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ESTIMATION OF WILLINGNESS TO PAY FOR DRINKING WATER QUALITY IMPROVEMENT

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This study estimated individuals' compensating surplus (CS) as a measure of willingness to pay (WTP) for improving their drinking water quality and analyzed what factors influence their WTP. The drinking water supply is normally fixed and becomes constraints on each individual's choice of a consumption bundles. Individuals cannot adjust quantities of environmental goods supplied and therefore, CS would be the most appropriate measure of welfare changes for drinking water quality. A contingent valuation study was conducted for residents in the nine communities of southwestern Minnesota that experienced excessive hardness in their water. Censored tobit analyses showed that individuals were willing to pay $3.45 per month to reduce the level of hardness in their water. The aggregate annual WTP for those communities was estimated $1.26 - $2.01 millions.

JEL Classification: Q25, Q26
Keywords: Willingness-to-pay (WTP), Compensating Surplus (CS), Water Quality

I. INTRODUCTION

For conventional economic goods or services, markets provide important information about values, while environmental goods such as amenity and water quality are often not directly purchased and sold market. Hence, researches on environmental valuation have focused on non-market valuation. Non-market valuation is linked to the theory of valuation of price changes.

The welfare changes associated with price changes can be derived from

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measuring their choices among competing consumption goods and services. The typical measures of welfare change are Compensating Variation (CV) and Equivalent Variation (EV). CV represents the maximum amount that the individual would be willing to pay for the opportunity to consume at the new price set, while EV represents the minimum payment the individual would accept to give up the opportunity to purchase at the new price set. Both the EV and CV measures allow the individual to adjust the quantities of goods consumed in response to changes in prices and income levels.

The theory for price changes can be extended to environmental quality changes (i.e., drinking water quality changes). Many studies have used the CV or EV measures to estimate individual's willingness to pay for improved environmental conditions (McConnell, 1990; Hanemann et al., 1991; Whitehead, 1995; Kopp et al., 1997; Carson, 2000). McConnell (1990) developed the compensating variation function and examined the properties of compensating variation function for price changes under the assumption that the implicit property right is associated with the lower environmental quality level. Whitehead (1995) extended the McConnell's work to equivalent variation function for quality changes and investigated the effects of changing the level of prices, income, and quality under the assumption that the implicit property right is associated with the higher quality level.

However, none has examined the effects of changes in arguments on the compensating surplus (CS) function for quality improvement. Freeman (1993) and Bishop et al (1995) noted that CS is the relevant measures of welfare changes for environmental quality changes.

The purpose of this study is to develop a measure of CS for water quality improvements and develop properties of the WTP valuation function, and provide an empirical analysis of individual's WTP for water quality improvements in southwestern Minnesota.

The remainder of the paper is divided into five sections. The next section presents a theoretical model and characterizes the properties of the WTP valuation function such as income effect, own-price effect, and water quality effect. The following sections explain the survey design and the data used in this study. The section five and six describe the estimation of the model and the results respectively. The final section summarizes the results and highlights some suggestions for future research.

II. THE MODEL

Suppose an individual's preference is represented by an utility function of the form, $U=U(X,Z,Q)$, where X is a demand for use of water, Z is a composite of all other market goods, and Q is a water quality. Also, assume that the individual takes Q as given and does not have to pay, and S^0 =

(P_x^0, P_z^0, Q^0) denotes the state of the economy facing the individual. The minimum expenditure that the individual needs to obtain an utility level, u^0, at the state of the economy, S^0, is defined as the solution to a budget-minimizing problem:

$$E(P_x^0, P_z^0, Q^0, u^0) = Min \; \{P_x^0 \cdot X + P_z^0 \cdot Z \mid U(X, Z, Q) = u^0\} \tag{1}$$

where, P_x is a price of X and P_z is a price of Z. The expenditure function is increasing in $P = P(P_x, P_z)$ and u (i.e., $E_P(P_x, P_z, Q, u) > 0$ and $E_u(P_x, P_z, Q, u) > 0$), but decreasing in Q (i.e., $E_Q(P_x, P_z, Q, u) < 0$). If the water quality is improved from Q^0 to Q^1 with exogenously given price level $P = P(P_x^0, P_z^0)$, then the state of the economy is changed from S^0 to $S^1 = (P_x^0, P_z^0, Q^1)$. The minimum expenditure that the individual must spend to achieve an utility level, u^0, at the new state of the economy, S^1, is $E(P_x^0, P_z^0, Q^1)$. Hicksian CS resulting from a change in Q can be measured as:

$$CS = E(P_x^0, P_z^0, Q^0, u^0) - E(P_x^0, P_z^0, Q^1, u^0) \tag{2}$$

The CS measure is often interpreted as the maximum amount that the individual would be willing to pay for the opportunity to consume at the new state of the economy.

The inverse of the expenditure function generates an indirect utility function of the form:

$$V(P_x, P_z, Q, Y) = Max \; \{U(X, Z, Q) \mid P_x \cdot X + P_z \cdot Z = Y\} \tag{3}$$

where, Y is a monetary income. Then the CS is the amount of money given up by the individual that makes them indifferent between $V(P_x^0, P_z^0, Q^0, Y)$ and $V(P_x^0, P_z^0, Q^1, Y - CS)$, which can be interpreted as the individual's willingness-to-pay for an improvement of water quality. This compensating surplus can be measured by asking individuals their willingness-to-pay for a change in quality from Q^0 to Q^1 in a contingent valuation survey. Suppose that the implicit rights are associated with the lower quality level (Q^0). Then the CS (willingness-to-pay) for water quality improvement is defined as follows:

$$\begin{aligned} CS &= E(P_x^0, P_z^0, Q^0, u^0) - E(P_x^0, P_z^0, Q^1, u^0) \\ &= Y - E(P_x^0, P_z^0, Q^1, V(P_x^0, P_z^0, Q^0, Y)) \\ &= WTP(P, Q, Y) \end{aligned} \tag{4}$$

The willingness-to-pay valuation function in the equation (4) depends on various exogenous variables. Application of the envelope theorem can help understand how the WTP relates to income and the price of water, and sign the coefficient of those variables. These properties can be used to test or restrict the willingness-to-pay valuation function. To derive properties of the willingness-to-pay valuation function, the following analysis is adapted from McConnell (1990) and Whitehead (1995).

Income and Own-price Effects

The effect of income change on WTP valuation function is:

$$\frac{\partial WTP}{\partial Y} = 1 - \frac{\partial E(\cdot, Q^1)}{\partial V} \cdot \frac{\partial V(\cdot, Q^0)}{\partial Y} \quad \text{or}$$

$$WTP_Y = 1 - E_V^1 \cdot V_Y^0 \tag{5}$$

E_V^1 denotes the marginal cost of utility at $Q = Q^1$ and V_Y^0 is the marginal utility of income at $Q = Q^0$. Evaluating E_V and V_Y at the same arguments in (5) yields: $V_Y^0 == 1/E_V^0$. Substituting this equation into (5) yields:

$$WTP_Y = 1 - \frac{E_V^1}{E_V^0} \tag{6}$$

If water quality (Q) is a normal good, then the marginal cost of utility, E_V will decline as the water quality is improved from Q^0 to Q^1. Hence $E_V^0 > E_V^1$, and $[E_V^1 / E_V^0] < 1$, so $WTP_Y > 0$.

Meanwhile, the effect of the own-price of the good, P_x, on WTP(·) is:

$$\frac{\partial WTP}{\partial P_x} = -\frac{\partial E(\cdot, Q^1)}{\partial P_x} - \left(\frac{\partial E(\cdot, Q^1)}{\partial V}\right)\left(\frac{\partial V(\cdot, Q^0)}{\partial P_x}\right) \quad \text{or}$$

$$WTP_{Px} = -[E_{Px}^1 + E_V^1 \cdot V_{Px}^0] \tag{7}$$

Since $V_Y^0 = 1/E_V^0$, we have $1 = V_Y^0 \cdot E_V^0$. Substituting this equation into (7) yields:

$$WTP_{Px} = -[E_{Px}^1 + (E_V^1 / E_V^0) \cdot (V_{Px}^0 / V_Y^0)] \tag{8}$$

By the Shephard's lemma and the Roy's identity, the equation (8) can be written: [1]

[1] $X^*(\cdot, Q^1)$ is the compensated demand function when $Q = Q^1$ and $X(\cdot, Q^0)$ is the uncompensated demand function when $Q = Q^0$. Also, $u = V(\cdot, Q^0)$ and $X(\cdot, Q^0) = X^*(\cdot, V(\cdot, Q^0))$.

$$WTP_{Px} = -[X^*(\cdot, Q^1) - (E_V^1/E_V^0)\cdot X^*(\cdot, Q^0)] \tag{9}$$

If water quality is a normal good and a gross complement with X, then improvement of water quality from Q^0 to Q^1 can result in higher X^* (i.e., $X^*(\cdot, Q^1) > X^*(\cdot, Q^0)$). Also $0 < [E_V^1/E_V^0] < 1$. Thus $WTP_{Px} < 0$. Similarly, if water quality is a substitute for X, then $WTP_{Px} \geq 0$ depending on the size of $[E_V^1/E_V^0]$.

Water Quality Effects

The change on WTP valuation function with respect to change of quality is:

$$\frac{\partial WTP}{\partial Q} = -\frac{\partial E(\cdot, Q^1)}{\partial Q} - \left(\frac{\partial E(\cdot, Q^1)}{\partial V}\right)\left(\frac{\partial V(\cdot, Q^0)}{\partial Q}\right) \quad \text{or}$$

$$WTP_Q = -[E_Q^1 + E_V^1 \cdot V_Q^0] \tag{10}$$

Where, $E_Q^1 < 0$, $E_V^1 > 0$, and $V_Q^0 > 0$. Equation (10) can be rewritten by using the condition, $1 = V_Y^0 \cdot E_V^0$:

$$WTP_Q = -[E_Q^1 + (E_V^1/E_V^0)\cdot(V_Q^0/V_Y^0)] = -[E_Q^1 + \alpha(V_Q^0/V_Y^0)] \tag{11}$$

where $0 < \alpha < 1$ and $E_Q^1 = -X^{*Q}(\cdot, Q^1)$ is the inverse compensated demand (or marginal willingness-to-pay) for water quality with $X^{*Q} > 0$.[2] Also $(V_Q^0/V_Y^0) = -X^Q(\cdot, Q^0) < 0$ is the inverse Marshallian demand for water quality. Then the equation (11) can be rewritten:

$$WTP_Q = [X^{*Q}(\cdot, Q^1) + \alpha X^Q(\cdot, Q^0)] > 0 \tag{12}$$

Thus, changes in water quality (i.e., quality improvements) have a positive effect to the WTP.

III. SURVEY DESIGN

The population to be surveyed were households who obtain their water from a public water supply system in southwestern Minnesota that has above the standard levels of ***hardness***.[3] In order to determine the WTP for an

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[2] refer to Freeman (1993, p. 99) for more detailed information of the inverse compensated demand.

[3] Groundwater contains dissolves minerals. Dissolved calcium and magnesium cause water to be "*hard*". Although hard water does not affect human health, it interferes with all types of

improvement in drinking water quality, a survey questionnaire was mailed to 390 residents of the 9 communities in Southwestern Minnesota. The *WTP* question in the survey questionnaire was simply designed to establish a realistic hypothetical market in which water quality improvement is to be traded. Also, efforts were made to word the questionnaire for respondents from all educational levels to be able to comprehend the language, concepts, and questions used in the survey. The *WTP* question provided both general information about the characteristics and specific information about the level of hardness found in the city water. The respondents were asked to circle, from a set of predetermined values, the most he/she would be willing to pay above his/her current monthly water bill for improvements in drinking water quality. The *WTP* question for hardness was stated as follows:

> Water hardness is measured as a sum of the calcium and magnesium in the water. The Minnesota Department of Health has not set a standard for hardness. However, the World Health Organization (WHO) has established a recommended level for hardness in drinking water at **250** milligrams per liter. Monitoring results from the Minnesota Department of Health shows that your community water system has _____ milligrams per liter.
>
> In order to reduce the current level of hardness to below the recommended level (250 *mg/l*), your community could soften the water in the public water system. But since this would involve increased costs, it would be necessary to increase your water bill to support this project.
>
> What is the **LARGEST monthly payment ABOVE** your current water bill that you would be willing to make for a new or improved softening system that would remove the unpleasant taste and color resulting from hardness in your drinking water and make your water softer? (Please circle **ONE** answer):
> **$0, $1, $2, $3, $4, $5, $6, $7, $8, $9, $10, $15, $20, $25, $30 or more EACH MONTH**

The checklist arrayed number in $1.00 increments up to $10.00 and in $5.00 increments until $30.00 and designed to capture minimum and maximum WTP values of the respondents. These intervals in the checklist were finalized after the pilot survey results. An increase in the respondent's current monthly water bill was selected as a payment vehicle since most residents are quite familiar

cleaning tasks. Over time, clothes washed in hard water may look dingy and feel harsh and scratchy. White clothing continually washed in hard water will gradually show a grayish tinge. Dishes and glassware washed in dishwashers using hard water may be spotted when dry. Also glass shower doors, walls and bathtub surfaces will become filmy.

with paying a water bill and the increments above current water bill could make people do not state their *WTP* higher than they are really willing to pay, even in hypothetical situation.

This survey was conducted in September 1995. A pilot survey was conducted to design and test the survey instruments. The main purpose of the pre-test was to bring attention to any confusing parts of the survey and to determine if the survey responses appeared to be a measure of the variables asked. The instrument's wording was also reviewed at various stages in its development by outside reviewers. After redesigning the survey questionnaire based on the result from the pilot survey, a total of 390 surveys were mailed out in three different successive mailing followed closely Dillman's (1978) recommendations for maximizing response rate. A questionnaire along with a cover letter explaining the purpose and importance of completing the survey was sent to residents. A reminder letter with questionnaire was sent to the non-respondents 2 weeks after the original mailing, and a third letter to non-respondents with a survey that was sent 2 weeks after the reminder was sent.

IV. DATA

The survey resulted in 245 completed questionnaires and an overall response rate of 62.8%. About 44 percent of the respondents were female. Thirty three percent of respondents had children less than 13 years old living in their home. The average age of respondents was 54.7 years. Sixty two percent of the respondents' houses were built after 1945. The estimated average water bill of respondents was $16.88 per month. Over 80 percent of the respondents had at least a high school education. The average annual total household income using the midpoint of reported intervals was $32,566. Compared to the average for Minnesota, the mail survey had a relatively higher proportion of male respondents. Also, there were a large number of respondents who had graduated from high school but the average household income of respondents is slightly less than that for Minnesota ($33,682) in 1993.

About 53 percent of respondents used either bottled water or had a home water treatment device. Almost 18 percent of sample purchased bottled water regularly, and about 44 percent of respondents used a water treatment device (including a filter or water softener). Among them, 9 percent of respondents both purchased bottled water and used a water treatment device. The main reasons for purchasing bottled water or using a water treatment device were taste (50.5%) and health concerns (40.3%). Other reasons were to soften the water for washing and laundry and to make better coffee or fruit drinks.

Overall, 63 percent of the respondents said that they would be willing to pay at least one dollar a month to improve water quality. The *WTP* responses ranged from zero to $25 per month. About 98 percent of respondents' *WTP* were between zero and $10 per month. Almost 53 percent of respondent selected either zero *WTP* or $5 *WTP* per month (37.1% selected $0 and 16.3% selected $5). No one chose $9. The number $6, $7, and $8 had very low frequency of selection (less than 5%). The respondents tended to select $1, $2, $3, $4, $5, and $10 from the checklist.[4]

[Table 1] Description and Descriptive Statistics of the Variables

Variable	Description	Mean	Std. Dev.
ACT	One if the respondent purchased bottled water or uses water treatment device, 0 otherwise	0.534	0.500
PERCEPT	Perception of tap water, rating it on a 5-point scale with 1 being 'very poor' quality and 5 being 'very good'	3.600	0.827
SEX	Sex of respondent, 1 for Male and 0 for Female	0.559	0.498
AGE	Age of respondent (year)	54.673	17.775
EDUC	Education level of the respondent, 1 for eleventh grade or less, 2 for wigh school graduate, 3 for completed technical school or some college, and 4 for college graduate or more	2.641	0.984
CHILD	One if there are children under 13 years old in household, 0 otherwise	0.327	0.470
W-BILL	Average monthly water bill ($/month)	16.884	9.673
INCOME	Annual household total income before tax, using 9 reported intervals with 1 for $10,000 or less and 9 for $100,000 or more	3.751	1.783
BLDG	One if the respondent's house was built after 1945, 0 for otherwise	0.624	0.485
QUALITY	Difference between the recommended level and the actual level of hardness that was found in the respondent's community water supply system (*mg/l*)	391.490	329.930
QUALITY2	QUALITY squared	261,674.0	314,274.1
WTP	Willingness-to-pay for reducing the current level of hardness to below the recommended level ($/month)	3.438	4.137

V. ESTIMATION

Suppose that we obtain the consumer's *WTP* and auxiliary information from

[4] Please see Cho (1996) for the details of the survey results.

a survey. The structure of the model to be considered is: $WTP_i = X_i'\beta + e_i$. The ordinary least squares (OLS) method can be used to estimate the unknown parameters, β_{OLS}. However, if the *WTP* data are censored so that negative values appear as zero, then the ordinary least squares coefficient estimates would be less desirable (Maddala, 1983; Greene, 1991). The proper method for estimating unknown parameters from CV data, that contain a large number of zero values for *WTP*, is a censored-tobit model. The censored tobit model is of the form:

$$\begin{aligned} WTP_i &= X_i'\beta + \varepsilon_i \text{ if } WTP_i^T > 0 \\ &\quad 0 \text{ if } WTP_i^T \leq 0 \end{aligned} \tag{13}$$

which is censored at zero because all negative values of WTP_i are observed as zero. The expected value of WTP_i is obtained from:

$$E[WTP_i] = X_i'\beta_{tobit} \cdot \Phi(X_i'\beta_{tobit}/\sigma) + \sigma \cdot \phi(X_i'\beta_{tobit}/\sigma) \tag{14}$$

where $\Phi(X'\beta)$ is the CDF and $\phi(X'\beta)$ is the PDF for the normal distribution.

Empirical investigations of previous studies regarding estimation of WTP function have dealt with numerous determinants of WTP. This study considered the following specific econometrics model for the factors that influence the willingness-to-pay to obtain better quality of water.

WTP = F(ACT, PERCEPT, CHILD, W-BILL, INCOME, QUALITY, QUALITY2) (15)

Following the discussion in the section II, income (INCOME) is expected to affect *WTP* positively. The monthly water bill (W-BILL) can be considered as the own-price of water, and is expected to have negative influence on the *WTP*.[5] It is anticipated that individual's *WTP* for better quality water will increase as his/her income increases and will increase as monthly water bill decreases. The expected signs of quality of hardness (QUALITY) should be positive. The larger numbers of the QUALITY variable denote the difference between recommended level and current actual level is bigger, and also the reduction amount of hardness from the respondent's community water supply system is larger. Thus, it is expected that consumer's *WTP* to obtain better quality water will have positive relationship with this variable.

In addition, it is expected that the *WTP* of those purchasing bottled water or

[5] Suppose that the water quality is a normal good and the water quality and a demand for use of water are gross complements. Then the price of water (i.e., water bill) has negative influence on the WTP for better quality water.

using a home water treatment device will be smaller than that of their counterparts. Hamilton (1985a) found that concern over water contamination in the communities was highest among younger respondents, women, and person with children living at home. In another study of the public's attitude toward groundwater protection in New Hampshire, Hamilton (1985b) found that respondents from more affluent households, younger and newer residents, and women with children were more concerned about water pollution than their counterparts. Thus, the expected signs of CHILD is positive. Respondent's perception (PERCEPT) is expected to have a negative influence on the WTP. That is, as consumers perceive that their water is of higher quality, they will be less willing to pay for improved quality.

VI. RESULTS

The factors having a significant effect at α=0.10 or lower levels on the magnitude of their *WTP* for obtaining softer water are PERCEPT, CHILD, INCOME, W-BILL, QUALITY, and QUALITY2 (see [Table 2]). The household income has a significantly positive effect on the magnitude of *WTP*. This indicates that consumers with greater annual household income are more willing to pay to obtain better quality water. The larger the amounts of hardness reduction in consumers' water, the larger the WTP for better quality of water. However, the negative sign of QUALITY squared (QUALITY2) indicates that the magnitude of consumers' *WTP* for each additional amount of hardness reduction becomes smaller after it has reached a given level.

[Table 2] Results of the Tobit Analysis of Factors Affecting *WTP*

Variable	Coefficient	t-ratio
CONSTANT	1.28009	0.622
ACT	-0.31348	-0.425
PERCEPT	-1.54471	-3.256***
CHILD	3.10469	3.800***
W-BILL	0.73382	1.863*
INCOME	0.35652	1.675*
QUALITY	0.01758	3.875***
QUALITY2	-0.00002	-3.296***
σ		5.290
Log-Likelihood		-543.306
N		245

Note that the dependent variable is *WTP* for reducing the level of hardness.
*, **, *** denote significance at the 10%, 5%, and 1% level, respectively

The presence of young children in the household also has statistically significant and positive impacts. This suggests that consumers who lived with children under 13 years old have a higher demand for better quality water. Consumer's perception (PERCEPT) has a significantly negative effect on *WTP*. This indicates consumers who perceive that their tap water is of poor quality are willing to pay more to reduce the level of hardness. Meanwhile, the estimated coefficient of W-BILL variable, unlike expectation, has a positive sign. This implies that consumers who paid higher monthly water bill are more likely to be willing to pay for better water quality.

The mean *WTP* for reducing hardness from current levels to below the standard level in the drinking water was estimated at $3.45 per month for each household from the censored tobit analysis, which is about twenty percent of the estimated average monthly water bill ($16.88).

In expanding a contingent valuation sample to general population, this study constructed a range of *WTP* based on the two assumptions for non-respondents: the mean estimated *WTP* assigned to the non-respondents and zero *WTP* assigned to those who did not respond. As shown in [table 3], the aggregate annual *WTP* for the nine communities in southwestern Minnesota that do not meet desired water quality standards was estimated at $1.26 - $2.01 millions.[6]

[Table 3] Individual Annual Mean *WTP* and Aggregate Annual Mean *WTP* Estimates.

Assumptions on Non-respondents	Individual Monthly Mean WTP	Aggregate Annual WTP (N=48,556)
No adjustment estimate[a]	$3.45	$2,010,218
Zero-bid estimate[b]	(1.72)	$1,262,417

[a] Assigned the mean estimated WTP to non-respondents.
[b] Attached a zero WTP for non-respondents.
( ) denoted standard deviation.

VII. CONCLUSION

The study employed a compensating surplus (*CS*) measure to estimate individuals' willingness to pay (*WTP*) for improving the drinking water quality and also analyzed the factors influencing their WTP in southwestern Minnesota. A censored tobit model was appropriately used to estimate individuals *WTP*

[6] The aggregate WTP for the nine communities of southwestern Minnesota, however, may not be sufficient to finance a new treatment system which will keep the level of hardness below the standard. Fifty-five percent of the public water supply systems in southwestern Minnesota are systems that served less than 500 households, and those are likely to have a problem financing improvements in their public water systems. Groundwater systems that serve less than 500 people had an average household cost of $91 in 1992 dollars.

from the survey data which contains a large number of zero values. The results of this study reflect community support for better quality of tap water. The study found that individuals were willing to pay $3.45 per month for reducing the level of hardness to below the standard levels. Significant positive relationships were observed between *WTP* and household income (INCOME), the amounts of hardness reduction (QUALITY), the presence of young children in the household (CHILD), and water bill (W-BILL). Respondent's perception variable had negative impact on *WTP*.

While this study focused on estimating individuals' *CS* and factors affecting their *WTP* in southwestern Minnesota, much more work still remains to be done in estimating individuals' *WTP* for water quality improvement. First, since the levels of water contamination vary across the states by different contaminants, more empirical studies measuring individuals' *CS* for different regions need to be conducted. Second, it is essential to have studies done on the costs of improving water quality. The information on benefits and costs will help policy makers find the socially optimal abatement of water contamination and decide what water policies are needed to provide high quality water and prevent water pollution. Finally, more research is needed to examine more factors influencing individuals' *WTP* for improving their drinking water quality.

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