The Economic Valuation of Groundwater Pollution Policies:

The Role of Subjective Risk Perceptions

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Abstract

A utility theoretic model is derived to examine personal risk and environmental perceptions as determinants of households' valuations of groundwater protection. Perceived severity of health effects and non-use environmental effects are important determinants for both rural and urban households. Inter-personal altruism is an important determinant for rural households.

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Groundwater pollution is a subject of continuing policy debate at the local, state, and private levels. Fueling the concern are the importance of groundwater as a water supply, particularly in rural areas, and increasing evidence of groundwater pollution in regions across the U.S. (Pye et al 1987). Past efforts in the economic evaluation of policies to address groundwater pollution have typically focused on the health benefits of pollution control (Raucher 1983; Sharefkin et al 1984; and Shechter 1985). Emphasis has been on the health costs of pollution and material costs of remedial action as the basis for estimating pollution control benefits.

A potential weakness of these studies is their exclusive focus on mortality and material costs. Two potentially important reasons exist as to why this focus on mortality may result in incomplete or erroneous policy benefit estimates. First, a divergence may exist between values obtained from the mortality benefits approach and those derived from the households' perception of the health risk from groundwater pollution. A substantial body of research, both in psychology and economics, suggests that people frequently perceive health risks in a different manner than would be expected from a technical risk assessment based on the probability of mortality (Lichtenstein et al. 1978 and Fischhoff et al. 1978). Psychological research has shown that people are unlikely to perceive risk in the abstract terms of a typical economic model or technical risk assessment. Households appear to view both probabilities and utility in terms of a multi-dimensional set of descriptors. Households are also likely to vary in their risk perceptions. Consequently, to elicit policy values that are accurate reflections of consumer preferences, it is beneficial to search for ways to specify probabilities and utility outcomes in terms that are meaningful to ordinary consumers.

Second, values not directly related to the impact of groundwater pollution on household health may be a significant source of benefits. Altruistic, aesthetic and moral concerns may, in a given context, represent motivations with significant explanatory power regarding variations in household bids for

pollution control policies.

To address these ideas in greater depth, a research study was developed comprised of both theoretical and empirical components with the main objective of examining the relationship between benefit values and their underlying motivations and determinants. These motivations include: (a) household perceptions of the health risks from groundwater pollution; (b) household perceptions of the impact of groundwater pollution on environmental amenities; and (c) such conventional economic concerns as income, education and other socio-demographic characteristics. An expected utility model is used to examine, from the perspective of the household, the effect of risk and environmental perceptions on the valuation of groundwater pollution policies. A contingent valuation mail survey was undertaken to obtain the necessary data to test hypotheses derived from the model.

Theoretical Framework

Groundwater pollution can affect human well-being in a variety of ways. For example, direct contact with polluted water by ingestion, skin contact or inhalation of volatilized contaminants may result in health effects depending on a variety of factors, including: (a) contaminant type; (b) water concentration of contaminant; (c) length of exposure; (d) age and (e) physical and health status of exposed individual (USEPA 1988). Sources of potential exposure include household domestic wells, public water supplies which depend on groundwater, and surface water bodies such as lakes and streams which are recharged by groundwater (Pye et al. 1987).

Aside from direct and indirect (other households, future generations) health effects, households may be affected by the impacts of groundwater pollution on environmental amenities. These amenities may affect both use values (such as water-related recreation, aesthetics of an area) and non-use values (such as existence value for the resource itself and ecosystem integrity).

Groundwater pollution can be controlled or prevented in two ways: (a) by affecting the type and

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amount of pollutants introduced into the groundwater system and (b) by reducing the likelihood of exposure once groundwater pollution has occurred. **Preventive** policies control pollution at the source. Preventive policies use source reduction and various types of barriers to intervene between the source and the environmental medium. **Remedial** action policies intervene only after environmental pollution has occurred. Remedial action tends to focus on reducing human exposure in order to protect human health. Remedial action would include filtering or treating water used for human consumption, providing alternative drinking water sources, and other means of avoidance.

The discussion above indicates that two types of services are provided to households depending on the policy: (1) health services provided by both preventive and remedial action policies; and (2) environmental services provided by the prevention policy only. An important question for policy valuation is the extent to which household perceptions of policy services are related to perceived policy benefits as measured by household wtp. The following section develops a simple model which focuses on those features with potentially important implications for policy valuation.

Household Valuation of Groundwater Pollution Policies

Household valuation of groundwater policies can be specified in the expected utility framework by considering the situation faced by households with a new groundwater pollution policy mix. Specifically,

(1) $$u^o = \pi_{P1}v_P(m\text{-}t) + \pi_{R1}(1\text{-}\pi_{P1})v_C(m\text{-}t) + (1\text{-}\pi_{R1})(1\text{-}\pi_{P1})v_H(m\text{-}t)$$

where v_P is a household's indirect utility function when the groundwater aquifer has not been polluted, v_C is the indirect utility function when the household is not exposed to polluted groundwater; v_H is the household's indirect utility function when exposed to groundwater pollution; π_{P1} is the household's subjective probability that the new policy is successful in preventing aquifer pollution; π_{R1} is the

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household's subjective probability that the remedial action component of the new policy is successful; m is household income; and t is a Hicksian compensating measure.

Taking the total differential of equation (2) with respect to π_{P1}, π_{R1}, and t; setting $du^0 = 0$; and rearranging terms, the following relationship is obtained:

$$\text{(3a)} \qquad dt/d\pi_{P1} = [(1 - \pi_{R1})(v_C - v_H) + (v_P - v_C)]/E(u_M)$$

$$\text{(3b)} \qquad dt/d\pi_{R1} = [(1 - \pi_{P1})(v_C - v_H)]/E(u_M)$$

where $E(u_M)$ is the expected marginal utility of income.

Equations (3a) and (3b) define the change in wtp with respect to a unit change in the subjective probability of a successful prevention and remedial policy respectively.

The right hand side of equation (3a) specifies the marginal benefits of a prevention policy. The first term in the numerator represents a discount factor health which reduces the value of marginal health benefits from prevention by an amount proportional to the probability that remedial action will be successful. The second term in the numerator constitutes the ordinary or basic marginal health benefits of prevention. It is the monetized value of the difference in utility between being exposed and not being exposed to groundwater pollution. The third term in the numerator represents the marginal non-health environmental benefits of prevention. It is the monetized value of the difference in utility when the groundwater aquifer is polluted and unpolluted, given that no exposure occurs. This term occurs only if households have some positive level of concern regarding the non-health environmental effects of pollution. If such is the case, then v_P does not equal v_C and the third term is positive. If households are concerned only with the health impacts of groundwater pollution and indifferent to the non-health environmental effects of groundwater pollution, then v_P equals v_C and marginal non-health environmental

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benefits is eliminated.

Equation (3b) is an expression for the marginal benefits of remediation. Similar to equation (3a), the second term in the numerator represents the basic marginal health benefits of remedial action. The first term in the numerator is also similar to its counterpart in equation (3a), except that the health benefits from remedial action are discounted by an amount proportional to the probability of a successful prevention policy. Unlike equation (3a), equation (3b) does not have a third component since remedial action does not affect aquifer pollution and hence does not provide non-health environmental services.

WTP Hypotheses

The hypotheses to be tested are derived from equations (3a) and (3b). The RHS of both equations identifies marginal policy benefits. The term $(v_C - v_H)$ is the difference in indirect utility between being exposed and not being exposed. As this difference increases, marginal benefits increase. Likewise, as this difference decreases, marginal benefits decrease. The magnitude of this difference is hypothesized to be a function of how the health threat from groundwater pollution is perceived by consumers. The greater the perceived risk, the higher the wtp for a groundwater policy. Specific hypotheses regarding subjective risk perceptions are derived based on the set of risk descriptors identified by Fischhoff et al (1978). These descriptors can be divided into three categories: (a) choice, including the descriptors voluntariness and control; (b) knowledge, addressing the extent of knowledge of scientific experts and exposed individuals about the risks of health effects from exposure; and (c) severity, the households' perceptions of the severity of consequences of exposure to groundwater pollution.

Specific hypotheses include: (a) household perceptions of choice are negatively correlated with wtp for groundwater pollution policies--the more choice that people associate with groundwater pollution risk, the lower the wtp will be; (b) household perceptions of the degree of knowledge associated with groundwater risk will be negatively correlated with wtp--the less knowledge associated with groundwater risk situations, the greater the wtp for groundwater policies; and (c) household perceptions of the severity

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of pollution exposure outcomes are positively correlated with wtp-- the more severe pollution outcomes are perceived, the greater the wtp for groundwater pollution policies.

The indirect non-use altruistic effects of groundwater pollution on marginal policy benefits can be examined using the term $(v_P - v_C)$. The term $(v_P - v_C)$ represents the difference in indirect utility between a polluted and unpolluted aquifer, given that no human exposure occurs. Specific hypotheses are as follows: (a) household perceptions of environmental amenities will be positively correlated with wtp--the greater the concern over the non-health related environmental amenities derived from groundwater, the greater the wtp for policies which protect the groundwater aquifer.

Empirical Study

In Michigan, groundwater is an important source of freshwater for household use. Fifteen percent of all households obtain groundwater from public systems, while 28 percent depend on private wells (Solley et al 1985). A number of studies have been done in Michigan concerning specific groundwater pollution episodes (USGS, 1984; Michigan Farm Bureau, 1989; Kittleson, 1987). The state of Michigan has expressed the need for groundwater protection policies from a legal and legislative perspective (Michigan State Legislature, 1987; Michigan DNR, 1988). However, little is known about how Michigan consumer's perceive the problem of groundwater pollution. Regarding the dichotomy of generic and non-generic values discussed above, reliance on the standard technical risk assessment using generic health benefits may significantly understate or overstate policy benefits. The extent to which this occurs depends on the individual perceptions of consumers.

The survey sample consisted of Michigan households divided into urban and rural subsets. The subsets were categorized based on whether a county was included in a metropolitan statistical area (MSA) as defined by the U.S. Census Bureau (Michigan Office of Policy Analysis, 1990). A total of 2020 Michigan households were sent questionnaires. The urban sample consisted of 673 households, the rural

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sample 1347 households. The survey was implemented using the total design method developed by Dillman (1978). The gross response rate was 66.5 percent. This compares favorably with other mail surveys in general (Dillman, 1978, pp.21-24) and contingent valuation mail surveys in particular (Mitchell and Carson, 1989, p.281).

Five types of information were elicited: (a) water quality perceptions; (b) qualitative risk perceptions; (c) perceptions of environmental concern; (d) socio-economic information; and (e) household policy bids. The remainder of the paper will focus on the econometric analysis of the data.

Econometric Analysis

To test the hypotheses, the following relationship is defined:

$$
(1) \quad BID = \beta_1 \, D1 + \beta_2 \, D2 + \beta_3 \, D3 + \beta_4 \, D23 + \beta_5 \, \text{Severity}
$$
$$
+ \beta_6 \, \text{Knowledge} + \beta_7 \, \text{Newness} + \beta_8 \, \text{Control}
$$
$$
+ \beta_9 \, \text{Voluntariness} + \beta_{10} \, \text{q-altruism} + \beta_{11} \, \text{inter-being altruism}
$$
$$
+ B_{12} \, \text{Education} + B_{13} \, \text{Income} + e.
$$

where D1, D2, D3, and D23 are policy dummy variables denoting the scientific, preventive, remedial and combined policy respectively and e is an error term assumed to be normally distributed with a mean of zero. Table 1 provides detailed definitions of the independent variables.

This model shows the specific impact of household perceptions as embodied in these variables on each of the policy bids. This equation defines a linear relationship between the dependent and independent variables. Consequently, a linear regression technique such as ordinary least squares can be used to estimate the coefficients. The use of the policy dummy variables allows coefficient estimation to be derived from one equation instead of using one equation for each policy. By specifying the independent

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Table 1. Independent Variables Used in Policy Bid Estimation

Variable	Definition
D1	A 0-1 dummy variable where 1 indicates the scientific information policy.
D2	A 0-1 dummy variable where 1 indicates the prevention policy.
D3	A 0-1 dummy variable where 1 indicates the remedial policy.
D23	A 0-1 dummy variable where 1 indicates the combined policy.
Severity	A variable identified by principal components analysis associated with the perceived severity of the health risk from exposure to groundwater pollution.
Severity $_i$	An interactive variable defined as D_i*Severity where i=1, 2, 3, 23 corresponding to dummy policy variables.
Knowledge	A dimension of risk identified by principal components analysis associated with the perceived level of existing scientific and personal knowledge of groundwater pollution.
Knowledge $_i$	An interactive variable defined as D_i*Knowledge where i=1, 2, 3, 23.
Inter-being altruism	A variable identified by principal components analysis associated with the level of concern for others (both human and non-human) affected by groundwater pollution.
Inter-being altruism $_i$	An interactive variable defined as D_i*Inter-being altruism where i=1, 2, 3, 23.
Q-altruism	A variable identified by principal components analysis associated with perceived importance of the existence value of groundwater.
Q-altruism $_i$	An interact variable defined as D_i*Q-altruism, where i=1, 2, 3, 23.
Newness	A 0-1 dummy variable where 1 indicates that households perceive groundwater pollution risk as a new or somewhat new environmental problem.
Control	A 0-1 dummy variable where 1 indicates household perceptions that the damage from groundwater pollution is very difficult or impossible to control through technology.
Voluntariness	A 0-1 dummy variable where 1 indicates household perceptions that people are involuntarily exposed to groundwater pollution.
Education	Last year of school completed on a six point scale with 1=no school and 6=last year of college or more.
Income	Expected annual income in one year, thousands of dollars.

variables in mean deviations form and suppressing the constant term, the coefficients for the policy dummy variables will equal the sample mean for that particular policy.

Results

Table 2 shows the regression results for the above specified model. The purpose of the interactive variables specified in Table 6 is to test the effect of specific independent variables on specific policies. The variable representing severity is not significant for three of the four policies for the rural sample. The combined policy has a positive and statistically significant coefficient. A linear restrictions test on the severity variables associated with the scientific information policy, prevention policy and the well protection policy respectively finds these three variables significant as a set. Additionally, removing inter-being altruism from the regression run results in all four of the severity interactive variables to be positive and statistically significant (estimated coefficients and standard error: scientific information policy, 12.35 (3.33); prevention policy, 14.01 (4.80); well protection, 15.11 (4.59); combined policy, 21.58 (4.68)). The urban sample shows that three of the four interactive severity variables are positive and significant. Only the interactive variable associated with the well protection program is not significant. Consequently the hypotheses associated with this policy are not confirmed with the exception of the well protection policy.

For both the rural and urban sets, only the coefficient associated with the knowledge variable for the combined policy is significant. A linear restrictions test shows that the estimated coefficients for the knowledge variables associated with the scientific information policy, the prevention policy and the well protection policy are statistically significant as a set for the rural sample. The same variables as a set are not significant for the urban sample. The sign on the combined policy coefficients are different for two samples. The coefficient is positive for the rural sample, thus confirming the hypotheses (for the combined policy) relating knowledge and policy bids. The coefficient for the urban sample is negative. This means the lower the perceived knowledge regarding the health effects of groundwater pollution, the

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Table 2. Estimated Coefficients for Bid Equations with Interactive Policy Variables[1]

Variables		Rural[2]	Urban[2]
Severity:		Coefficient (SE)	Coefficient (SE)
	Science Policy	6.40 (4.55)	20.05* (10.12)
	Prevention	5.24 (6.09)	28.81* (14.65)
	Well Protection	9.62 (6.94)	-2.29 (15.12)
	Combined Policy	11.97* (4.54)	17.42* (10.12)
Knowledge:			
	Science Policy	3.91 (3.30)	-4.33 (7.60)
	Prevention	6.11 (4.71)	-17.91 (11.8)
	Well Protection	0.02 (4.62)	-2.80 (10.67)
	Combined Policy	6.79* (3.30)	-15.68* (7.60)
Inter-being Altruism			
	Science Policy	8.72* (4.48)	2.13 (10.05)
	Prevention	13.81* (5.88)	-2.68 (14.86)
	Well Protection	7.62 (7.01)	11.18 (14.19)
	Combined Policy	13.75* (4.48)	-0.53 (10.04)
Q-altruism			
	Science Policy	6.14* (3.36)	14.20* (7.59)
	Prevention	8.17* (4.75)	23.50* (11.92)
	Well Protection	-2.48 (4.75)	3.54 (10.15)
	Combined Policy	6.18* (3.36)	19.97* (7.59)
Newness		6.16 (4.35)	-11.74 (10.19)
Control		-2.06 (4.09)	-0.30 (9.57)
Voluntariness		-2.38 (4.01)	7.82 (9.42)
Education		10.76* (1.91)	3.54 (5.07)
Income		0.23* (0.07)	0.19 (0.18)
Adjusted R^2		.38	.33

1. Estimated coefficients for policy dummy variables are equal to the mean bids for that sample:
Rural: D1=$45.35; D2=$51.54; D3=$40.16; D23=$57.89.
Urban: D1=$71.22; D2=$73.19; D3=$38.54; D23=$75.15.

2. The "*" signifies the estimated coefficient is statistically different from zero at the 95 percent confidence level.

lower the policy bid. Alternatively, the higher the perceived knowledge of pollution's health effects, the greater the bid. Similar to the discussion concerning averaged independent variables, the negative coefficients on knowledge for the urban group might be associated with perceptions of the likelihood of the policy actually achieving its stated objectives. The reasoning might be that the greater the level of scientific and personal knowledge concerning the health risks from groundwater pollution, the greater the possibility that policies can be designed and implemented with a reasonable chance of success.

Individually, newness, control and voluntariness are not statistically significant for either sample. However, these variables are statistically significant as a set for the rural sample. The calculated F statistic was 26.20, an indication of the strength of the significance. The estimated coefficients for the urban sample are not significant as a set.

For the rural sample, the estimated coefficients on q-altruism are positive and statistically significant with the exception of the well protection program. This confirms the hypotheses developed for the impact of existence value on policy bids. Similarly, the coefficients for the urban sample, again with the exception of the well protection program, are positive and statistically significant. Three of four inter-being altruism variables for the rural sample are positive and statistically significant. None of the inter-being altruism coefficients for the urban sample are significant, either individually or as a set.

Significance of Risk and Altruistic Perceptions

The data analysis showed the empirical significance of risk and altruistic perceptions in explaining policy bid variations. An important implication of the empirical results is that the use of probability and a single outcome descriptor such as death results in an incomplete and inadequate description of the risk/income trade-off situation faced by households. In essence, their subjective perception of groundwater pollution risk is expressed through underlying variables composed of the qualitative risk descriptors and is systematically related to wtp. An important point is that certain risk descriptors which

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appear to be important in the formulation of groundwater risk perceptions are not systematically related to respondent behavior as evidenced by policy bids. In other words people may have perceptions of a particular risk but may not act on it in the sense that it is not a significant motivation behind the trade-offs a person is willing to make in order to reduce the risk from groundwater pollution. For example, severity is important both to perceptions and behavior. Newness, which has been shown in other studies to be an important component of an underlying risk dimension (Fischhoff et al, p. 145, 1978), is shown not to be economically significant in explaining groundwater policy bids. Knowledge, which has been shown to be a significant underlying dimension of risk for both samples, is economically significant for the rural sample but not for three of the four policies for the urban sample. Knowledge then is an example of an important component of people's risk perceptions but (for the urban sample) not related to behavior in the form of wtp.

The empirical analysis showed that other reasons exist to protect groundwater quality besides consideration of the direct health effects to the household. Both types of altruism are important in explaining bid variations for the rural sample. Only q-altruism is significant for the urban sample. This difference may be due to a greater familiarity on the part of rural residents with services provided by groundwater. Three general implications are evident from the economic significance of altruistic perceptions. First, ignoring this aspect of household concern results in an insufficient amount of pollution prevention. The marginal benefits of prevention will be understated if benefits derived from altruistic concern are not included in the policy evaluation and households have some degree of altruistic concern regarding the potential effects of groundwater pollution. Second, groundwater policies will be biased towards remedial action. If values derived from concern over the environmental effects of groundwater pollution are not considered, an inefficient allocation of expenditures will result. Third, by ignoring these values, a given expenditure on protection results in a smaller gain in well-being than if prevention and remedial action were efficiently balanced.

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