \frac{\partial C}{\partial I} \tag{11}$$

The first and last term in (11) states that the marginal value of additional information equals the marginal cost of information

Since in the household production framework, whatever level of risk perception chosen in the expected utility maximization process must be produced at minimum cost, self-protection expenditure consists of $C^* = p_t \times v(p_t, I, \pi)$. Taking the total differential of the self-protection expenditure function C^*, the second term of (11) can be re-stated as (12):

$$\frac{\partial C}{\partial \pi}\frac{\partial \pi}{\partial I} = \frac{\partial \pi / \partial I}{\partial \pi / \partial v} p_t \tag{12}$$

Substituting (12) into (11) gives the expression for marginal value of information as:

$$\frac{\partial M}{\partial I} = \frac{\partial \pi / \partial I}{\partial \pi / \partial v} p_t = \frac{\partial C}{\partial I} \tag{13}$$

Equation (13) implies that the ex ante marginal willingness to pay for additional information is equal to the marginal cost of acquiring information in terms of the increase in self-protection expenditures, while hodling the ex ante indirect utility, *EV* constant.[8] Again, this ex ante *MWTP* expression does not require that we observe the ex ante *MRS* but can be derived with knowledge of technical relationship between information and self-protection actions in the risk perception functions.[9]

Marginal *WTP* for new information in (13) deserves further explanation. First, a household's *ex ante MWTP* will be higher as its "full" price of v, p_t (mainly the opportunity cost of its time) is higher and its marginal productivity of v in risk perceptions ($\partial \pi / \partial v$) is lower. Equally important, ex ante *MWTP* will be higher for

[8] When changes in expenditure on marketed protective behavior are used to measure individuals' values on non-marketed goods such as risk information, we have to recognize that there are three possible measures: (1) the change in expenditure on protective behavior, v, given a constant income, M, (2) the change in expenditure on v to hold the final service flow, π, constant, and (3) the change in expenditure on v to hold expected utility, *EU*, constant. The third measure is a correct measure of individuals' willingness to pay for the change in an exogenous factor, I. In the case in which an protective behavior, v, is a perfect substitute for the exogenous factor, I, the second measure will be equal to the third measure. However, the first measure is not the same as the third measure because of the income reallocation associated with the change in I (see Smith (1990) for detail).

[9] Gerking and Stanley (1986) derived the parallel results with (13) from averting behavior models with certainty.

those households in which new information has greater impact on risk perceptions ($\partial\pi/\partial I$). This possible connection between individuals' demographic profile and the acquisition of and use of information has been recognized by economists for some time. For example, Grossman (1972) hypothesized that schooling increases the efficiency of household health production, and therefore that better educated individuals may react to risk information differently from those less educated people. Kenkel (1991) empirically found that education levels reflected in the number of years of schooling helped individuals to undertake more preventive actions by improving their knowledge of the relationship between protective behavior and health outcomes.

IV. SELF-PROTECTION MODEL WITH LEARNING AND VALUE OF INFORMATION

The analysis developed above incorporated self-protection and available information into the risk perception process. But the process still is "static"; it gives an account of effects of information on risk perceptions at a given point in time but does not describe how a household acquires and uses the information overtime. In practice, the household takes self-protection actions while it acquires more information (through product labeling or news media reports)[10] and learns about the risk. In this situation, the household's objective function at any time period $t=i$ is equal to (14):

$$EU_i = (1 - \phi(v_i, I_i))U_g(X_i, Y_i) + \phi(v_i, I_i)U_b(X_i, Y_i) \tag{14}$$

The difference between (8) and (14) is that the acquisition of information in (14) is a part of the household's optimizing choice at a particular point in time, whereas information available in (8) was exogenously given.

Since risk perceptions are endogenously determined, observed outcomes at time $t=i$—subjective risk perceptions and household behavioral decisions—reflect influences of both the acquired information and feasibility of self-protection. If so, it will be a difficult, if not impossible, task to sort out the effects of information and self-protection on risk perceptions and behavioral decisions in a timeless expected utility framework. Hence, some restrictions on this integrated framework are required to separate the relative influence of acquired information and self-protection on risk perceptions from that on averting behavior decisions.

Before proposing an integrated framework, consider first a simple Bayesian learn-

[10] In this paper, households are assumed to acquire new information mainly through the public information programs such as product labeling or news media reports. Thus information searching costs and free rider problems are assumed to be negligible given no private information searching activities. And the exogeneity of information at each period is still held.

ing model to explain how the household processes new information and revises risk perceptions (see Viscusi (1989)). For the sake of simplicity, we formulate the risk perception process only before receiving new information about food-related risks (i.e., $t=1$) and after receiving new information (i.e., $t=2$). The Bayesian updating rule implies that risk perceptions at a given time are a weighted average of prior beliefs about uncertain events and "sample" risk inferred from new information. In this perspective, the risk function in (7) can be replaced with a reduced form of posterior risk perceptions.

$$\pi_2 = \alpha_1\pi_1 + \alpha_2\pi_s \tag{15}$$

where π_1 represents prior perceived risk and π_s represents "sample" risk implied by new information. Weights α_1 and α_2 in (15) capture the household's assessment of the relative precision of the underlying distribution that generates the risk.[11]

Now to incorporate self-protective actions into the Bayesian learning framework, the household's prior risk assessment at $t=1$ would become $\pi_1 = \psi_1(v_1)$, where v_1 denotes the level of self-protection undertaken at $t=1$. It is also assumed that the functional relationship of $\psi(v)$ is known and processed recursively. As Crawford (1973) has shown, the recursive notation of the information set at time $t=2$, I_2, can be written as follows:

$$I_2 = h(I_1(v_1),\ \pi_s) \tag{16}$$

where I_1 designates a set of information available at time $t=1$. The $h(.)$ function in (16) can be interpreted as an updating rule.

With a new information set similar to that hypothesized to underlie (16), the posterior risk perception is determined to be:

$$\pi_2 = \psi(v_2, I_2) = \alpha_1\psi_1(v_1) + \alpha_2\psi_2(v_2) \tag{17}$$

As we see in (17), the household's new information would alter its risk perception. But it does not affect its perception of the effect of self-protection on the parameters of risk assessment. In this specification, learning becomes a part of a household's decision-making with risk. However, it is still separately processed from the household's behavioral decisions (i.e., "exogenous" learning). In other

[11] More specifically, Viscusi and O'Connor (1984) assumed the random event (the occurrence of the adverse health outcome) follows the sequence of Bernoulli trials and prior risk perceptions follow beta distributions. The beta distribution is quite flexible and can reflect a variety of skewed and symmetric shapes by varying the parameters of the distributions (Winkler and Hays (1975)). These properties are useful to explain the self-protection model.

words, a household's decision-making with learning becomes a sequential process; the amount and framing of information lead to revisions in a household's risk perception to π_2. Then, the household makes self-protection decisions, v_2, using I_2.

With this background, we now attempt to develop an integrated framework describing the interaction between risk perceptions, learning and behavioral decisions. To link the information acquisition and learning processes, the self-protection model developed earlier is extended to a two-period context. With the extended time horizon for decision making, a more explicit consideration can be given to the way posterior risk perceptions are influenced by information as well as self-protection actions, and how learning takes places over time.

Households' preferences are still represented by the von Neumann-Morgenstern utility function, $U(Z_1, Z_2)$, where $Z_t = (X_t, Y_t)$, $t = 1, 2$, is a vector of consumption goods X and Y at time $t = 1, 2$. Thus, state-dependent utility functions, $U_g(Z_1, Z_2)$ and $U_b(Z_1, Z_2)$, in this final model combine Cook and Graham's (1977) single-period state-dependent utility function with Epstein's (1975) two-period specifications.

To implement the model, several assumptions must be made: first, prior perceived risk, π_1, and optimal averting expenditure, C_1, at $t = 1$ (i.e., $\pi_1 = \psi(C_1)$) are assumed to be known. Second, the second-period price and income are known with certainty. Household savings, S, results in certain yields $(1+r)*S$ at $t = 2$, where r is an interest rate. Third, the household is still assumed to be engaged in a two-stage decision process according to the household production framework. The household in this two-period model selects optimal levels of averting expenditure, C_2, levels of savings, S, and consumption levels for Z_1 and Z_2.

Following Epstein (1975) and Chavas et al. (1986), the household's expected utility maximization problem can be written as

$$\underset{Z_1, S, Z_2, V_2}{Max} \quad E_1[EU_2] \tag{18}$$

where $EU_2 = [1-\psi(v_2, I_2)]U_g(Z_1, Z_2) + \psi(v_2, I_2)U_b(Z_1, Z_2)$ and E_1 denotes the expectation operator conditional on information available at time $t = 1$. The household's budget constraint at each period would be

$$M_1 = p_{z1}' Z_1 + C_1 + S \qquad \text{at } t = 1 \tag{19}$$

$$M_2 + (1+r) * S = p_{z2}' Z_2 + C_2 \quad \text{at } t = 2 \tag{20}$$

where M_1 and M_2 are the household's full income at $t = 1$ and $t = 2$, respectively, and p_{zt}', $t = 1, 2$, is a vector of prices of goods including time costs as well as money prices.

In the first period, the household has imperfect knowledge about the risk but has subjective prior beliefs. If the household has an opportunity to undertake self-protection, C_1, and acquires new information through product labeling or public provision, the household will form the central tendency of the distribution of posterior perceived risk based on a Bayesian framework.

A backward induction method is used to solve this sequential problem (DeGroot, 1970). If a household receives new information about food-related risks during the first period, then its risk perception would be updated according to (17). Because of the "exogenous" learning process structured in (17), the set of information available when the household makes choices over Z_2 and C_2 at $t=2$, I_2, can be treated as an exogenous factor. So, the second-period choice problem becomes

$$\underset{Z,C}{Max}\ EU_2 = (1-\pi_2)U_g(Z_1,\ Z_2) + \pi_2 U_b(Z_1,\ Z_2) \tag{21}$$

$$s.t\ \pi_2 = \phi(C_2, I_2) \tag{22}$$

$$M_2(1 + r) * S = p'_{z2}Z_2 + C_2 \tag{23}$$

Note that the choice of v_2 in (18) is converted to the choice of C_2 in (21), because our framework is still based on the household production framework. To take advantage of the interrelationship between periods, first order conditions are solved using the Lagrangian.

$$(1-\pi_2)\frac{\partial U_g}{\partial Z_2} + \pi_2\frac{\partial U_b}{\partial Z_2} - \mu_2 p_{z2} = 0 \tag{24}$$

$$\frac{\partial \pi_2}{\partial C_2}(U_b - U_g) - \mu_2 = 0 \tag{25}$$

$$M_2 + (1+r) * S - p'_{z2}Z_2 - C_2 = 0 \tag{26}$$

Manipulating first order conditions will yield marginal conditions similar to those in (5). However, the expected utility function at $t=2$ is maximized given Z_1. Thus, the expected value of the marginal utility of income, μ_2, is also a function of Z_1. The solution of (24) – (26) will be

$$Z_2^* = Z_2(Z_1,\ p'_{z2},\ M_2 + (1+r) * S,\ \pi_2^{ii}) \tag{27}$$

$$C_2^* = C_2(C_1,\ p_{c2},\ I_2,\ \pi_2^{ii}) \tag{28}$$

$$\mu_2^* = \mu_2(Z_1,\ C_1,\ p'_{z2},\ M_2 + (1 + r) * S,\ \pi_2^0) \tag{29}$$

Substituting Z_2^* and C_2^* into (21) yields an ex ante variable indirect utility function conditional on Z_1, S, and C_1.

$$EU_2 = [1 - \phi(C_2^*(I_2))]U_g(Z_1,Z_2^*) + \phi(C_2^*(I_2))U_b(Z_1,Z_2^*) \tag{21$'$}$$ [12]

In the first period, the household chooses its optimal level of consumption Z_1, and savings, S, given averting expenditure, C_1, provided that Z_2 and C_2 are determined in the optimal manner in the second period. However, the current consumption decisions at $t=1$ must be made subject to uncertainty about future risks. The first-period choice problem is to

$$EU_1 = \underset{z_1,\ s}{Max} \quad E_1[EU_2] \tag{30}$$

$$s.t.\ M_1 = p_{z1}Z_1 + C_1 + S \tag{19}$$

Using the envelope theorem, first order conditions are

$$E_1[(1 - \pi_2)\frac{\partial U_g}{\partial Z_1} + \pi_2\frac{\partial U_b}{\partial Z_1} - \mu_1 p'_{z1}] = 0 \tag{31}$$

$$-\mu_1 + E_1(\mu_2) * (1 + r) = 0 \tag{32}$$

$$M_1 - p'_{z1}Z_1 - C_1 - S = 0 \tag{33}$$

The first order conditions, (31)$-$(33), can be solved for the optimal level of current consumption, Z_1^* and savings, S^*, where $Z_1^* = Z_1(M_1,\ p'_{z1},\ r,\ \pi_2)$ and $S^* = S(M_1, p'_{z1}, r, \pi_2)$.

Substituting Z_1^* and S^* into (21$'$) and plugging EU_2 into (30) will lead the first period maximization problem to (34) in terms of ex ante indirect expected utility function.

$$EU_1 = E_1(EU_2) = E_1\{[1 - \phi(C_2^*(I_2))]V_g(Z_1^*,\ Z_2^*) + \phi(C_2^*(I_2))V_b(Z_1^*,\ Z_2^*)\} \tag{34}$$

where $Z_1^* = Z_1(M_1,\ p'_{z1},\ r,\ \pi_2)$; and $Z_2^* = Z_2(M_1,\ M_2 + (1+r)\times S,\ p'_{z1},\ p'_{z2},\ r,\ \pi_2^0)$.

Taking total differentials with respect to I_2 while holding EU_1 constant, the marginal willingness to pay for information, I_2, which is chosen and paid at time $t=1$ will be given as (35):

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[12] This type of variable indirect utility function was defined by Epstein and was applied by Chavas et al. (1986) to derive the option price.

$$\frac{\partial M_1}{\partial I_2} = \frac{E_1[(\partial \pi_2/\partial C_2)(\partial C_2/\partial I_2)(V_b - V_g)] * p_{2i}}{E_1[(1-\pi_2)\partial V_g/\partial M_1 + \pi_g \partial V_b/\partial M_1]} \tag{35}$$

Using the first order conditions, (25) and (26), and the assumption of linear budget constraint at each period, equation (35) can be simplified as (36):

$$\frac{\partial M_1}{\partial I_2} = \frac{E_1[\mu_2 C_{2I}]}{\mu_1} \tag{36}$$

where $C_{2I} = (\partial C_2/\partial I_2)$; μ_1 and μ_2 are expected values of marginal utility of income at $t=1,2$.[13] The left-hand side of (36) represents a change in the first-period income that must be taken away in response to additional information to keep a household's expected utility constant. The additional information acquired during $t=1$ does not resolve the uncertain nature of risk at time $t=2$, π_2. Since we focus on ex ante *MWTP* which is paid at the first period, the posterior risk perception at $t=2$ can be viewed as the expected value of future risk perceptions such as $\pi_2 = E_1[\psi(I_2, v_2)]$. As a result, π_2 and C_{2I} in (36) become random variables when evaluated at time $t=1$, which are functions of π_2 as well as M_2, p_{z2}, and so on.

If the *MWTP* was paid, we obtain $\mu_1 = E_1(\mu_2)(1+r)$ from (32). Substituting this expression into (36), we obtain (37).[14]

$$\frac{\partial M_1}{\partial I_2} = \frac{1}{(1+r)} * E_1(C_{2I}) + \frac{COV(\mu_2, C_{2I})}{\mu_1} \tag{37}$$

where $COV(\mu_2, C_{2I})$ is the covariance between μ_2 and C_{2I}. Since we are dealing with two states of the world and the perceived risk, π_1, at time $t=1$ is assumed to be known, equation (37) can be reduced to:

$$\frac{\partial M_1}{\partial I_2} = \frac{1}{(1+r)} * \frac{\partial C_2}{\partial I_2} + \frac{COV(\mu_2, C_{2I})}{\mu_1} \tag{38}$$

Equation (38) suggests that the ex ante marginal willingness to pay for additional information is equal to the discounted marginal self-protection expenditure plus an adjustment term.

Now suppose that the amount of *MWTP* is chosen at time $t=1$ but paid at time $t=2$; the marginal willingness to pay becomes

[13] The detailed properties of these terms are illustrated by Chavas et al. (1986).

[14] Since μ_2 and C_{2I} are treated as random variables, $E_1(\mu_2 C_{2I}) = E_1(\mu_2) E_1(C_{2I}) + COV(\mu_2, C_{2I})$.

$$\frac{\partial M_2}{\partial I_2} = \frac{\partial M_1}{\partial I_2} * (1+r) = \frac{\partial C_2}{\partial I_2} + \frac{COV(\mu_2, C_{2I})}{\mu_1} * (1+r) \tag{39}$$

As we see in (39), the *MWTP* for information with learning is represented by the sum of the marginal cost of acquiring information plus an adjustment term. The second term in (39) was not included in the willingness to pay measure derived in a timeless framework (see equation (13)). This adjustment term may reflect the influence of second-order uncertainty on consumers' decision makings related to food risks. In other words, the term may reflect effects of learning over time on households' ability to make better consumption decisions, which may result in reallocations of their constrained resources.

As shown in (39), the sign and magnitude of adjustment term depends on how the marginal utility of income in the second period moves with changes in the protective expenditure due to new information (i.e., $COV(\mu_2, C_{2I})$) and households' internal time preferences, which are embedded in the marginal utility of income in the first period, μ_1. Because the expected value of marginal utility of income at $t = 1$ is greater than zero, the sign of the adjustment term depends on the sign of the covariance term, $COV(\mu_2, C_{2I})$.

Following the result proved by Chavas et al. (1986),[15] the adjustment term in (39) can be shown to be positive. The specification of the Bayesian updating rule in the subjective self-protection model, (17), leads the covariance term to be:

$$COV(\mu_2, C_{2I}) > 0 \text{ because} \tag{40}$$
$$\alpha_2^3 * \left[\frac{\partial V_b}{\partial M_2} - \frac{\partial V_g}{\partial M_2}\right]^2 * (V_g - V_b) > 0$$

Therefore, a relationship between the *MWTP* without learning and with learning can be derived from (13) and (40):

$$\frac{\partial M}{\partial I} = \frac{\partial C}{\partial I} > \frac{\partial C_2}{\partial I_2} = \frac{\partial M_2}{\partial I_2} - \frac{COV(\mu_2, C_{I2})}{\mu_1} * (1+r) \tag{41}$$

The equation (41) concisely summarizes the difference between values of information with and without the learning opportunities. In response to new information, the marginal changes of self-protection expenditure without learning opportunity (the second term in (41)) is greater than those when households have opportunities to learn about the uncertain event (the third term in (41)). As households learn more about very small risks arising from food contaminants, they may recognize that they do not need to spend as much protective expenditure as before to

[15] Chevas et al. (1986) proved that the covariance($COV(\mu_2(I_2), C_2(I_2))$) is positive if $[(\partial\mu_2/\partial I_2) * (\partial C_{2I}/\partial I_2)]$ is positive.

achieve the same level of risk reductions. The consequent reductions in protective expenditure would allow households to have more disposable income that can be reallocated to other consumption activities.

V. CONCLUDING REMARKS

This paper was motivated by observations suggesting that food-related risks are not well understood by consumers. Nonetheless, consumers seemed to take self-protection actions to reduce the risks while learning more about risks in response to new information. To describe such situations, I developed a conceptual framework investigating the effects of information and learning on consumers' protective behavior.

The framework incorporating the learning process did not change the basic structure of the expected utility theory: self-protection and consumption decisions that affect utility directly are separated from the processes of risk perceptions and learning. As long as we can identify protective behavior undertaken specifically to reduce health risks, the values of risk information could be measured from the knowledge of the technical relationship between risk and self-protection action, which is observable in principle.

These learning and adjustment opportunities over time may provide an explanation of consumers' strong reactions to extremely low but unfamiliar food risks (e.g., Alar scare in the USA during 1989). If a household has to take self-protection actions in a single period context, while the process underlying food-related risks are involved in multiple time periods, then the household may tend to take unnecessary or even "alarmist" responses, leading to more than the desired level of self-protection actions. But greater understanding on the part of consumers with learning opportunities may reduce the degree of overestimation of small risks, as reflected in smaller self-protection expenditures. This main result derived from this paper is also consistent with the empirical findings of market experiments (e.g., Camerer (1987)): individuals' learning opportunities gained through experience and better information reduced biases in market prices with regard to the predictions of a Bayesian model.

Moreover, this possibility of connecting consumers' risk perception processes with protective behavior will have important implications on the roles of government and the consumer in the product safety area. It is particularly noteworthy considering the recent movement away from the government regulatory approach and towards the informed buyer approach. Thus, public information programs such as product labeling or hazard warning could be used to narrow the gap between consumers' risk perceptions and scientific experts' risk assessments. Unlike the product safety regulations often yielding uniform levels of product standards, consumers would be able to make informed choices of food products under these conditions. Furthermore, consumers could have a substantial role in choosing the socially acceptable level of health risk through information acquisition and self-protection decisions.

Unfortunately, the empirical implementation of the conceptual framework developed in this paper requires intensive data collection efforts. Required are household-level primary data on patterns of food consumption and expenditures, time allocations including different cooking and shopping activities, wage rates, and the prices and quantities of protective behaviors, along with measures of levels of food attributes (such as health risks) consumed by the same households. In addition, to understand households' learning processes, we need to accurately elicit consumer perceptions about food attributes *before* and *after* receiving new information and the effect of changes in perceptions on self-protection activities.

One direction that this line of research can take to meet intensive data needs is to examine the possibility of combining different sources of behavioral responses. For example, consumer preferences for food product attributes can be jointly estimated by using both actual market demand responses for food products and contingent behavior responses to information about food attributes.[16] This composite research strategy will exploit individuals' behavioral "windows" more completely and thus provide more reliable measures of the value of information about health risks.

[16] Indeed, Eom and Smith (1994) developed a framework for combining revealed preferences and contingent valuation (or stated preferences) data in estimating individuals' responses to environmental risks. They jointly estimated an actual continuous demand model for aggregate measure of fresh produce and a contingent discrete choice model for safer produce in terms of pesticide residue risks.

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