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Risk Valuation in the Presence of Risky Substitutes: An Application to Demand for Seafood

Ju-Chin Huang, Timothy C. Haab, and John C. Whitehead

We attempt to value health risks by combining traditional demand impact analysis with direct elicitation of individuals' risk perceptions of food safety. We examine the impact of multiple risks of related goods on consumption of a risky good. We argue that the consumption of a risky good depends on both its absolute risk level and its relative risks to other risky goods. Seafood consumption in eastern North Carolina was studied. We elicited, in a survey, individual perceived risks as reference points to derive the economic value of reducing health risk in seafood consumption. Revealed and stated data were combined to trace out demand changes in response to absolute and relative risk reductions. Our results show that seafood consumption is affected by the perceived absolute risk and by the relative risk to poultry and that individuals react to the multiple risks in a nonlinear way, as was suggested by our analytical model.

Key Words: Absolute and Relative Risks, Food Borne Health Risk, Revealed and Stated Data, Risk Substitutes

JEL Classifications: D1, D8, I12, Q21

It has been estimated by the Centers for Disease Control and Prevention that foodborne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths in the United States each year. The perceivable benefits of improving food safety have prompted federal agencies such as the U.S. Department of Agriculture, the Food and Drug Administration, and the Environmental Protection Agency to devote significant resources to research on reducing food related health risks and its economic benefits.[1] The valuation of food safety has attracted the attention of both policy makers and researchers during the past two decades. Various methods have been used to value food safety. As summarized by Caswell (1995), the five major methodologies for valuing food safety are contingent valuation, experimental auction, conjoint analysis, hedonic price and demand analysis, and costs of illness. The first three

Ju-Chin Huang is associate professor, Department of Economics, University of New Hampshire, Durham, NH. Timothy C. Haab is associate professor, Department of Agricultural, Environmental and Development Economics, Ohio State University, Columbus, OH. John C. Whitehead is associate professor, Department of Economics and Finance, University of North Carolina at Wilmington, NC.

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[1] For detailed information, see the website Gateway to Government Food Safety Information, http://www.foodsafety.gov.

methods involve the direct elicitation of consumer preferences for food safety, and the last two use labor and product market data to indirectly recover the values of food safety.

The three direct elicitation methods typically estimate the willingness to pay (WTP) for a specified improvement of food safety (e.g., Baker; Buzby et al.; Eom; Fox et al.; Henson; Huang, Kan, and Fu 1999, 2000; Lin and Milon 1995; Ott, Huang, and Misra; Shogren et al.; Wessells and Anderson; Wessells, Johnston, and Donath). The cost-of-illness method derives the benefit estimates by aggregating the saved costs of medical treatments, lost productivity, and premature death (e.g., Buzby et al.; Roberts, Buzby, and Ollinger; Roberts and Marks). The hedonic method builds on Lancaster's product attribute demand model to examine the demand for food attributes such as safety (e.g., Kim and Chern; Smallwood and Blaylock). Comparatively, the traditional demand analysis derives a quantitative relationship between consumption and the risk information (e.g., Blend and van Ravenswaay; Chern, Loehman, and Yen; Henneberry, Piewthongngam, and Qiang; Liu, Huang, and Brown; Park and Davis; van Ravenswaay and Hoehn 1991). All methods have their advantages and face certain challenges. In particular, these methods often do not account for all benefits of food safety, and the choice of methods can depend on the research purposes (Caswell 1998; Golan and Kuchler; van Ravenswaay and Hoehn 1996).

Two issues arise that are common to all the valuation methods. The first is the treatment of risky substitutes. Most food safety valuation studies focus on the economic impact of health risk of one food or one pathogen. Some studies have compared risks across foods (e.g., Brooks), but the effect of multiple risks of related foods on food consumption has not been empirically examined. In reality, individuals often consume multiple foods that can be substitutes or complements; hence, the consumption of one food can be affected by perceived health risks of related foods. The omission of effects of health risks of other foods on consumption can bias the economic value of risk-reduction policies. Furthermore, few studies have examined whether individuals respond to changes in the absolute risk of illness from consuming a particular food or changes in the risk of consumption relative to other foods.[2]

The second common issue in risk valuation is the derivation of baseline risk and risk changes. Given the inability to observe individuals' perceived or subjective baseline risk measures in a market setting, many risk-valuation studies have used objective or technical risk measures acquired from historical events to explain changes in economic behavior (e.g., Brown and Schrader; Lin and Milon 1993; Smith, van Ravenswaay, and Thompson). Two challenges arise when the objective risk is used as the baseline risk for all individuals to value risk changes. First, the use of objective risk assumes the same technical risk as the baseline risk for all individuals. The potential discrepancy between the risk reduction stated in the research design and the risk change perceived by consumers can be the source of miscalculation of benefits. Van Ravenswaay and Wohl cautioned against assuming that all respondents have similar risk perceptions and found that making such an assumption will result in incorrect measures of WTP for risk reductions. Second, individual risk perceptions can differ and can be important in describing individuals' ex ante consumption decisions (Adamowicz et al.). Using the objective risk for all individuals can be quite misleading and cause inconclusive results.[3] Cropper also cautioned that the use of objective measures of risk reduction could lead to biased value estimates.

Direct elicitation methods offer researchers

[2] Lin and Milon (1995) examine the WTP for reducing health risk of consuming oysters to the same health risk of consuming chicken. To the authors' knowledge, this is the only study considering relative risks of related foods in food safety valuation literature. There are a few studies that have explored the effect of risk information in a demand system (e.g., Chern et al.; Henneberry, Piewthongngam, and Qiang), but the value of risk reductions was not estimated in these studies.

[3] There have been attempts to combine risk perception and objective risk information in valuing food safety (e.g., Eom), but the welfare gains remain unclear.

the opportunity to vary the methods and types of information conveyed to individuals in a controlled setting. Furthermore, the elicitation of stated preferences allows researchers to measure changes in perceived risks relative to a baseline risk assessment by an individual. The individual's baseline risk assessment serves as a reference point for comparison. In contrast, the traditional demand impact analysis of food safety examines the effects of risk information on consumption patterns. Economists generally prefer indirect valuation methods that use revealed market data. However, the difficulty of describing the link of information (e.g., media coverage) and an individual's risk perception has made the methodology less appealing than the stated preference methods for valuing risk reductions.[4] A feasible strategy is to elicit perceived risks through the direct questioning of survey respondents to accompany the demand analysis, as suggested by Cropper.

We valued health risks by combining the traditional demand impact analysis with direct elicitation of individuals' risk perceptions of food safety. The purpose of this research was to examine the impact of multiple risks on demands. We argue that, when individuals consume multiple risky goods, both absolute and relative risks affect demands. A possible analytical explanation of the importance of relative risks on the consumption of a risky good is presented. In an application to seafood safety, we derived the individual-specific risk reference points by eliciting the subjective baseline risk from survey respondents and acquired multiple quantity responses to proposed price and/or risk changes. The information helps trace out the movement along and the shift of the individual seafood demand curve for welfare analysis. Both revealed and stated data were used in the welfare analysis of risk reductions.

[4] There are many studies that have examined the impact of information on (nonfood) risk perceptions (e.g., McCluskey and Rausser; Smith and Johnson; Viscusi and Evans). In general, there is no unique formula to describe the relationship between information and risk perception.

Analytical Model

To begin our exploration of consumer reaction to multiple risky goods, suppose that an individual consumes n goods, $x_1, x_2, \ldots, x_n$ that could possibly cause illness and a numeraire good z with no possibility of causing illness. The predetermined probabilities of illness from consuming a single unit of each good are $\pi_1, \pi_2, \ldots, \pi_n$. Each individual maximizes the expected utility obtained from consuming the set of goods $\{x_1, x_2, \ldots, x_n, z\}$ conditioned on the set of probabilities of illness and a set of individual specific characteristics **s.** The consumer is constrained by a budget, such that total expenditures on all goods cannot exceed the available income:

$$Y \geq \sum_{i=1}^{n} p_i x_i - z,$$

where Y is income and $p_1, \ldots, p_n$ are the prices of the n goods (the price of the numeraire has been normalized to 1). The budget-constrained expected utility maximization problem is represented as

$$\text{(1)} \quad \max_{x_1,\ldots,x_n,z} L = EU(x_1, \ldots, x_n, z; s, \pi_1, \ldots, \pi_n) + \lambda\left(Y - \sum_{i=1}^{n} p_i x_i - z\right),$$

where EU is the expected utility function. The expected utility model describes an individual's utility before the resolution of any uncertainty. In such a case, perceived probabilities of illness are more plausible than the objective/scientific risks to describe an individual's ex ante expected utility.

To examine the effect of multiple risky commodities on the consumer's utility-maximizing bundle, note that the consumers utility maximized budget identity is

$$Y = \sum_{i=1}^{n} p_i x_i^* + z^*,$$

where x_i^* represents the uncompensated demand for good i. Differentiating the budget identity with respect to an arbitrary risk probability π_j yields

$$(2) \quad \frac{\partial z^*}{\partial \pi_j} + \sum_{i=1}^{n} p_i \frac{\partial x_i^*}{\partial \pi_j} \equiv 0.$$

Under the assumption that an increase in the risk associated with a good will decrease the quantity-demanded for that good such that $\partial x_j^*/\partial \pi_j \leq 0$, Equation (2) implies that at least one other good (either another risky good or the numeraire) must be a risk substitute for good j. For example, if the risk of eating seafood increases, then Equation (2) implies that the consumer will substitute at least one other good to compensate for the decrease in seafood consumption.

To see how these changes in multiple risks affect the demand for multiple goods, a simple model of a two-good world is presented. Because of nonlinearity in the ex ante optimal demand function, is the level of consumption affected by not only an absolute risk change but also by the induced changes in the risk of consuming the good relative to the risks of consuming other goods.

The Two-Good Case

Suppose that the consumption of two risky goods in a fixed time period, x_1 and x_2, are associated each with two states of the world (0 and 1). For simplicity, we will call state of the world 0 the healthy state and state of the world 1 the sick state. Let π_1 and π_2 be the probabilities of getting sick from consuming one unit of x_1 and x_2, respectively. The standard expected utility function is comprised of the weighted sum of the utilities from both healthy and sick states:

$$(3) \quad EU = g(\pi_1, \pi_2, x_1, x_2)U^0 + [1 - g(\pi_1, \pi_2, x_1, x_2)]U^1,$$

where $g(\cdot)$ is the probability of staying healthy in a fixed time period as a function of π_1, π_2, and the consumption of x_1 and x_2. If we assume that the probabilities of illness are independent across units of consumption and the marginal probabilities of illness resulting from consuming x_1 and x_2 are independent of each other, then the expected utility function in Equation (3) becomes

$$(4) \quad EU = (1 - \pi_1)^{x_1}(1 - \pi_2)^{x_2}U^0 + [1 - (1 - \pi_1)^{x_1}(1 - \pi_2)^{x_2}]U^1.$$

Solving the budget-constrained utility maximization as described in Equation (1), the optimum expected utility (i.e., the indirect expected utility function, EV^*) can be written in terms of the optimum good consumption, x_1^* and x_2^*, and the indirect utilities $V^0(p, Y, \pi, s)$ and $V^1(p, Y, \pi, s)$. It can be seen from Roy's identity that the utility-maximized consumption of x_1^* depends (nonlinearly) on both π_1 and π_2.

$$\begin{aligned}
(5) \quad x_1^* &= -\frac{\dfrac{\partial EV^*}{\partial p_1}}{\dfrac{\partial EV^*}{\partial y}} \\
&= -\{[\log(1 - \pi_1)h_{p_1} + \log(1 - \pi_2)k_{p_1}] \\
&\quad \times (1 - \pi_1)^h(1 - \pi_2)^k(V^0 - V^1) \\
&\quad + (1 - \pi_1)^h(1 - \pi_2)^k V_{p_1}^0 \\
&\quad + [1 - (1 - \pi_1)^h(1 - \pi_2)^k]V_{p_1}^1\} \\
&\quad \div \{[\log(1 - \pi_1)h_y + \log(1 - \pi_2)k_y] \\
&\quad \times (1 - \pi_1)^h(1 - \pi_2)^k(V^0 - V^1) \\
&\quad + (1 - \pi_1)^h(1 - \pi_2)^k V_y^0 \\
&\quad + [1 - (1 - \pi_1)^h(1 - \pi_2)^k]V_y^1\} \\
&= -[(1 - \pi_1)^h(1 - \pi_2)^k \\
&\quad \times \{[\log(1 - \pi_1)h_{p_1} + \log(1 - \pi_2)k_{p_1}] \\
&\quad \times (V^0 - V^1) + (V_{p_1}^0 - V_{p_1}^1)\} + V_{p_1}^1] \\
&\quad \div [(1 - \pi_1)^h(1 - \pi_2)^k \\
&\quad \times \{[\log(1 - \pi_1)h_y + \log(1 - \pi_2)k_y] \\
&\quad \times (V^0 - V^1) + (V_y^0 - V_y^1)\} + V_y^1],
\end{aligned}$$

where h and k are the optimum consumption of x_1 and x_2 as functions of p_i, Y, and π_i; h_{p_i}, k_{p_i}, and V_{p_i} are the partial derivatives with respect to p_1; h_y and k_y are the partial derivatives with respect to Y; and V_y is the marginal utility of income. If the marginal utility of income is constant across states, then $V_y^0 - V_y^1$ in the denominator in Equation (5) becomes 0. The ex

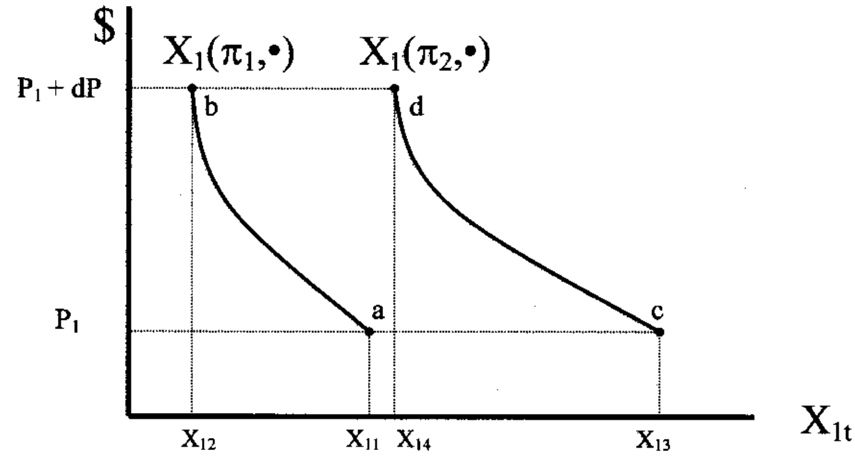

Figure 1. Seafood Demand

ante optimum demand x_1^* is a highly nonlinear function of π_1 and π_2. Because these probabilities can affect the demand interactively, a demand equation linear in π_1 and π_2 may not capture the full effects. Additional terms such as the ratio or product of the two probabilities are needed. The implication is that the demand for x_1 can depend not only on the (absolute) risk of illness from consuming x_1 but also the relative risks of illness to other goods.[5]

This simple expected utility model with two risky goods shows the effects of both absolute and relative risks on the demands for these goods. This result is not specific to the two-good independent states of the world case described here. The result extends to n goods and general joint probability functions for the n states of the world. In general, we should allow for a nonlinear relationship between the risks associated with each good in the empirical estimation of the partial demand for any particular good. The exact form of this demand relationship will depend on the assumed form of the expected utility function. Alternatively, using the analytical results derived above, we can directly assume a reduced form for the estimable Marshallian demand function and investigate the behavior of various interaction assumptions between own and cross risks on the estimated partial demand function. This is the strategy used in the empirical exercise below.

[5] In the two-good independent risk case, the marginal effect of π_1 on the consumption of x_1 is

$$\frac{\partial x_1^*}{\partial \pi_1} = -\frac{\partial\left[\dfrac{\partial E(V)}{\partial p_1} \Big/ \dfrac{\partial E(V)}{\partial Y}\right]}{\partial \pi_1} = -\frac{\left[\dfrac{\partial^2 E(V)}{\partial p_1 \partial \pi_1}\right]\left[\dfrac{\partial E(V)}{\partial Y}\right] - \left[\dfrac{\partial E(V)}{\partial p_1}\right]\left[\dfrac{\partial^2 E(V)}{\partial Y \partial \pi_1}\right]}{\left[\dfrac{\partial E(V)}{\partial Y}\right]^2},$$

which in general is also a highly nonlinear function of π_1 and π_2.

Survey and Data

To investigate the effects of multiple risks on demand, data on food consumption were collected in a summer 1998 telephone survey of eastern North Carolina residents, performed by the East Carolina University Survey Research Laboratory (Wilson et al.). Individual consumption of fresh seafood (fish and shellfish), poultry (chicken and turkey), and meat (pork and beef) was surveyed under varying prices. (See the Appendix for the seafood questions. Similar questions were asked for poultry and meat consumption.) Respondents were first asked to *reveal* their consumption of fresh seafood, poultry, and meat meals during a typical month under current prices (point a in Figure 1). The price was defined as the average cost of a fresh seafood meal whether purchased in a restaurant or a store. Next, respondents were told that fresh seafood prices vary according to catch. To illustrate the changes in prices, a hypothetical price increase (dP) was randomly drawn from one of five amounts: $1, $3, $4, $5, and $7. Respondents were then asked about the number of seafood meals that they thought they would eat in a typical month with the higher price (point b in Figure 1). With these data, we were able to trace out the seafood demand under current safety conditions, which is illustrated as $X_1(\pi_1, \cdot)$ in Figure 1.

To establish the baseline perceived risk, survey respondents were asked the number of meals out of 1,000,000 consumed in eastern North Carolina that they thought would result in sickness.[6] This question was repeated for seafood, meat, and poultry. The respondent's perceived risk is calculated as the number of reported meals causing illness divided by 1 million [π_k, where $k = 1$ (seafood), 2 (poultry), and 3 (meat)].

Before the risk-perception questions, survey respondents were asked to identify the food that they thought was the safest to consume. If a respondent thought poultry or meat to be the safest, the respondent was presented with a proposed seafood inspection program that would ensure seafood to be as safe as the food that the respondent considered safest.[7] The respondent was then asked to state how his or her consumption of seafood would be affected by the proposed seafood inspection program without an increase in seafood prices (point c in Figure 1). Finally, the respondent was asked to state how the proposed seafood inspection program would affect his or her consumption of seafood with another randomly assigned increase in seafood prices (point d in Figure 1). With these data, we were able to trace out the stated seafood demand under improved safety conditions. This is illustrated as $X_1(\pi_2, \cdot)$ in Figure 1, where the probability of getting sick from seafood, π_1, is reduced to the probability of getting sick from another food, π_2. For each scenario, questions about changes in poultry and meat consumption were also asked.

These various price/risk scenarios allow us to compare the relative risk of eating seafood to that of consuming another food. The size of the absolute risk reduction will depend on the perceived absolute baseline risk as defined by the respondent. By allowing the respondent to define the baseline risk, we avoided the assumption that all respondents perceive risk similarly, which allowed the risk reference point to vary across individuals.[8]

The telephone survey had a 73% response rate. Discarding cases with item nonresponse on key variables (such as seafood price and inability of ranking food risks), non–seafood eaters, duplicate/out of range identification numbers, and observations with unusually large perceived health risk of seafood relative to other foods, the study includes 265 respondents with four observations from each respondent, for a total of 1,060 observations.[9] The definition of variables is given in Table 1.

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[6] In the pretest, we tried different denominators including 1,000 meals, 10,000 meals, and 1,000,000 meals. The mean perceived risk was similar. We chose to use 1,000,000 meals in the actual survey.

[7] In the survey, 33% of the respondents considered seafood to be the safest. Those respondents who thought seafood to be the safest to eat were asked to value a risk prevention program that would prevent deterioration of seafood safety. Because of the different valuation scenarios, we only include the observations that considered poultry or meat to be the safest and the value of a seafood risk-reduction program, as described in the text. See footnote 9 for more discussion.

[8] We focused on deriving individual perceived baseline risk and the consumption changes for a proposed risk reduction. It is assumed that there was no information update during the survey other than the proposed scenario of a fixed risk reduction.

[9] In total, there were 457 observations with complete seafood consumption information. Among them, 302 respondents thought that poultry or meat was the safest food and were asked to evaluate a seafood health risk-reduction program. Of those 302 observations of interest, 37 respondents' perceived risk of seafood consumption was as least 10 times larger than the risk of either poultry or meat consumption (compared with the 80% of respondents who reported relative risk of 1 or smaller), which can result in convergence problems in the empirical estimation. The estimation results reported in the present article exclude those observations. We also tried less stringent criteria for identifying outliers, such as response of a seafood risk more than 25 (or 100) times higher than either the poultry or meat risk, which resulted in 31 (or 27) observations being excluded from the analysis. The qualitative results of estimation were the same. These results are available on request from the authors.

Table 1. Description of Data

Variables	Definition	Combined Sample		Poultry Safest		Meat Safest	
		Mean	SD	Mean	SD	Mean	SD
SEAMEAL	No. of seafood meals per month	4.96	6.03	4.87	6.34	5.02	5.86
PRICE	Price per seafood meal ($)	11.80	6.15	11.63	6.11	11.90	6.18
RSKCFOOD	Prob. of sickness from a seafood meal	0.041	0.122	0.057	0.154	0.032	0.098
RSKPL	Prob. of sickness from a poultry meal	0.046	0.124	0.054	0.153	0.041	0.104
RKSMT	Prob. of sickness from a meat meal	0.049	0.136	0.081	0.187	0.031	0.090
RELRSKPL	(*RSKCFOOD* − *RSKPL*)/*RSKPL*	0.11	1.17	0.33	1.23	−0.01	1.11
RELRSKMT	(*RSKCFOOD* − *RSKMT*)/*RSKMT*	0.27	1.47	0.07	1.26	0.39	1.56
PFIESTER	= 1 heard of Pfiesteria	0.634	0.482	0.625	0.485	0.639	0.481
EFF	= 1 if thought the proposed seafood inspection program to be effective	0.86	0.35	0.87	0.33	0.85	0.36
EFFECTDK	= 1 if did not know whether the proposed seafood inspection program could be effective	0.01	0.11	0.01	0.10	0.01	0.11
COASTAL	= 1 live in a coastal county	0.72	0.45	0.67	0.47	0.76	0.43
WHITE	= 1 if white	0.72	0.45	0.64	0.48	0.76	0.43
FEMALE	= 1 if female	0.62	0.49	0.71	0.46	0.57	0.50
MARRIED	= 1 if married	0.60	0.49	0.58	0.49	0.62	0.49
AGE	Age of the respondent	44.40	15.66	45.04	17.43	44.03	14.55
HSGRAD	= 1 high school graduate	0.94	0.25	0.91	0.29	0.95	0.21
UNIVGRAD	= 1 college graduate	0.16	0.37	0.16	0.36	0.17	0.37
INCOME	Annual income in $1,000	37.17	21.68	34.24	21.08	38.84	21.85
GROUP2	= 1 if poultry is thought safest among seafood, poultry, and meat	0.36	0.48				
REVERSE	= 1 if (poultry is thought safest yet *ABSRSK* − *RSKPL* < −0.001) or (meat is thought safest yet *ABSRSK* − *RSKMT* < 0.001)	0.10	0.30	0.07	0.26	0.11	0.32
No. of Respondents		265		96		169	
No. of Observations		1,060		384		676	

Note: SD is standard deviation. No. is number. Prob. is probability.

Two groups of respondents are included in the analysis: those who thought that poultry was the safest (*GROUP2* = 1) and those who thought that meat was the safest (*GROUP2* = 0).[10] In the combined sample, 36% of the respondents thought poultry to be the safest. The demand for seafood is measured by seafood meals per month (*SEAMEAL*). The self-reported average price of seafood plus the hypothetical price increase that varies across individuals was *PRICE*. Using simple t-tests to compare the means of seafood consumption and prices, there was no statistical difference between the two groups.

In contrast, the perceived probability of sickness from eating seafood (*RSKCFOOD*) was significantly different between the two groups (t-statistic = 2.87). The perceived relative risks of seafood to poultry and to meat were represented by *RELRSKPL* and *RELRSKMT*, respectively. The relative-risk variables indicate how much more likely it is to be sick from seafood than from the other foods. There were 26 respondents who thought poultry (meat) to be the safest yet reported a higher perceived risk from poultry (meat) than from seafood. We created an indicator variable, *REVERSE*, to identify the observations with a noticeably large discrepancy in their quantitative and qualitative risk perceptions.[11]

As described previously, each respondent was confronted with the proposed seafood inspection program that would lower the risk of sickness from seafood consumption to the same level as the food (poultry or meat) that the respondent thought was the safest. In total, four quantities of seafood consumption were elicited: the consumption at the current price, at an increased price, at the current price with a lower risk, and at the increased price with a lower risk. The first quantity *reveals* the current seafood consumption and the next three quantities are the *stated* quantities under hypothetical scenarios. The seafood consumption corresponding to the four scenarios is summarized in Table 2. On average, individuals perceived that they are 31% more likely to get sick from eating seafood than from eating poultry (the mean of *RELRSKPL* in the scenario 1) and 59% more likely to get sick from eating seafood than from eating meat (the mean of *RELRSKMT* in the scenario 1). The average proposed risk reduction is 0.4% (4.3%–3.9%; i.e., 4 fewer meals out of 1,000 would result in sickness). On average, seafood consumption increased by one meal (4.96–5.95 meals) per month with the proposed lower risk. The data allowed us to compare the revealed and stated demand shifts caused by changes in absolute and relative risks and in prices.

Empirical Model and Welfare Measure

In our survey, seafood consumption was measured as meals per month, and each respondent gave four quantities under different scenarios. A count data model that accounts for the panel nature of the data was proposed. We used a negative binomial model with random group and fixed scenario effects. The random-group effects allowed for individual hetero-

[10] Kahneman and Tversky showed that consumers are risk averse to gains but are risk taking to losses. According to their prospect theory, consumers evaluate gains and losses differently relative to the reference point. Because the "seafood safest" group was asked to evaluate a program to guard against losses, as opposed to the "poultry/meat safest" groups, which were asked to evaluate a program to improve (gain) quality of seafood, we expected the seafood safest group to respond differently than the poultry/meat safest groups. To avoid combining the evaluation of two types of alternatives, we focused only on the valuation of gains (risk reductions). That is, we focused on the valuation of risk reduction based on those respondents who considered seafood to be less safe than poultry or meat (the poultry/meat safest groups). Joint models were also estimated in which the seafood safest group was included with various dummy interaction schemes to separate the estimated parameters for the seafood safest group from the poultry/meat safest subsample. The parameter estimates for the poultry/meat safest subsample were invariant to the inclusion of the seafood safest group. These results are available on request from the authors.

[11] In the estimation, we tried both with and without these observations and found the same qualitative results. We report the results with these observations included. Other results are available on request from the authors.

geneity and correlation among responses from the same individual. The fixed scenario effects variables (the scenario dummy variables) determine the structural changes in demand for seafood under different price/risk scenarios. A brief discussion of the construction of the model is as follows.

The Poisson regression is typically used to study count data, in our case the number of seafood meals in a month. Assume that X_{it}, the number of seafood meals eaten by the individual i in the scenario t, was drawn from a Poisson distribution with mean μ_{it}.

$$\text{(6)} \quad \text{Prob}(X_{it} = x_{it}) = \frac{e^{-\mu_{it}}\mu_{it}^{x_{it}}}{x_{it}!} \qquad x_{it} = 0, 1, 2, \ldots .$$

The logarithm of the mean seafood consumption μ_{it} was assumed to be a linear function of a vector of variables W, including price, risks, income, and individual characteristics. In addition, to allow for variation across observations that cannot be explained by the regressors, we assume that μ_{it} also depends on a random variable (u_{it}).

$$\text{(7)} \quad \ln \mu_{it} = \beta' W_{it} + u_{it} \qquad i = 1, \ldots, n; \quad t = 1, 2, 3, 4.$$

If $\exp(u_{it})$ follows a gamma distribution with equal (and constant) scale and shape parameters (θ, θ), then the unconditional number of meals x_{it} follows a negative binomial distribution. If $\exp(u_{it})$ is assumed to follow a γ distribution with parameters varying across groups (θ_i, θ_i), and $\theta_i/(1 + \theta_i)$ follows a beta distribution with parameters (a, b), then the random group effects are "layered onto the negative binomial model" (Greene). This random-effects negative binomial model was first proposed by Hausman, Hall, and Griliches.[12] To examine other potential differences across scenarios, fixed-scenario dummy variables were included.

An important and debated issue in the environmental valuation literature is the com-

Table 2. Summary Statistics

Variables	Total Sample		Scenario 1: Current Price and Current Risk		Scenario 2: Higher Price and Current Risk		Scenario 3: Current Price and Lower Risk		Scenario 4: Higher Price and Lower Risk	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SEAMEAL	4.96	6.03	4.91	5.48	4.06	5.49	5.95	6.68	4.94	6.27
PRICE	11.80	6.15	9.78	5.66	13.82	5.98	9.78	5.66	13.82	5.98
RSKCFOOD	0.041	0.122	0.043	0.127	0.043	0.127	0.039	0.118	0.039	0.118
RELRSKPL	0.11	1.17	0.31	1.52	0.31	1.52	−0.09	0.58	−0.09	0.58
RELRSKMT	0.27	1.47	0.59	1.98	0.59	1.98	−0.04	0.46	−0.04	0.46
Number of Observations	1,060		265		265		265		265	

Note: SD is standard deviation.

[12] Alternatively, we may assume u_{it} to be normally distributed, although the estimation will be much more complex.

patibility of revealed and stated data. The first scenario represents the *revealed* seafood consumption, and the other three scenarios contain information on *stated* seafood consumption. We included fixed scenario effects dummy variables, *T*2, *T*3, and *T*4, to measure any structural shifts between the three stated preference scenarios and the baseline revealed preference scenario. The significance of the fixed scenario effects is one test for incompatibility of the revealed and stated data.[13]

An individual's change in consumer surplus (*CS*) of a risk reduction is measured by the area between two demand curves corresponding to two risk levels and bounded by current and choke prices. Corresponding to our econometric specification of a semilog seafood demand function, the total change in *CS*, which is the area bounded by two demand curves as shown in Figure 1, can be calculated as (Bockstael, Hanemann, and Strand)

$$(8) \qquad \Delta CS = \frac{X_1(\pi_2)}{\beta_1} - \frac{X_1(\pi_1)}{\beta_0}.$$

$X_1(\pi_1)$ is the seafood consumption with current risk and β_0 is the price coefficient in the original demand function; $X_1(\pi_2)$ is the seafood consumption under reduced risk and β_1 is the price coefficient in the new demand function. The independent variables are evaluated at their means for these calculations. If the slope coefficient of price remains the same after the risk reduction, the benefit measure in Equation (8) can be simplified to $\Delta CS = [X_1(\pi_2) - X_1(\pi_1)]/\beta$. We can also calculate the change in *CS* per meal by dividing Equation (8) by the average number of meals consumed per month.

Estimation Results

The negative binomial model estimated the mean seafood demand as a semilog function of price, absolute and relative risks, income, individual characteristics, and a random variable (u_{it}) to allow for variation across individuals that cannot be explained by the regressors. Model 1 included the perceived absolute risks (*RSKCFOOD, RSKPL,* and *RSKMT*) of seafood, poultry, and meat as regressors, and Model 2 examined the perceived absolute seafood risk and its relative risk to poultry and meat (*RSKCFOOD, RELRSKPL,* and *RELRSKMT*). Model 2 allowed the impact of seafood risk on seafood consumption to be influenced by the perceived risks of poultry and meat, which is quite plausible, as was discussed above. The relative risk variables, *RELRSKPL* and *RELRSKMT,* were defined as the additional risk of seafood relative to poultry or meat. We chose this definition of relative risks for the clear interpretation of their coefficients. Alternatively, one could use the proportional risks *RSKCFOOD/RSKPL* and *RSKCFOOD/RSKMT* as regressors.

Model 3 is a combination of Models 1 and 2 that included both the absolute and relative risk measures in the seafood consumption equation. All three models allowed random-group and fixed scenario effects. Models 1 and 2 served as the base models for Model 3, to examine the impact of perceived health risks on the consumption of seafood. The estimation results of the three models are presented in Table 3. Results of the likelihood-ratio test indicated that the two relative-risk coefficients in Model 3 were jointly significant at the 0.1 level [$\chi^2 = (-2{,}367.3 + 2{,}369.6) \times 2 = 4.6$; d.f. = 2]. In other words, Models 3 was preferred to Model 1. In contrast, the absolute risks of poultry and meat were insignificant at any reasonable significance level [$\chi^2 = (-2{,}367.3 + 2{,}367.5) \times 2 = 0.4$; d.f. = 2].

Overall, the estimation results supported that seafood consumption is affected by the price, the health risk perception of seafood, and its relative health risk to poultry. The price of seafood and the perceived absolute seafood risk had significant negative effects on seafood consumption.[14] The perceived absolute risks of

[13] A random scenario effects model could also be estimated, although the number of periods is too short to have a meaningful hypothesis test.

[14] The effect of the price on seafood meals was also tested by decomposing *PRICE* into the current price and the hypothetical price increase (*dP*) and including

Table 3. Negative Binomial Models

Variable	Model 1	Model 2	Model 3
Constant	3.352 (0.427)	3.430*** (0.420)	3.421*** (0.428)
T2	−0.163** (0.074)	−0.163** (0.074)	−0.162** (0.074)
T3	0.177** (0.073)	0.161** (0.078)	0.161** (0.078)
T4	0.037 (0.076)	0.022 (0.076)	0.023 (0.078)
PRICE	−0.016** (0.007)	−0.016** (0.007)	−0.016** (0.007)
RSKCFOOD	−1.137** (0.531)	−0.935** (0.402)	−0.909 (0.555)
RSKPL	−0.228 (1.249)		−0.453 (1.262)
RSKMT	0.391 (0.881)		0.382 (0.887)
RELRSKPL		−0.046** (0.023)	−0.047** (0.023)
RELRSKMT		0.002 (0.020)	0.003 (0.020)
PFIESTER	−0.101 (0.111)	−0.113 (0.112)	−0.114 (0.112)
EFF	−0.151 (0.186)	−0.146 (0.200)	−0.138 (0.200)
EFFECTDK	−0.562 (0.946)	−0.551 (0.950)	−0.551 (0.954)
COASTAL	−0.079 (0.129)	−0.078 (0.131)	−0.074 (0.132)
WHITE	−0.360*** (0.125)	−0.373*** (0.123)	−0.363*** (0.126)
FEMALE	−0.148 (0.108)	−0.157 (0.109)	−0.156 (0.110)
MARRIED	−0.183 (0.116)	−0.183 (0.117)	−0.180 (0.120)
AGE	0.006 (0.004)	0.006* (0.004)	0.006 (0.004)
HSGRAD	0.333 (0.247)	0.310 (0.235)	0.317 (0.249)
UNIVGRAD	0.225 (0.148)	0.218 (0.148)	0.228 (0.149)
INCOME	0.003 (0.003)	0.003 (0.003)	0.003 (0.003)
GROUP2	−0.117 (0.127)	−0.101 (0.125)	−0.112 (0.127)
REVERSE	−0.444* (0.262)	−0.464* (0.250)	−0.457* (0.258)
A	10.130*** (1.307)	10.414*** (1.378)	10.409*** (1.380)
B	1.962*** (0.250)	1.950*** (0.249)	1.949*** (0.250)
Log likelihood	−2,369.6	−2,367.5	−2,367.3
Cases × Panels	265 × 4	265 × 4	265 × 4
Number of observations	1,060	1,060	1,060

Notes: The numbers in the parentheses are the *t* ratios. The symbols *, **, and *** indicate significance at 0.1, 0.05, and 0.01 levels, respectively.

poultry and meat did not affect seafood consumption directly, but the perceived relative risk of seafood to poultry had a significant negative impact on seafood consumption. The riskier that seafood is relative to poultry, the less seafood is consumed. The results indicate that individual seafood consumption is affected by the perceived seafood risk and its risk relative to poultry, but not meat, which indicates that poultry is a risk substitute for seafood. By examining the correlation of food consumption in our data, seafood and poultry are negatively correlated, and seafood and meat are positively correlated. The effect of the relative seafood-poultry risk on seafood consumption makes sense for the substitutability between seafood and poultry. These results confirm the impact of interrelationship of risks from different goods on good consumption, as was suggested by the analytical model.

Other results are that white respondents tend to consume less seafood. There is a slight increase in seafood consumption as one ages (based on Models 1 and 2). Two of the three

both in the demand models. In these, the coefficient on the current price was not significantly different from zero. This result is not surprising with cross-section data and a definition of seafood meals that includes finfish and shellfish and seafood purchased from restaurants and from stores. The coefficient on the hypothetical price change was negative and significantly different from zero at the .01 level.

Table 4. Welfare Measures of Risk Reductions

Welfare Measure (Change in Consumer Surplus Per Meal)	Model 1	Model 2	Model 3
To make seafood as safe as poultry (23.7% risk reduction)	0.707 (0.466)	1.449 (0.757)	1.422 (0.800)
To make seafood as safe as meat (37.1% risk reduction)	1.112 (0.734)	2.287 (1.198)	2.244 (1.266)
To make seafood twice as safe (50% risk reduction)	1.504 (0.994)	2.819 (1.465)	2.763 (1.566)

Note: The numbers in the parentheses are the standard errors.

stated preference dummy variables were significantly different from zero at the 0.05 level of significance. Holding other things constant, in general, there was a difference of seafood consumption between the *revealed* and *stated* data. We also examine the possible slope change by interacting *PRICE* with the scenario dummy variables and concluded that there is no slope change across scenarios.[15]

We calculated *CS* changes for three risk reductions across the three estimated models. From the data summary, we know that, on average, seafood is perceived as 31% riskier than poultry and is 59% riskier than meat. On the basis of the estimated models, we calculated the changes in *CS* per meal to make seafood as safe as poultry [$1 - (1/1.31) \approx 23.7\%$ risk reduction] and meat [$1 - (1/1.59) \approx 37.1\%$ risk reduction]. For comparison, we also calculated the change in *CS* for a 50% risk reduction. For Model 1, the calculation of welfare measures was straightforward, because the risk reduction only affected the value of the seafood risk variable (*RSKCFOOD*). In Models 2 and 3, because the seafood risk was reduced, the values of both absolute and relative risk variables (*RSKCFOOD, RELRSKPL,* and *RELRSKMT*) were changed and should be reflected in the *CS* calculation. For simplicity, the change in *CS* per meal for a risk reduction was calculated by dividing the total change in *CS* by the average initial seafood consumption (4.96 meals per month).[16] The welfare estimates are presented in Table 4.

When seafood was made as safe as poultry (23.7% risk reduction), *CS* increased by $0.71 per meal in Model 1 and by $1.45 and $1.42 per meal in Models 2 and 3, respectively. When seafood was made as safe as meat (37.1% risk reduction), *CS* increases by $1.11 per meal in Model 1 and by $2.29 and $2.24 in Models 2 and 3. The estimated *CS* results from Models 2 and 3 were similar, because the additional absolute risk variables in Model 3 were insignificant. As noted, Models 2 and 3 allowed for the impact of relative risks on seafood consumption, whereas Model 1 did not. Failing to account for relative risks results in a roughly 50% underestimation of welfare effects across risk reductions.

Concluding Remarks and Caveats

The focus of the present study was the impact of multiple risks on the consumption of a risky good. It differs from other risk and food safety studies in a number of ways. We showed analytically how multiple risks enter demand equations in a nonlinear way, which implies an im-

[15] These results are available on request from the authors.

[16] According to the survey responses, on average the seafood consumption went up to 5.95 per month for the proposed risk reduction. Using the initial seafood consumption as the denominator to calculate the per-meal *CS* could overestimate the welfare effect. Alternatively, we could use the new average seafood consumption (5.95) or estimated consumption predicted by the estimated models (Bockstael and Strand). Nonetheless, the qualitative conclusion was the same.

pact of relative risks on demands. We elicited subjective baseline risk from survey respondents to help relax the unrealistic assumption of common baseline risk, which is crucial in examining relative risks. We elicited multiple quantity responses under varying prices and risks, to trace out movement along the demand curve and the shift of the demand curve. We incorporated panel data analysis into our empirical model to account for individual heterogeneity, response correlation, and the potential structural changes in demand across different scenarios. We combined revealed and stated data in examining the effect of risk changes on demand, and we computed the welfare gains for consuming a good when it is made as safe as other related goods. We did not intend to address the issue of the potential gap between perceived and objective risks, nor did we examine the information impact on perceived risk.

Our empirical results support those of the analytical model that risk substitutes exist and relative risks matter. In the application, our results showed that seafood consumption is affected by the perceived absolute risk and by its relative risk to poultry. This suggests that an individual's seafood consumption is affected by the risk relative to poultry but not to meat. The results suggest the possibility of a particular formulation of the expected utility model. The possible "risk separability" of the consumption of goods in various functional forms of the utility and probability functions is left for future study.

The prices of related goods are assumed to be unchanged in our estimation because of the unavailability of data. To fully examine the impact of changes in absolute and relative risks on demands, it is necessary to construct the full demand system of equations, to account for substitution effects. We also examined the general risk perception of illness from food consumption. The severity of illness was not distinguished, nor was the short-term versus long-term risk. To explore the welfare effects of different levels/types of risks, more extensive risk information must be elicited in future research.

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Appendix: Sample Survey Questions

Q4. Do you eat seafood (fish and shellfish)?

1 yes   2 no

Q5. About how many times, including breakfast, lunch, and dinner, do you eat fresh seafood (fish and shellfish) in a typical month?

______ meals

Q10. To the nearest dollar, how much does an average fresh seafood meal cost you? [if asked whether this is for restaurant or store bought meal, tell them whatever is typical for them]

$________

Q11. Seafood prices change over time. For example, if a lot of fish are caught prices go down. When fewer fish are caught prices go up. Suppose the price of your average seafood meal goes up by $[randomly choose one of the following dP amounts: $1, $2, $3, $4, $5] but the price of your average poultry and meat meals stay the same. How many meals of fresh seafood do you think you would eat in a typical month?

______ meals

Q20. There is a small chance of getting sick from eating most food due to poor food handling practices or pollution. Among fresh seafood, poultry, and meat, which food do you think is MOST LIKELY to make you sick?

1 fresh seafood
2 poultry
3 meat

Q21. Which food do you think is LEAST LIKELY to make you sick?

1 fresh seafood
2 poultry
3 meat

Group 2 [For those who think poultry is the safest]

Q54. How likely do you think it is that you will get sick from eating fresh seafood in a typical month? Would you say . . . ?

1 definitely
2 very likely
3 somewhat likely
4 not very likely

Q55. To get a better idea of how likely you think it is that you will get sick from eating fresh seafood, consider the following situation. Suppose 1 million fresh seafood meals are prepared and eaten in a typical month in eastern NC. How many of these 1 million meals do you think will result in someone getting sick?

______ meals

Q60. Currently, there is no fresh seafood inspection program in the US. But the US Food and Drug Administration is proposing a regulation to establish one. The program will establish uniform guidelines for fresh seafood inspection and start random inspections and labeling of fresh seafood. The goal of the program is to reduce the risk of getting sick from eating seafood to be equal to the risk of getting sick from eating poultry. How effective do you think this program will be in reducing the risk associated with eating fresh seafood?

1 very effective
2 somewhat effective
3 not very effective
4 completely ineffective

Q61. Suppose the proposed seafood inspection program is successful in reducing the risk of getting sick from eating seafood to that of eating poultry. If the price of your average fresh seafood, poultry, and meat meals stay the same, how many meals of fresh seafood do you think you would eat in a typical month?

______ meals

Q64. The proposed inspection program may result in higher prices for fresh seafood in restaurants and supermarkets. Suppose the price of your average seafood meal rises by $[insert dP from Q11]. The price of your average poultry and meat meals stay the same. And the risk of getting sick from eating seafood would be the same as eating poultry. How many meals of fresh seafood do you think you would eat in a typical month?

______ meals