Journal of Agricultural and Resource Economics 34(3):428–449

The Economic Value of Improved Wastewater Irrigation: A Contingent Valuation Study in Addis Ababa, Ethiopia

Alebel B. Weldesilassie, Oliver Frör, Eline Boelee, and Stephan Dabbert

In developing countries the use of wastewater for irrigation can cause considerable harm to public health and the environment. This paper uses contingent valuation to estimate the economic value of safe use of wastewater for crop production on farms within and around Addis Ababa, Ethiopia. We estimate a surprisingly large welfare gain from policies for safe use of wastewater for irrigation. Our study highlights the potential and the possible pitfalls of using nonmarket valuation techniques as an input into public decision making where traditional resource use interacts with public health and environmental concerns in complex ways.

Key words: contingent valuation, dichotomous choice, Ethiopia, irrigation, wastewater, willingness to pay

Introduction

Wastewater is increasingly being used for irrigation in urban and peri-urban areas as well as in distant downstream rural areas of large cities in developing countries. The practice of wastewater use in crop production is also common in Ethiopia, the second most populous country in Sub-Saharan Africa. It is essential for the livelihoods of many poor farm households, and supplies fresh vegetables at low prices to the nearby cities. Moreover, it serves as a means of supplementary income for small businesses through the vegetable marketing channels. Without adequate safeguards, however, wastewater irrigation can cause serious drawbacks to public health and the environment (Habbari et al., 2000). These positive and negative consequences of wastewater use challenge decision makers to identify practical and affordable strategies for the safe use of wastewater that do not threaten the various livelihoods depending upon it. Addressing this challenge requires identifying, assessing, and evaluating the negative and positive impacts of wastewater use in crop production, based on a comprehensive analysis of economic costs and benefits.

The use of wastewater for irrigation is associated with adverse effects on farmers, public health, and the environment (Hussain et al., 2001, 2002). Farmers are affected by direct contact with contaminated wastewater, and its use in agriculture causes negative externalities both to public health through the consumption of agricultural produce irrigated with wastewater and to the environment by constantly polluting the groundwater and soils (Rashed et al.,

---

Dr. Alebel B. Weldesilassie is research associate, Ethiopian Development Research Institute (EDRI), Addis Ababa, Ethiopia; Dr. Oliver Frör is research assistant, Institute of Economics, especially Environmental Economics, Universität Hohenheim, Stuttgart, Germany; Dr. Eline Boelee is senior researcher, International Water Management Institute, Addis Ababa, Ethiopia; and Dr. Stephan Dabbert is professor, Institute of Farm Management, Universität Hohenheim, Stuttgart, Germany. The authors would like to acknowledge the International Water Management Institute (IWMI) for a substantial contribution in financing this research. We also thank an anonymous reviewer for very helpful comments on an earlier version of the paper.

Review coordinated by Douglas M. Larson.

1995; Bond, 1999). In Ethiopia, both domestic and industrial wastewater is discharged mostly untreated into the nearby rivers, which are used as sources of irrigation water. Hence, smallholder farmers cannot enforce their right to clean water, and have no control over the availability and quality level of the wastewater used for irrigation. Since farmers in and around the cities depend on the use of wastewater for irrigation, adequate policies are needed to ensure farmers can use it safely for crop production without negative externalities to the health of consumers and the environment.

The main objective of this study is therefore to assess the value farmers attach to safe use of wastewater as a basis for devising government policies for regulating wastewater discharge, treatment, and agricultural use. Since wastewater is a nonmarket good, this study employs the contingent valuation method (CVM), which is regularly applied in the field of environmental valuation. Farmers' willingness to pay (WTP) for policies to ensure such a safe use of wastewater for irrigation is used here as an indicator of the welfare gain of those policies. Specifically, we assess two different policy options, as well as a combination of the two, in order to determine their suitability for the assessment of the value of safe wastewater use. Moreover, the study also compares the value of safe wastewater irrigation with the reference case of freshwater irrigation for crop production and assesses comparable policy options for that case.

Though the CVM is in principle applicable in developing countries (Whittington et al., 1990; Whittington, Lauria, and Mu, 1991), only a few published studies have applied this method to forests (Alemu, 1997) and environmental protection (Tegene, 1999) in Ethiopia. To our knowledge, there has been no study published using the CVM to compute the value of irrigation (waste)water in this country. We believe our study is the first of its kind in using this technique for valuing wastewater resources in Ethiopia.

The remainder of the paper is organized as follows. The next section describes the methodological approach of this study and lays out the challenges to applying the CVM in the context of Ethiopia, and briefly describes the study area of our survey. The third section presents the survey design of the actual CVM survey carried out in and around Addis Ababa. This is followed by a section that lays out the empirical model used for data analysis. We then discuss the results from the descriptive and econometric analysis, and estimate the welfare gain from safe use of wastewater for irrigation. The final section presents a summary and conclusions.

Assessment of Welfare Changes Using the CVM

Conventional economic tools for cost-benefit analysis can be used for decision making when some public project leads only to income and price changes of market goods. However, if the project involves changes in nonmarket or public goods (e.g., environmental goods or a reduction of water quality due to wastewater contamination), those methods are not sufficient. Direct valuation methods, like the CVM, have become common practice for assessing the economic value of such public projects, using surveys with respondents from a representative sample of the population affected by that project.[1] The objective of such nonmarket valuation methods is to assess the effects of a public project on the utility of those people affected by the project. In theory, such utility changes can be expressed in monetary terms by the Hicksian compensating variation:

[1] Environmental valuation techniques are classified into two main groups—those relying on revealed preferences (indirect methods) and stated preferences (direct methods). CVM is based on stated preferences. For more discussion on this topic, see Freeman (2003) and Mitchell and Carson (1989).

(1) $$CV_h^{01} = e_h\left(\mathbf{p}^1, z^1, U_h^1\right) - e_h\left(\mathbf{p}^1, z^1, U_h^0\right),$$

where $e_h(\mathbf{p}, z, U_h)$ represents a household's expenditure function given a price vector $\mathbf{p}$, the level z of a public good, and the household's utility level U_h (cf. Ahlheim, 1998, p. 207). The superscript 0 refers to the situation before implementation of the project, and superscript 1 refers to the situation after implementation. Thus, in the case of a utility-increasing project, the compensating variation equals the maximum amount of money that could be extracted from the household after the project implementation to leave the household just as well off as without the project. Consequently, in this case, the compensating variation stands for the household's willingness to pay (WTP) for the project. If prices and incomes remain constant, equation (1) can be expressed as:

(2) $$CV_h^{01} = e_h\left(\mathbf{p}^1, z^0, U_h^0\right) - e_h\left(\mathbf{p}^1, z^1, U_h^0\right),$$

which is also known as the compensating surplus for the environmental change resulting from the project (cf. Freeman, 2003). Equation (2) then can be expressed as the integral of the household's shadow price function of the environmental good:

(3) $$CV_h^{01} = \int_{z^0}^{z^1} \pi_h\left(\mathbf{p}^1, z, U_h^0\right) dz,$$

where the shadow price function $\pi_h(\mathbf{p}, z, U_h) = -\partial e(\mathbf{p}, z, U_h) / \partial z$ is, of course, not observable. In practice, therefore, the utility change resulting from a change in the level of the public good is assessed by asking respondents in CVM interviews their WTP for the proposed public project leading to this change—in our case, a governmental policy resulting in safe use of wastewater for irrigation.

A typical CVM survey entails three operations that offer many possibilities for methodological variation: (*a*) designing a survey questionnaire, (*b*) conducting the survey, and (*c*) analyzing the survey results using econometric techniques. Although there is no standard approach to designing a contingent valuation questionnaire, it should contain the following basic components: a detailed description of the project scenario(s) respondents are asked to value, a description of the payment mechanism for the public good and of the conditions under which it will be provided, the WTP elicitation question, and finally, some debriefing questions regarding respondents' attitudes toward the project and their socioeconomic characteristics. From the responses, one can estimate the average WTP per household, which, by convention, is multiplied by the number of households affected by the project to obtain the overall change in the population's welfare resulting from the project (cf. Mitchell and Carson, 1989).

Although the CVM has become a standard procedure for the assessment of economic benefits resulting from nonmarket goods in developed and industrialized countries, its application in developing countries such as Ethiopia poses a number of challenges (cf. Whittington, 2002). In this study we assess whether the CVM can be employed in Ethiopia as a tool for modern cost-benefit analysis in the context of a rather complex public project. Apart from the requirement that respondents have sufficient cognitive capabilities to understand the public project proposed to them and to envision the benefits it would entail for them (cf. Frör, 2008), the greatest challenge in developing countries is the widespread lack of trust in government and the authorities. Respondents need to perceive that the proposed project will actually lead to the promised improvements and that their responses given during the interviews will influence the chances of the project's implementation. Also, respondents must be certain that their individual financial contributions will be used exclusively for the project. Another serious limitation of the CVM is the often very low level of disposable income, especially of smallholder farmers, which might cause them to restrict their stated WTP based on their low ability to pay. In such a situation, welfare gains would be systematically underestimated (cf. Ahlheim and Lehr, 2008). In this study, we address these issues to scrutinize the applicability of the CVM in the Ethiopian context.

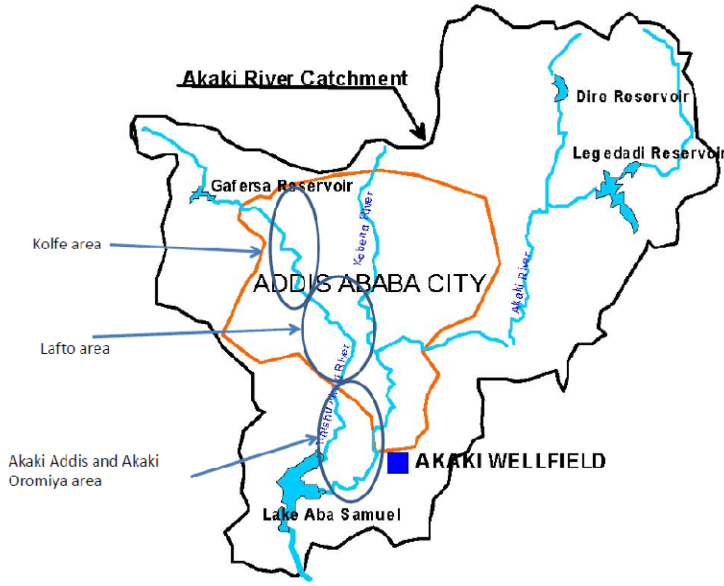
The Empirical CVM Survey

Description of the Study Area

This study was conducted within and around the city of Addis Ababa. The population of the city is currently estimated to be about 5 million, with an annual growth rate of 2.9% (Ethiopian Economic Association, 2005). Environmental sanitation services are very limited in the city. For example, discussions with the city's water and sanitation officials reveal that less than 15% of the population has access to adequate sanitation services and less than 1% of households are connected to sewer lines. Moreover, 35% of the solid waste is disposed of improperly. The existing publicly owned treatment plants treat no more than 1% of the total annual domestic wastewater production of 31 million cubic meters. Industries in the city, constituting about 65% of the country's total, do not have functional wastewater treatment or disposal systems connected with the city's network. These industries produce about 5 million cubic meters of wastewater per year. Almost all the wastewater generated from the city is discharged directly into the rivers or streams flowing within the city without any kind of treatment.

As illustrated in figure 1, these rivers and streams are tributaries of the Akaki River, which is the source of irrigation water for vegetable growers. Since it serves as a sink to the wastes from the city, the river is highly polluted with organic and inorganic substances, and the pollution level, as measured by biochemical oxygen demand (BOD), phosphates, suspended solids (SS), ammonia, and total coliform bacteria, exceeds by a large margin the standard values set by the Ethiopian Environmental Protection Authority (EEPA, 2003). The pollution level varies among the different streams of the river and between the different seasons, being higher in the downstream areas and during dry and short rain seasons.

Farmers are using water from the Akaki River to produce vegetables both for market and for home consumption. The crops grown are the main source of income for the villagers, so their livelihood is directly linked to the untreated wastewater. The share of wastewater farm income ranges up to 97% of total annual household income. The wastewater farms also provide about 61% of the vegetables supplied to Addis Ababa, and many poor traders depend on the vegetable market for their survival (Weldesilassie, Boelee, and Dabbert, 2008). Clearly, the unsafe use of this wastewater for crop production raises specific potential health concerns. The crops grown include leafy and root vegetables, which can be eaten raw, and the irrigation techniques can expose farmers to the contaminated soil and wastewater, especially since they do not wear protective clothing during farming. In addition to the health risk to farmers and consumers, the wastewater also adversely affects the environment by polluting the air and contaminating the soil. Overall, even though the wastewater from the city is an appreciated resource, its use in agriculture must be carefully managed in order to maximize the substantial benefits at minimum health and environmental risks.



Source: Lulu et al., 2005 (wastewater farming areas added by authors).

Figure 1. Addis Ababa catchments and wastewater irrigated areas

A comparison group of farmers using freshwater for irrigation are located about 40 kilometers east of the center of the city. Similar to the wastewater group, these farmers reside within the Awash River basin. Both groups share similar agro-ecological and climatic conditions, produce similar irrigated crops, and are full-time farmers. The freshwater group is in a rural area where drinking water supply and other basic infrastructure are at a lower level compared to their wastewater counterparts. Problems occurring in that area linked to irrigation include health concerns (water-logging can create favorable circumstances for mosquitoes, and thus for malaria) and sustaining productivity of the soil, because improper irrigation practices can lead to erosion.

Data Source and Sampling

This study uses mainly primary cross-sectional data for the year 2006. The main data source is a CVM survey conducted on both wastewater and freshwater farm households within and around Addis Ababa city. A double-bounded dichotomous- or discrete-choice format was used to elicit respondents' WTP for improved or safe use of wastewater for crop production.[2] The survey areas were selected because the farmers are performing irrigated farming activities using irrigation water of varying quality. This enables us to estimate the value of the wastewater and compare it with that of freshwater in irrigation.[3]

[2] There are four types of value elicitation formats: open-ended, bidding game, payment cards, and dichotomous- or discrete-choice CV formats. Each of these elicitation methods has advantages and disadvantages. Interested readers can consult Mitchell and Carson (1989) and Haab and McConnell (2002) for more discussions on these formats.

[3] In this study wastewater is defined as water that contains domestic effluents (excreta, urine, kitchen, bathroom, or other wastewater), water from commercial establishments, hospitals, garages, industrial effluents, storm, and other urban runoff. In contrast, freshwater is defined as spring or river water that is not polluted with domestic, commercial, industrial, or other wastes.

To ensure homogeneity in the grouping of the households, the wastewater farmers were divided into four subgroups depending on the location of the farm areas. These include the Kolfe, Lafto, Akaki-Addis, and Akaki-Oromiya farm areas. We also divided the freshwater farmers into two subgroups depending on the source of irrigation water. These are the Godino farm area, where farmers use diverted water from the Godino river, and the Fultino farm area, where farmers use spring water for irrigation.

The distribution of the number of samples between the freshwater and wastewater areas was determined based on the number and proportion of farm households engaged in irrigated agricultural activities within the respective areas, and the available financial resources. Accordingly, a total of 415 sample farm households were included in our survey, of which 175 were freshwater and 240 were wastewater farm households.

Survey Procedure

Before the main survey, the enumerators were given one day of training, mainly focusing on the technicalities of the questionnaire, and a pilot survey was conducted to check its wording, ordering, and timing, and to determine the starting bids for the dichotomous-choice valuation question in both wastewater and freshwater areas. In the pilot survey, an open-ended elicitation format was employed to determine the starting bids. The maximum WTP obtained from the pilot survey ranged from zero to ETB 100 per year per hectare.[4] We used the most frequently occurring WTP values of ETB 20 and ETB 40 as starting prices to elicit the value to households of safe wastewater use/proper use of irrigation water for crop production. Respondents were divided randomly between these two starting prices. The survey was administered as in-person interviews. During the interviews, efforts were made to collect information from the head of the household. In the event the household head was unavailable, the interview was conducted with a member of the household above the age of 18, who was able to provide reliable information about the household.

In our CV survey, respondents were asked about their current use of irrigation water (wastewater or freshwater), the benefits of using irrigation water, the potential risks from unsafe use of irrigation water, and the advantages of improved (safe) use of irrigation water. Subsequently, government policies were described to respondents which aimed at improving the current system of irrigation water use. These policies would result in both health improvements of farmers and the general population, as well as in preserving soil fertility and quality. Further, the circumstances under which these policies would come into effect were explained to respondents.

Wastewater farmers were given the choice between two government policy options. The first policy option would focus on advantages to the farmers by introducing a safe wastewater irrigation practice. This would be achieved by implementing a training program offered by the local department of agriculture that would increase the problem awareness regarding wastewater irrigation among farmers and would introduce and implement simple, available, and affordable measures to be taken during farm work, harvesting, and consumption of the produce. The second policy option would address the polluters' side by implementing a government program to rigorously enforce existing anti-pollution laws. The concentration of contaminants in effluents and surface water bodies would regularly be monitored and

[4] At the time of survey, $1US = 8.65 Ethiopian Birr (ETB).

unlawful emissions of pollutants by households and firms would be legally prosecuted by the environmental protection authority. Consequently, improved or safe use of wastewater for irrigation was described as the possibility of using wastewater for irrigation with little or no risk to the health of farmers and consumers so that farmers could continue to use the wastewater without any concern that the municipality would eventually ban this practice. For respondents who were using freshwater for irrigation, the policy option presented pursued similar general objectives; however, they were adapted to the specific situation of freshwater farmers. The policy program (including technical elements and advice to the farmers) would minimize health risks to the freshwater farmers and avoid soil erosion, thereby guaranteeing long-term sustainable yields.

Following the scenario description, the payment mechanism was introduced and the WTP question was asked. The payment vehicle was implemented in the form of an annual water charge per hectare to be paid just after the harvest,[5] which would contribute to the costs of the described governmental programs. Respondents were told that in the event the program were implemented, they would actually have to pay such a water charge.

The WTP question was asked in a double-bounded dichotomous-choice format with an open-ended follow-up. In the first question, a respondent was asked whether she was willing to pay a certain specified amount of money (either ETB 20 or 40). If she responded “yes” to the initial bid, the respondent would be asked the same question but with a higher amount of money (either ETB 30 or 50). If the respondent’s response was “no” to the initial bid, a follow-up question with a lower amount was asked (either ETB 15 or 30). This was then followed by an open-ended question in which each respondent was asked to express her maximum WTP for the chosen scenario. Just before asking the WTP question, respondents were told to consider their available budget and were reminded that the annual water charge would decrease their incomes.

Finally, in designing and conducting the questionnaire, attempts were made to minimize biases such as strategic, hypothetical, and compliance biases, which may arise in a CVM survey. In attempting to minimize strategic biases, we explained the purpose of the study explicitly so that the respondent would not strategically respond to influence the provision of the program. This was done both at the beginning of the survey during focus group discussion, and during the main survey by explaining that the primary purpose of the survey is academic. In order to reduce compliance bias, we carefully developed the questionnaire, conducted a pilot survey, and trained the enumerators, who were quite experienced in household and contingent valuation surveys. In addition to the respondents’ WTP, a range of information was collected in our CV survey, including the socioeconomic characteristics of the farm households, the farming system, irrigation water management, asset ownership, income, and expenditures at the household level.

Empirical Model

As noted above, this study employed a dichotomous- or discrete-choice elicitation format in a double-bounded version with an open-ended follow-up question. The double-bounded CV model was first proposed by Hanemann (1984) with the aim of improving the statistical

[5] While some farmers harvest twice per year, there are also some farmers, especially from the downstream wastewater areas, who have only one harvest per year. Thus, the payment vehicle is suggested to be implemented annually just after the harvest to accommodate both situations.

efficiency of single-bounded dichotomous choice.[6] In the double-bounded CV format, the respondent is presented with two bids (as described in the previous section) where the level of the second bid is contingent upon the response to the first bid. If the individual responds "no" to the first bid (denoted by B), the second bid is a lower amount $B_l < B$, while if she responds "yes," it is some higher amount $B_u > B$. Thus, there are four possible outcomes: (*a*) both answers are "yes," i.e., (Yes, Yes); (*b*) a "yes" followed by a "no," i.e. (Yes, No); (*c*) a "no" followed by a "yes," i.e., (No, Yes); and (*d*) both answers are "no," i.e., (No, No). Following Hanemann, Loomis, and Kanninen (1991), the probabilities of these response outcomes can be expressed as:

$$\Pr\{\, Yes / Yes \,\} \equiv \pi^{yy}(B_i, B_{iu}) = 1 - G(B_{iu}; \boldsymbol{\theta}), \tag{4}$$

$$\Pr\{\, Yes / No \,\} \equiv \pi^{yn}(B_i, B_{iu}) = G(B_{iu}; \boldsymbol{\theta}) - G(B_i; \boldsymbol{\theta}), \tag{5}$$

$$\Pr\{\, No / Yes \,\} \equiv \pi^{ny}(B_i, B_{il}) = G(B_i; \boldsymbol{\theta}) - G(B_{il}; \boldsymbol{\theta}), \tag{6}$$

$$\Pr\{\, No / No \,\} \equiv \pi^{nn}(B_i, B_{il}) = G(B_{il}; \boldsymbol{\theta}), \tag{7}$$

where $G(B_i; \boldsymbol{\theta})$ denotes the cumulative probability distribution (e.g., normal or logistic) of the bid with the parameter vector $\boldsymbol{\theta}$. Given a sample of N respondents, the corresponding log-likelihood function for the responses to the double-bounded CV survey is written as:

$$\ln L(\boldsymbol{\theta}) = \sum_{i=1}^{N} \left\{ \begin{array}{l} d_i^{yy} \ln\left[1 - G(B_{iu}; \boldsymbol{\theta})\right] + d_i^{yn} \ln\left[G(B_{iu}; \boldsymbol{\theta}) - G(B_i; \boldsymbol{\theta})\right] \\ + d_i^{ny} \ln\left[G(B_i; \boldsymbol{\theta}) - G(B_{il}; \boldsymbol{\theta})\right] + d_i^{nn} \ln G(B_{il}; \boldsymbol{\theta}) \end{array} \right\}, \tag{8}$$

where $d_i^{yy} = 1$ if the *i*th response is (Yes, Yes), and 0 otherwise, and the other response dummies d_i^{yn}, d_i^{ny}, and d_i^{nn} are defined similarly. The maximum-likelihood (ML) estimator for the double-bounded model $\hat{\boldsymbol{\theta}}$ is the solution to the first-order condition,

$$\frac{\partial \ln L(\hat{\boldsymbol{\theta}})}{\partial \boldsymbol{\theta}} = 0,$$

and can be readily estimated with statistical software packages such as STATA or LIMDEP.

However, a prerequisite for using this empirical model for double-bounded responses, also called the "interval-data model" (cf. Alberini, 1995), is that respondents' preferences regarding the proposed public good remain the same when answering to the first and the second bids. Technically, the error terms of the responses to the first and the second bids are assumed to be perfectly correlated, i.e., the correlation $\rho = 1$. While this is a plausible and desirable assumption from a theoretical point of view, it is not a trivial one. It has been shown repeatedly in the literature that the second answer may be influenced by the answer to the first bid, where this first bid serves as an anchor (cf. Cameron and Quiggin, 1994; DeShazo, 2002; Aprahamian, Chanel, and Luchini, 2007; Ready, Buzby, and Hu, 1996). In such a situation, it would be more realistic, and thus appropriate, to model the double-bounded responses by means of a bivariate probit model which allows for ρ being less than one. The response probabilities to

[6] The double-bounded CV elicitation format has the advantage of improving statistical efficiency over the single-bounded format in at least three ways. First, yes-no and no-yes answers to the initial bid clarify bounds on the unobservable true WTP. Second, even though yes-yes or no-no responses do not bound the actual WTP, additional questions will sharpen the true WTP, leading to efficiency gains. Third, more questions in double-bounded elicitation lead to a larger number of responses so that a given function can be fitted with more observations (Haab and McConnell, 2002).

the first and second bids then can be expressed by making use of the bivariate standard normal distribution $\Phi(B_{i1}, B_{i2}, \boldsymbol{\theta}_1, \boldsymbol{\theta}_2, \rho)$, with B_{i1} and B_{i2} being the first and second bid, respectively, and ρ denoting the correlation between the error terms (cf. Cameron and Quiggin, 1994; Alberini, 1995). The higher the correlations between the two error terms, the more consistent are the responses to the consecutive bids, i.e., the less respondents anchor their response to the second bid on their response to the first. Consequently, the interval-data model is a special case of the more general bivariate model with $\boldsymbol{\theta}_1 = \boldsymbol{\theta}_2$, equal variances, and $\rho = 1$.

In a Monte-Carlo simulation study, Alberini (1995) computes welfare estimates using an interval-data and a bivariate probit model in comparison and finds that the results of the interval-data model are rather robust for values of ρ around 0.9 (indicating imperfect correlation between the responses to the first and second bids) in the case when covariates are used. In models without covariates, the interval-data model is still astonishingly robust even with values of ρ being much lower. However, since the interval-data model yields smaller variances of the parameter estimates, and hence is statistically more efficient, it is suggested to apply both model specifications in parallel and select the results from the interval-data model if ρ has been found to be sufficiently large. We follow this suggestion here, and it will constitute an important criterion for judging the validity of our empirical results.

Results and Discussion

Basic Characteristics of the Existing Irrigation Systems

Among all households interviewed, 14% are female-headed and the remainder are male-headed households. In the study area, the average household head is 47.6 years old if female and 42.2 years old if male. Of all respondents, 72% are heads of the household, and the rest are other household members above the age of 18 years. The education levels of the household heads range from unable to read and write to college graduate. About 77% received at most four years of formal schooling, while approximately 13% attended second-cycle primary school (5–8 years of formal schooling) and 10% attended at least nine years of formal schooling. About 75% of all the respondents are married, and the average family size in the study area is 5.3 persons. The average family size of a wastewater farm household is 5.6, of whom 3.6 members are of productive age (15–64 years of age); the remainder are dependents (below 15 and above 65 years old). Freshwater farm households have 4.9 members, of whom 2.9 are of productive age.

Irrigated agricultural activity is the main source of income for the farm households. The average irrigator has 0.72 hectares of irrigated farmland, which varies between the two groups of farmers (0.4 hectares for the average wastewater farmer and 1.16 hectares for the freshwater farmer). Wastewater farm income accounts for 62% of annual total household income, ranging from 27% to 97%. A freshwater irrigator receives about 67.6% of his or her total annual income from irrigated agriculture. This highlights the importance of irrigated farming to the livelihood of the farmers. Other sources of income, in order of importance, are off-farm income, livestock income, and remittances.

Farmers use irrigation water for multiple purposes. Of the total sample, at least 70% of the farm households use irrigation water for domestic use in addition to crop production. Comparing the two farm groups, nearly 49% of the wastewater farmers and all of the freshwater farmers use irrigation water for both growing crops and domestic purposes. Domestic uses of

Table 1. Farmers' Perceptions Regarding Benefits and Health Effects of Irrigation Water

Description	Name of Wastewater Irrigation Area (%)				Waste-water Farmers (%)	Fresh-water Farmers (%)	Total Sample (%)
	Akaki-Oromiya	Akaki Addis	Lafto	Kolfe			
Do you benefit from irrigation water?							
Yes, a lot	95.9	71.4	95.7	82.5	88.0	80.4	84.8
Yes, somewhat	2.0	21.4	4.3	15.0	9.2	18.0	13.0
Too little	2.1	7.2	0.0	2.5	2.9	1.7	2.4
Health risks of irrigation water:							
Affect producers' health (Yes)	37.8	21.4	0.0	0.0	20.6	31.4	25.2
Affect consumers' health (Yes)	21.4	16.4	2.2	0.0	13.0	3.4	9.0

Source: Survey results.

wastewater include bathing, laundry, livestock drinking, and washing of vehicles, bags, and other items. However, this use varies among the different locations within the wastewater farm areas. The upstream and middle-stream farmers use the wastewater only for irrigation purposes, whereas the downstream farmers use it for all the purposes identified above.

Our study shows that even if irrigation water poses potential health risks to both farmers and consumers, farmers perceive that its benefits outweigh the health hazards. Of the total sample, nearly 85% state that they benefited a lot from the use of irrigation water. About 88% of the wastewater farmers report that it is their only means of survival. Income from wastewater farming was the largest share in the total annual income of the farm households. Only 3% of the wastewater farmers indicate that they benefited only a little, though they still work on the farm for lack of livelihood alternatives. On the other hand, about 21% of the wastewater farmers and 31% of the freshwater farmers perceive that their health is affected by the irrigation water. This difference is mainly because the freshwater farmers are affected by malaria due to the higher prevalence of mosquitoes in their surroundings.

As shown in table 1, the wastewater farmers also accept the notion that working on wastewater farm areas and consumption of vegetables produced using the wastewater has health risks, which is as expected. This perception differs between the downstream (Akaki-Oromiya and Akaki-Addis) and the middle (Lafto area) and upstream (Kolfe) farm areas because of variation in the pollution level, which is higher in the downstream areas of the Akaki River. As anticipated, the perception of risk is stronger in downstream areas than in the middle and upstream areas.

Table 2 confirms that the wastewater causes a bad odor in the surrounding area, and this effect is worse in the downstream areas as compared to the middle and upstream areas due to the difference in pollution levels. Obviously, the current use of wastewater for vegetable production is unsafe for the health of both farmers and consumers. Wastewater farmers are more likely than freshwater farmers to suffer from parasitic infection diseases (Weldesilassie et al., 2008). The wastewater is also polluted with chemicals and bacteria that can cause diseases for farmers. The vegetables produced by wastewater contain metals that potentially cause illness for consumers (Fisseha, 2002). Because farmers use furrow irrigation methods with bare feet and carry out weeding and harvesting with their bare hands, they are exposed to the wastewater and the contaminated soils. Moreover, almost all farmers and their family

Table 2. Wastewater Farmers' Perceptions Regarding Air Pollution

Description	Overall Wastewater Areas (%)	Name of Wastewater Farm Area (%)			
		Akaki-Oromiya	Akaki-Addis	Lafto	Kolfe
Do you agree that the wastewater causes a bad odor in the environment?					
Agree strongly	44.8	92.0	29.0	2.2	0.0
Agree somewhat	17.2	7.0	34.6	19.6	15.0
Do not agree	36.8	1.0	34.6	73.9	85.0

Source: Survey results.

Table 3. Preferred Policy Options for Safe Use of Wastewater for Crop Production

Options	Wastewater Area (%)	Name of Wastewater Farm Area (%)			
		Akaki-Oromiya	Akaki-Addis	Lafto	Kolfe
Enforcing polluters	39.8	26.8	60.7	67.4	10.0
Awareness creation	20.9	1.0	14.3	10.9	90.0
Both enforcing polluters and awareness creation	37.7	72.2	25.0	13.0	0.0

Source: Survey results.

members consume raw vegetables directly from their fields without any treatment. This situation needs to be improved so that farmers can use the wastewater for vegetable production safely or with minimal health risks to their families and to consumers.

Improving the Existing Irrigation Systems

As described above, wastewater farmers in the survey were presented with different policy options to achieve the goal of safe use of wastewater irrigation from which they could choose their preferred option (either one of the two, or both). This procedure was used to ensure respondents only value those options that they deem credible and feasible. Among the different options presented, the second option, "forcing emitters to comply with the existing environmental regulations," is the most preferred. Nearly 40% of the wastewater farmers voted for implementing only this option. About 21% of the wastewater farmers, however, preferred "awareness promotion on the methods of safe use of wastewater" as an option to improve the situation. This includes awareness about improved irrigation management techniques, types of crops grown, safe consumption of raw vegetables, quality protection during harvesting and marketing, and provision of protective dress at affordable prices. Finally, as shown in table 3, about 38% of the wastewater farmers prefer that both options be implemented jointly (i.e., regulation enforcement and awareness promotion).

Our survey reveals that 98% of freshwater irrigators are willing to contribute to improve the existing irrigation practice to minimize the malaria risk and soil erosion, while 90% of wastewater farmers are willing to contribute to a program designed to improve the existing situation aiming at safe wastewater irrigation. Only 7.5% of the wastewater farmers responded negatively to the improvement program. Three main reasons are provided by this latter group.

Table 4. Detailed Discrete Responses to the Double-Bounded Valuation Question (wastewater and freshwater areas combined)

Bid		First Bid (%)		Second Bid (%)	
First	Second	Yes	No	Yes	No
20	15	—	20.4	24.5	75.5
20	30	79.6	—	72.4	27.6
40	30	—	50.7	43.1	56.9
40	50	49.3	—	63.8	36.2

Source: Survey results.

First, the farmers state that they are paying land tax to the government, and therefore the government should protect the environment. Hence, this group of respondents might be classified as protest respondents (cf. Meyerhoff and Liebe, 2006). Second, since they are already using the wastewater properly and have not experienced any noticeable adverse effects, the program is not perceived to be relevant. Third, some wastewater farmers state that the issue is not of great concern to them because they perceive little damage to the community or the environment occurring as a result of wastewater use. Freshwater farmers who responded negatively to the government program also perceive the program as irrelevant since, from their perspective, they are using the irrigation water properly. The vast majority of the wastewater farmers (75%) who are willing to contribute to the improvement program suggest the contribution should be made in the form of an annual tax or water charge once just after harvest time, and should depend on land size. Accordingly, this payment scheme is used in our valuation study.

Willingness to Pay for Wastewater and Freshwater

In the WTP elicitation questions, the initial bids are ETB 20 and ETB 40 per hectare per year, randomly assigned to all respondents. As mentioned above, in the follow-up question, if a respondent said "yes" to an initial bid of ETB 20, the bid is increased to ETB 30, and if she said "no," it is reduced to ETB 15. If ETB 40 is used as the initial bid, the bid in the follow-up question is increased to ETB 50 for a "yes" response and decreased to ETB 30 for a "no" response. Table 4 summarizes the bids and responses to the double-bounded questions. For each initial bid offered, there are two possible responses. The first row for the initial bid of ETB 20 summarizes the "no" responses to that bid. The second row summarizes the "yes" response to the first bid, etc. For example, for the initial bid of ETB 20, 20.4% respond "no" and 79.6% respond "yes." Of the 20.4% "no" responses to the initial bid of ETB 20, the follow-up bid of ETB 15 results in 24.5% "yes" responses and 75.5% "no" responses.

Econometric Results for Wastewater and Freshwater Farmers

Out of our sample total of 415 farmers, 408 responded to our valuation questions. However, due to item nonresponses for some socioeconomic variables, only 372 households were included in the final econometric analysis, 223 of whom are wastewater farmers and 149 use only freshwater for irrigation. Following the earlier discussion on econometric specifications, we estimated three different models: a standard probit model was estimated using only the responses to the initial bid (single-bounded dichotomous-choice, SBDC); the full responses to the double-bounded questions were estimated using a bivariate probit (BV-DBDC) and the interval-data model (ID-DBDC). In both the SBDC and BV-DBDC, the dependent variable is a binary response to the valuation question, in which respondents are given a value of one if they respond "yes" and zero if they respond "no" to the first bid. In the double-bounded model, we have another dependent variable where respondents are given a value of one if they respond "yes" to the second bid and zero if they say "no." The following discussion is mainly based on the interval-data model, with regression results shown in table 5.[7]

As observed from table 5, for the wastewater farm area the number of years with irrigation experience, education, total annual yield value, and the kind of policy option significantly affect the probability of "yes" responses to the initial bid. Further, the location of the farm significantly influenced WTP. As expected, it was found that the longer the experience of farmers with wastewater irrigation, the higher their WTP for an improvement policy. This effect is plausible since those farmers are more familiar with wastewater being a valuable resource for their agricultural production and also know of its risks. This variable is not significant in the freshwater farm areas where irrigation is only a recent phenomenon. Moreover, the less educated households seem to care less for such policies, as indicated by a significantly negative relationship of the education category "maximum of four years of schooling" with WTP. It can be hypothesized that these households have difficulties in perceiving the environmental and health problems arising specifically from the contaminated irrigation water, and consequently consider the improvement policy less useful.

In contrast, as expected, income (total annual yield value) is positive and significant, implying that those farm households who obtained higher yields benefit more from an improved and safe wastewater irrigation system, and therefore state a higher WTP. It is quite unexpected, however, that in the ID-DBDC model the kind of policy option to make wastewater irrigation safer has a significant effect on WTP. Respondents appear to be less willing to contribute to the "regulation enforcement" policy than to the "awareness creation" policy. This may be due to the notion that it is essentially the government's task and responsibility to enforce existing regulations and prosecute violators. However, this variable is not significant in either the SBDC or the BV-DBDC models.

Use of irrigation water for purposes other than crop production, and households' perception of the benefits they receive from irrigation water have no significant effect in the ID-DBDC model, though both variables had a positive sign. Perceived benefits from irrigation water are significantly positive only in the BV-DBDC model for wastewater irrigators but not for freshwater irrigation. This finding implies that, as expected, wastewater farmers attach a positive value to the wastewater. The variable for the water extraction method has no significant effect on the probability of a positive response to the first bid. Therefore, other factors remaining the same, the farmers' WTP for the improvement program is not related to the way the water is extracted from its source. Consequently, to improve the safety of wastewater crop production, it is possible to introduce water saving and improved irrigation methods such as drip irrigation without affecting farmers' utility from irrigation.

[7] It was tested whether the responses from the wastewater farmers and freshwater farmers can be pooled. However, the test of poolability was rejected at the 1% level of significance. In table 5, the results from the BV-DBDC model are missing for the freshwater farmers due to the failure of the model to converge. Thus, we limit our presentation to a comparison of the SBDC and the interval-data model in this case.

Table 5. Regression Results for Wastewater and Freshwater Farm Households

	Wastewater Farm Area			Freshwater Farm Area	
Variable	SBDC	BV-DBDC	ID-DBDC	SBDC	ID-DBDC
Bid	−0.089***	−0.099***	0.394***	−0.089***	0.293**
Use of irrigation water (1 = only for irrigation; 0 = all purpose)	0.179	−0.088	3.521		
Benefited from irrigation? (1 = yes; 0 = no)	0.614	0.598*	1.956	−0.126	0.153
Position of respondent in household (1 = head; 0 = otherwise)	−0.198	−0.113	−1.729	−0.147	−0.640
Marital status of respondent (1 = married; 0 = otherwise)	0.458	0.417	1.547	0.281	1.689
Gender of head (1 = male; 0 = female)	−0.721	−0.665	−2.436		−12.047***
Dummy for remittance (1 = yes; 0 = no)	−1.086**	−1.274***	−5.044	0.092	−0.948
Years of irrigation experience	0.049***	0.058***	0.221***	−0.051**	−0.337***
Water shortage problem (1 = yes; 0 = no)	0.334	0.456	0.324	−0.961***	−5.386***
Land shortage problem (1 = yes; 0 = no)	0.604	0.460	1.228		−3.301
Membership in water users association (1 = yes; 0 = no)	0.036	−0.051	−3.925		
Family head completed 5–8 years schooling (1 = yes; 0 = no)	−0.373	−0.260	−0.232	−1.286**	−9.035**
Family head attained maximum of 4 years schooling (1 = yes; 0 = no)	−1.025**	−0.767*	−5.340**	−0.358	−5.030
Number of productive age family members	0.126	0.174**	0.181	−0.214**	−1.265**
Number of dependents	0.105	0.119	0.441	0.136	1.308**
Annual total yield value in ETB	0.0005	0.0005	0.001***	0.0001*	0.0003***
Total value of household assets	−0.0005	−0.0007	−0.0003	−0.001***	−0.006**
Total value of livestock assets	0.0002	0.00003	0.0002	0.0006*	0.0003
Annual off-farm income in ETB	−0.0005	−0.0005	0.001	0.0005**	0.0002**
Dummy for Kolfe farm area (1 = yes; 0 = no)	0.292	1.117	2.269		
Dummy for Lafto farm area (1 = yes; 0 = no)	1.497*	2.147***	11.896***		
Dummy for Akaki-Addis farm area (1 = yes; 0 = no)	1.325*	1.687**	6.472*		
Dummy for Godino farm area (1 = yes; 0 = no)				−0.945	−9.065***
Affects health of producer (1 = yes; 0 = no)	0.030	0.114	0.350	0.447	2.274
Age of family head	−0.011	−0.011	0.269	0.029	0.0327
Age squared	0.0004	0.0004	−0.002	−0.0005	−0.0007
Kind of program (1 = awareness creation on safe use of wastewater; 2 = enforce polluters; 3 = both 1 and 2)	−0.161	−0.234	−1.471*		
Constant	−97.69***	−113.8***	−427.22***	105.71	722.54***
Rho ρ		0.88***			
Number of observations	223	223	223	146	149
Wald χ^2	87.48***	133.23**	105.60***	45.70***	238.94***
Pseudo log likelihood	−87.54	−186.749	−354.671	−69.37	−235.32
McFadden's pseudo R^2	0.3035	—	—	0.3031	—

Note: Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.
Source: Survey results.

The dummy variables for location have significant effects, and their signs in the separate regressions are as expected. Farmers working on upstream and middle-stream of the wastewater farm areas have a higher WTP than those downstream. This is explained by the fact that the middle and upstream farmers harvest at least twice per year and obtain higher annual yield value than the downstream farmers, the majority of whom are producing only one harvest per year due to water-logging problems on their farms.

Farmers' perceptions of the health effect of irrigation are insignificant in the model, revealing that farmers attach a positive value to the wastewater regardless of the health risks, perhaps because its use as a means of livelihood outweighs the perceived risks.

In our fitted bivariate probit model for the wastewater farm area, the estimate of the coefficient of correlation of error terms ρ of the double-bounded model is 0.88 and statistically significant at the 1% significance level. This confirms the theoretical assumption that there is a strong positive linear relationship between the random components of the responses to the initial bid and the second bid. The estimate of 0.88 is rather close to perfect correlation, and consequently indicates respondents largely drew their responses to the first and the second bid from the same underlying WTP. Further, this high value of ρ validates our selection of the interval-data model as opposed to the more general bivariate probit model, since the bias of parameter estimates is only small at such a value of ρ while the statistical efficiency of the interval-data model is much higher (cf. Alberini, 1995).

Single- and Double-Bounded Models: A Comparison

The decision of whether to use the single-bounded or the double-bounded responses to the WTP elicitation question can be based on the comparison of the statistical efficiency of the BV-DBDC and SBDC models, and thus on the comparison of the precision of the estimates of the intercept term and coefficient of bids (Hanemann, Loomis, and Kanninen, 1991). The variance-covariance matrices for the ML estimates of the constant and coefficient of the initial bid of the SBDC and the BV-DBDC for the improvement program of the existing irrigation system are estimated as follows:[8]

$$\text{(9)} \qquad \text{SBDC}: \begin{pmatrix} 496.944 & 0.00635 \\ 0.00635 & 0.00008 \end{pmatrix} \quad \text{and} \quad \text{BV-DBDC}: \begin{pmatrix} 413.556 & -0.00143 \\ -0.00143 & 0.000047 \end{pmatrix}.$$

As expected, the estimated variance of the coefficient of the initial bid is smaller by almost half in the double-bounded as compared to the single-bounded specification. Also, the variance for the constant term is smaller in the double-bounded model. The covariance term is smaller by a factor of about 4.5, which translates into higher *t*-statistics for the BV-DBDC. In addition, the measure for the goodness of fit, the chi-squared statistic, is substantially higher for the BV-DBDC. It is 133.23 for the DB model but only 87.48 for the SBDC specification. This comparison underscores our decision to use the full responses to the double-bounded dichotomous-choice elicitation question due to the large gain in statistical efficiency as compared to using only the responses to the first bid. The high estimate for ρ in the BV-DBDC reveals that the anchoring effect often found in double-bounded DC data (cf. Herriges and Shogren, 1996) is negligible in our data set.

[8] Due to the different structure of the ID-DBDC model, this comparison can be done only for the SBDC and BV-DBDC models.

Table 6. Mean WTP, by Farm Area (ETB/ha/year)

	Mean WTP			
Description	SBDC	BV-DBDC	Open-Ended Follow-up	ID-DBDC
Total sample	39.57	39.10	35.35	39.72
Wastewater area	37.87	37.15	36.30	39.88
Freshwater area	41.89	41.91	34.08	39.50

Source: Survey results.

Table 7. Share of Farmers' WTP from Annual Net Farm Income per Hectare

Description	Annual Average Net Farm Income (ETB/ha) **[A]**	SBDC		BV-DBDC		Max. WTP from Open-Ended Follow-up		ID-DBDC	
		Mean WTP **[B]**	% of Net Farm Income **[C=100∗B/A]**	Mean WTP **[D]**	% of Net Farm Income **[E=100∗D/A]**	Mean WTP **[F]**	% of Net Farm Income **[G=100∗F/A]**	Mean WTP **[H]**	% of Net Farm Income **[I=100∗H/A]**
Total sample	10,660.73	39.57	0.37	39.1	0.37	35.35	0.33	39.72	0.37
Wastewater	13,995.38	37.87	0.27	37.15	0.27	36.30	0.26	39.88	0.28
Freshwater	6,087.38	41.89	0.69	41.91	0.69	34.08	0.56	39.50	0.65

Sources: Weldesilassie, Boelee, and Dabbert (2008); survey results.

Mean and Total WTP

The ultimate aim of fitting a statistical model to CV responses is to derive a summary measure of the WTP distribution (mean WTP) and to estimate the welfare change to society due to the improvement program (Hanemann, Loomis, and Kanninen, 1991).

The WTP results, in ETB per ha per year, were estimated assuming a linear random utility model (Haab and McConnell, 2002) and are reported in table 6. The result shows that mean WTP from the single-bounded model is ETB 39.57 per hectare per year, and for the bivariate-probit model is 39.10, which is only marginally smaller. The mean WTP from the interval-data model is 39.72, which is also similar to the mean WTP from both models, and thus in line with Alberini (1995). As expected, the mean WTP from the open-ended follow-up question (ETB 35.35) is slightly smaller than for the other models since respondents have a tendency to state their maximum WTP in close vicinity to the highest accepted bid. The mean WTP of wastewater farmers is higher than that of the freshwater farmers based on the open-ended and interval models, though this difference is not significant.

From an economic policy perspective, this mean WTP indicates that an average farm household is willing to pay 0.37% of its annual farm income for the improvement program (see table 7). Comparing the results from the two groups of farmers, an average wastewater farm household is willing to pay 0.27% or 0.28% of its annual average farm income per hectare, based on BV-DBDC and the interval-data mean WTP, respectively. The corresponding figures for the average freshwater irrigator household are 0.69% and 0.65% of its annual farm income per hectare. This means that taking the average farm land size in the wastewater area (0.4 ha) and average annual farm income of ETB 3,146.20 (Weldesilassie, Boelee, and

Table 8. Total WTP for Safe Use of Irrigation Water

	SBDC			BV-DBDC		Max. WTP from Open-Ended Follow-up		ID-DBDC	
Description	Total Farm Land Under Irrigation (hectares) **[A]**	Mean WTP **[B]**	Total WTP **[C=A*B]**	Mean WTP **[D]**	Total WTP **[E=A*D]**	Mean WTP **[F]**	Total WTP **[G=A*F]**	Mean WTP **[H]**	Total WTP **[I=A*H]**
Total sample	2,340.5	39.57	92,613.59	39.10	91,513.55	35.35	82,736.68	39.72	92,964.66
Wastewater	1,239.0	37.87	46,920.93	37.15	46,028.85	36.30	44,979.42	39.88	49,411.32
Freshwater	1,082.5	41.89	45,345.93	41.91	45,367.58	34.08	36,886.19	39.50	42,758.75

Source: Survey results.

Dabbert, 2008), the average wastewater farm household is willing to pay 0.5% of its annual farm income per year for the improvement program. Given this low share of WTP as compared to income, we deduce that in our study no systematic underestimation of benefits resulting from restrictive budgets did occur.

The total WTP (aggregate benefit) is the total economic benefit that can be obtained from the hypothetical improvement program for the safe use of irrigation water in agriculture. Mitchell and Carson (1989) discuss a number of issues that should be considered in benefit aggregation. These are population choice, sampling frame, sample nonresponse, and sample selection biases.

Accordingly, the potential individuals who would benefit from the improved program in our study areas are the farm populations. The farmers are those who receive the direct benefit from the improved service and pay for the services. Therefore, we estimated the total benefit for the total farm population from which our sample is drawn using information on the total farm lands used for irrigated agricultural activities, obtained from the local agriculture offices. Unit nonresponse is not a problem in our survey as all farm households who were asked for an interview agreed to participate. Still, item nonresponse was observed, since out of the 415 farm households who filled out the questionnaire, only 408 completed the entire questionnaire; i.e., 1.7% of the farm households did not respond to the valuation question even if they answered the remainder of our questions. This figure is very low compared to what is generally expected from any CV survey, and would not result in selection bias if excluded from estimation (Mitchell and Carson, 1989). Of the 408 farm households who responded to all questions, 15 responded zero WTP. We asked a follow-up question as to why the respondent was not willing to pay any amount so as to identify whether such responses are protest zeros or true zeros. None of the responses were found to be protest zeros, as the respondents explained that they cannot afford to pay any amount (Freeman, 2003). The mean WTP from table 7 was used to estimate the welfare gain for the farm population.

As shown in table 8, column I, the total WTP of the wastewater and freshwater farm population in the study area for the policy programs investigated is estimated at ETB 92,964.66 per year based on the interval-data mean WTP, and ETB 91,513.55 (column E) based on the bivariate probit model. From the open-ended mean WTP, the total welfare gain is estimated at ETB 82,736.68 (column G). The highest welfare gain is observed based on the estimate of the interval-data model. Note that we found ρ is significant and rather high in the bivariate probit model estimation, which implies interval-data estimation is more efficient (Alberini, 1995). As discussed above, the lowest welfare gain is obtained from the open-ended mean WTP. The table also shows the welfare gains to the wastewater farm community from improved use of wastewater for irrigation. It ranges from ETB 44,979.42 to 49,411.32 per year based on the open-ended and interval-data estimations, respectively. These findings can be compared with the welfare gain from the improvement program in the freshwater area shown in table 8, which is lower in all estimations.

Validity and Robustness of Results

The validity and robustness of the results are checked internally in light of the standard economic theory and by making use of specific indicators mentioned earlier.[9] We have already explained that the design and implementation of the survey was conducted to minimize the biases or problems that can arise when using CV methods, including scenario specification, elicitation questions, and payment vehicles, as well as in procedural matters including sample design and analysis of the data. Therefore, our CV study passes the content validity assessment. We also assess the robustness of our study based on construct validity in which we test whether the important explanatory variables are in line with what economic theory suggests (Mitchell and Carson, 1989). In the context of our study, we can hypothesize that the farm household's WTP increases with higher income from farming. As shown in the regression result, income, which indicates the household's ability to pay, increases the probability that the respondent will accept the offered bids, as well as the willingness to pay. The share of the amount of money farm households are willing to pay from their total household income, about 0.37% on average, is also quite reasonable (cf. Ahlheim, Frör, and Sinphurmsukskul, 2006). Moreover, consistent with the theory of demand, the coefficients of the first and second bid are negative and significant at the 1% probability level, indicating that a higher bid decreases the probability of accepting the offered bid.

As detailed previously, the application of the CVM in the socioeconomic setting of developing countries poses particular challenges. These may arise especially from limited cognitive capabilities, lack of trust in government, and low monetary incomes. We address these issues and conclude that the CVM is in principle applicable in the context of our survey population.

First, all household heads in our sample live in the vicinity of Addis-Ababa and received a minimum of formal education. However, the understandability of the relevance of the problem with wastewater irrigation and the policy options to reduce these were tested within various rounds of focus groups. This process allowed for the design and formulation of the questionnaire and valuation scenario as well as the payment scheme that is adapted to the cognitive capabilities of the survey population. Here, it was helpful that farmers have had a long-time experience with wastewater irrigation and are very familiar with its benefits and problems.

Second, it was found in our survey that, while the majority of respondents chose a combination of policy options 1 and 2 (awareness creation in combination with enforcement of existing regulations), WTP was significantly lower for the latter. From this finding we conclude that respondents are sensitive to the particular policy option presented in the scenario, and thus reflect on their willingness to contribute to such policies in a rather differentiated way.

---

[9] The robustness and validity of CV studies can be checked in different ways including criterion validity, convergent validity, construct validity, and content validity. Criterion and convergent validity have problems in relation to sampling variability and the source of discrepancy, which could be either from stated or revealed preference or both, respectively (Freeman, 2003).

Third, the shares of stated WTP to the households' incomes were found to be sufficiently small (as is typical in developed countries) to conclude that their WTP is not restricted by their ability to pay, and therefore not downward biased. This interpretation is underscored by the finding that WTP is not negatively influenced by the number of dependents, which would be a typical indicator for tight family budgets.

From these indicators, we conclude that the prerequisites for employing the CVM as an economic method to value the social benefit of environmental or nonmarket goods in the socioeconomic context of urban and peri-urban farmers in Ethiopia are satisfied.

Summary and Conclusions

This paper has examined the resource value of the safe (improved) use of wastewater in crop production within and around Addis Ababa, Ethiopia, based on farmers' willingness to pay. The potential welfare gain from a government policy to provide safe wastewater use was estimated employing the contingent valuation method (CVM). We also compared the value of the improvement program of wastewater with a comparable program for the improvement of freshwater use in irrigation. The double-bounded dichotomous-choice elicitation question format was applied to elicit farmers' value of the improvement program. In-person interviews were conducted at 415 farm households operating irrigation in wastewater and freshwater areas. Responses were analyzed using descriptive and econometric techniques.

The descriptive results indicate that wastewater is used for multiple purposes including domestic uses and irrigation. For the majority of wastewater farm households, the wastewater is the only means of survival, and the average income from wastewater farming accounts for 62% of total annual household income, with this value ranging from a low of 27% to a high of 97%. Accordingly, 88% of the wastewater farm households report that they benefit from the wastewater. Yet, farmers also perceive that the wastewater poses health risks for their families and for consumers. Likewise, they see negative externalities to the environment as it pollutes the soil and causes foul odors in the surrounding community. These negative externalities are more pronounced in the downstream wastewater farm areas where the pollution levels are higher and the benefits from wastewater are relatively lower.

Among the options provided to the wastewater farmers for improving the existing situation, "enforcing existing environmental regulations and prosecuting violators" is the most preferred option, with nearly 40% of the farmers selecting this choice. "Awareness promotion on safe use of wastewater" is another option selected by the farmers to improve the situation. This includes technical advice and training on improved irrigation methods, crop selection, safe consumption of vegetables, and quality protection, as well as access to protective clothing at affordable prices. Farm households are willing to contribute to the improvement programs proposed to them, and the payment vehicle could be made in the form of a mandatory annual tax just after harvest time, depending on the land size.

The WTP of farm households and its determinants were analyzed under different econometric specifications: the single-bounded probit, the double-bounded bivariate probit, and interval-data models. Comparing these specifications, we obtain robust results. The results show that, as expected, the number of years with irrigation experience, education, total annual yield value, and the kind of policy option significantly affect wastewater farmers' WTP. Further, the location of the farm significantly influenced WTP. Since we found that the coefficient of correlation of the error terms of the double-bounded bivariate probit model is close to 1 (almost perfect correlation) and statistically significant at the 1% significance level, we suggest using the interval-data model to achieve more efficient estimates of the WTP for the improvement program.

From our models, we conclude that wastewater farmers tend to be willing to pay more than freshwater farmers for an improvement policy. Additionally, as expected, wastewater farmers who stated they benefited from the wastewater are willing to pay more than those who did not perceive much benefit. The results also indicate that the middle and upstream farmers are willing to pay more than farmers in the downstream areas. This could be due to the water-logging problem in the downstream areas that limits the downstream users to only one harvest per year.

The variation in pollution levels is also reflected in farmers' responses to the foul environmental odor caused by the wastewater, on which the downstream farmers strongly agree but those from the upstream areas do not. This result implies that the value of the improvement program is also explained by variations in the pollution levels between the different wastewater farm areas.

The mean WTP of wastewater farm households from the bivariate probit and the interval-data models is estimated to be ETB 37.15 and 39.88 per hectare per year, respectively. Based on this mean WTP, the welfare gain for the wastewater farm populations obtained via the safe use of wastewater for irrigation ranges from ETB 46,028.85 to 49,411.32 per year, respectively.

Overall, the results presented here confirm that safe use of wastewater for irrigation, or improved use of the irrigation system, is important to farm households and that the welfare gain to the farm population is tremendous. It also confirms that wastewater is a valuable resource for the livelihoods of farmers. Both the wastewater and freshwater farmers are willing to pay for programs designed to improve the existing unsafe and improper use of irrigation water. This finding suggests it is possible to introduce an irrigation water users' fee that could signal scarcity in the quantity and quality of irrigation water and could optimize or at least improve efficiency in the use of wastewater or freshwater irrigation water.

The study not only provides useful estimates of farm households' WTP for safe use of wastewater, it also offers guidance for decision makers to make informed decisions concerning how to maximize the benefit from the use of wastewater for crop production while minimizing health and environmental risks. It provides an important option for the existing treatment plant to improve its services by selling treated (or semi-treated) wastewater to farmers for a fee, since farmers are willing to pay for such an improvement program.

From a methodological perspective, we conclude that the CVM is suitable for use in the socioeconomic setting of rural-urban farmers in a developing country like Ethiopia. In this survey very little protesting behavior was found, which we attribute partly to providing the respondents with a variety of policy option choices, all leading to the same safe use of wastewater for farming. Further, the robustness of the WTP estimates across various econometric specifications for the dichotomous-choice format shows that typical problems with this format, such as anchoring effects, were not influential in our survey.

However, our investigation is limited to the perceptions of farm households, and the results are subject to this limitation. We recommend further studies on the attitude and willingness to pay of the residents of Addis Ababa for improved waste management services, as they are both sources of wastes and consumers of wastewater-irrigated vegetables. We also suggest further analyses should be conducted to determine the optimum level of treatment on industrial wastewater and to develop incentive-based mechanisms to treat the wastewater before discharging into the rivers.

[*Received July 2008; final revision received October 2009.*]

References

Ahlheim, M. "Contingent Valuation and the Budget Constraint." *Ecological Econ.* 27(1998):205–211.

Ahlheim, M., O. Frör, and N. Sinphurmsukskul. "Economic Valuation of Environmental Benefits in Developing and Emerging Countries: Theoretical Considerations and Practical Evidence from Thailand and the Philippines." *Quart. J. Internat. Agr.* 45(2006):397–419.

Ahlheim, M., and U. Lehr. "Equity and Aggregation in Environmental Valuation." Hohenheimer Diskussionsbeiträge No. 307, Dept. of Econ. and Social Sciences, University of Hohenheim, Stuttgart, Germany, 2008.

Alberini, A. "Efficiency vs. Bias of Willingness-to-Pay Estimates: Bivariate and Interval-Data Models." *J. Environ. Econ. and Mgmt.* 29(1995):169–180.

Alemu, M. "Valuation of Community Forests in Ethiopia: A Contingent Valuation Study of Rural Households." *Environ. and Develop. Econ.* 5(1997):289–308.

Aprahamian, F., O. Chanel, and S. Luchini. "Modeling Starting Point Bias as Unobserved Heterogeneity in Contingent Valuation Surveys: An Application to Air Pollution." *Amer. J. Agr. Econ.* 89,2(2007):533–547.

Bond, W. J. "Effluent Irrigation—An Environmental Challenge for Soil Science." *Austral. J. Soil Res.* 36,4(1999):543–556.

Cameron, T. A., and J. Quiggin. "Estimation Using Contingent Valuation Data from a 'Dichotomous Choice with Follow-Up' Questionnaire." *J. Environ. Econ. and Mgmt.* 27(1994):218–234.

DeShazo, J. R. "Designing Transactions Without Framing Effects in Iterative Question Formats." *J. Environ. Econ. and Mgmt.* 43(2002):360–385.

Ethiopian Economic Association. *Transformation of the Ethiopian Agriculture: Potentials, Constraints, and Suggested Intervention Measures*. Report on the Ethiopian Economy, Vol. IV, 2004/05, Addis Ababa, Ethiopia, 2005.

Ethiopian Environmental Protection Authority (EEPA). "*Standards for Industrial Pollution Control in Ethiopia*. Prepared by the Environmental Protection Authority and the United Nations Industrial Development Organization under the Ecologically Sustainable Industrial Development (ESID) Project, Addis Ababa, Ethiopia, 2003.

Fisseha, I. "Metals in Leafy Vegetables Grown in Addis Ababa and Toxicological Implications." *Ethiopian J. Health Develop.* 16,3(2002):295–302.

Freeman, M.A. *The Measurement of Environmental and Resource Values: Theory and Methods,* 2nd ed. Washington, DC: Resources for the Future, 2003.

Frör, O. "Bounded Rationality in Contingent Valuation: Empirical Evidence Using Cognitive Psychology." *Ecological Econ.* 68(2008):570–581.

Haab, T. C., and K. E. McConnell. *Valuing Environmental and Natural Resources: The Econometrics of Non-Market Valuation.* Cheltenham, UK: Edward Elgar, 2002.

Habbari, K., A. Tifnouti, G. Bitton, and A. Mandil. "Geohelminthic Infections Associated with Raw Wastewater Reuse for Agricultural Purposes in Beni-Mellal, Morocco." *Parasitology Internat.* 48(2000):249–254.

Hanemann, M. W. "Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses." *Amer. J. Agr. Econ.* 66,3(1984):332–341.

Hanemann, M. W., J. Loomis, and B. Kanninen. "Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation." *Amer. J. Agr. Econ.* 73,4(1991):1255–1263.

Herriges, J. A., and J. F. Shogren. "Starting Point Bias in Dichotomous Choice Valuation with Follow-up Questioning." *J. Environ. Econ. and Mgmt.* 30(1996):112–131.

Hussain, I., L. Raschid, M. A. Hanjra, F. Marikar, and W. van der Hoek. "A Framework for Analysing Socioeconomic, Health and Environmental Impact of Wastewater Use in Agriculture in Developing Countries." Work. Pap. No. 26, International Water Management Institute (IWMI), Colombo, Sri Lanka, 2001.

———. "Wastewater Use in Agriculture: Review of Impacts and Methodological Issues in Valuing Impacts (with an extended list of bibliographical references)." Work. Pap. No. 37, International Water Management Institute (IWMI), Colombo, Sri Lanka, 2002.

Lulu, S., G. Abebe, T. Kebede, and S. Waltanigus. "Groundwater Management Using Groundwater Modelling: Case Study on Akaki Well Field" (in Addis Ababa City, Ethiopia). Paper presented at the 31st WEDC International Conference, Kampala, Uganda, 2005.

Meyerhoff, M., and U. Liebe. "Protest Beliefs in Contingent Valuation: Explaining Their Motivation." *Ecological Econ.* 57(2006):583–594.

Mitchell, R. C., and R. T. Carson. "Using Surveys to Value Public Goods: The Contingent Valuation Method." Resources for the Future, Washington, DC, 1989.

Rashed, M., S. R. Award, M. A. Salam, and E. Smidt. "Monitoring of Groundwater in Gabal el Asfar Wastewater Irrigated Area (greater Cairo)." *Water Science and Technology* 32,11(1995):163–169.

Ready, R. C., J. C. Buzby, and D. Hu. "Differences Between Continuous and Discrete Contingent Value Estimates." *Land Econ.* 72,3(1996):397–411.

Tegene, G. "Willingness to Pay for Environmental Protection: An Application of the Contingent Valuation Method (CVM) in Sekota District Northern Ethiopia." *Ethiopian J. Agr. Econ.* 4,1(1999):1–16.

Weldesilassie, A., E. Boelee, and S. Dabbert. "Wastewater Use in Crop Production: Impact on Productivity and Policy Implication." Discussion pap., Dept. of Production Theory and Resour. Econ., University of Hohenheim, Stuttgart, Germany, 2008.

Weldesilassie, A., E. Boelee, P. Drechsel, and S. Dabbert. "Health Impact of Wastewater Use in Crop Production in Peri-Urban Areas of Addis Ababa: Implication for Policy." Discussion pap., Dept. of Production Theory and Resour. Econ., University of Hohenheim, Stuttgart, Germany, 2008.

Whittington, D. "Improving the Performance of Contingent Valuation Studies in Developing Countries." *Environ. and Resour. Econ.* 22(2002):323–367.

Whittington, D., J. Briscoe, X. Mu, and W. Barron. "Estimating the Willingness to Pay for Water Services in Developing Countries: A Case Study of the Contingent Valuation Method in Southern Haiti." *Econ. Develop. and Cultural Changes* 38,2(1990):293–312.

Whittington, D., D. T. Lauria, and X. Mu. "A Study of Water Vending and Willingness to Pay in Onisha, Nigeria." *World Develop.* 19,2/3(1991):179–198.