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The Value of Household Water Service Quality in Lahore, Pakistan

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Abstract Most existing literature focuses on the benefits of establishing basic drinking water access for unserved populations, the extensive water supply margin. In contrast, this article examines the intensive margin—the benefits of improving water service to under-served households, a growing population in developing country cities. We use contingent valuation to estimate willingness to pay (WTP) for improved piped water quality and reductions in supply interruptions among a sample of 193 households in Lahore, Pakistan. The distribution of WTP is described using parametric and non-parametric models. Results indicate that households in Lahore are willing to pay about \$7.50 to \$9 per month for piped water supply that is clean and drinkable directly from the tap—comparable to the monthly cost of in-home water treatment, and about three to four times the average monthly water bill for sample households using piped water. Estimates of WTP for reducing supply interruptions are both smaller and more difficult to interpret, since a significant fraction of the estimated WTP distribution for supply improvements is negative. All of our WTP estimates are well below 4% of monthly household income, the World Bank's benchmark upper bound for affordable water service.

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1 Introduction

Inadequate drinking water access is one of the most significant and persistent environmental health problems in developing countries. Approximately 1.1 billion people worldwide lack access to safe water (United Nations 2003). More than 3 million children die from preventable water-related diseases annually (World Bank 2002), and many studies link access to safe water with better health, particularly among young children, and resulting improvements in welfare (Merrick 1985; Behrman and Wolfe 1987; Esrey et al. 1991; Lavy et al. 1996; Lee et al. 1997; Jalan and Ravallion 2003). The only quantitative environmental target in the Millennium Development Goals (MDGs) is the call to "reduce by half the proportion of people without sustainable access to safe drinking water" by 2015 (Kremer et al. 2007).

Moreover, as the world's population (especially in developing countries) is increasingly urban, there is a need to consider improvements to urban water service and infrastructure. Water quality improvements can result in very substantial welfare gains through reduced morbidity and mortality. Piped water filtration and chlorination introduced in major American cities during the early twentieth century was responsible for almost one-half of the reduction in urban mortality between 1900 and 1936, including three-quarters of the decline in infant mortality and two-thirds of the decline in child mortality over the period (Cutler and Miller 2005). Improvements in access to clean drinking water in Brazil between 1970 and 2000 resulted in a welfare gain of $7500 per capita over this 30-year period (Soares 2007). The privatization of water supply and resulting piped water service expansion in Argentinean municipalities during the 1990s reduced child mortality by 8% (Galiani et al. 2005).

The welfare effects of improving the reliability of piped water service by reducing supply interruptions are less well understood. Two studies in the literature suggest the gains from such improvements may be substantial in developing country cities, where supply interruptions are common and often unpredictable (Baisa et al. 2010; Whittington et al. 2002). Though water supply interruptions are less common in industrialized countries, urban residents in wealthier countries may also be willing to pay to reduce their probability of occurrence (Hensher et al. 2005).

Urban water service improvements can require large capital investments—a barrier for most water utilities in the developing world. Thus, the ability and willingness to pay of urban households for service expansion and improvement is an important factor to consider in designing policy to address this issue. The survey techniques typically applied to estimate willingness to pay for public services in developing countries face several challenges, including access to respondents, low responsiveness to convenient mediums of communication (e.g., telephone), and low levels of education among respondents.

This article makes a number of contributions to this critical area of research. We use contingent valuation (CV) to survey households in Lahore, Pakistan, that are currently tapping two different primary drinking water sources, private groundwater wells and connections to piped water systems, to estimate their willingness to pay for water quality and water supply improvements. Existing studies that estimate the value households place on water in developing countries have focused primarily on rural areas (World Bank Water Demand Research Team 1993; Whittington et al. 1990a) or on households obtaining water primarily from raw surface water sources and/or the informal sector (Whittington et al. 1991; Fujita et al. 2005). The focus in this literature has been on the extensive margin—estimating the benefits of providing basic water access where it is lacking. We assess households in a more "intermediate" group in a developing country setting—those in a city with incomplete water utility coverage, with service that is often intermittent, but where households rely little on informal sector water suppliers. Thus our focus is on the intensive margin—the value of improved service, once basic service through public or private means is available. Studies of similar populations include Pattanayak et al. (2006) in Sri Lanka and Whittington et al. (2002) in Nepal. We know of no other published work on this issue in Pakistan.

We find that households are willing to pay about \$7.50 to \$9 per month for piped water supply that is clean and drinkable directly from the tap, about three to four times the average monthly water bill in our sample for households that currently have a connection to the piped water system. Our WTP estimates are also well under what is typically considered "affordable" by the World Bank, a benchmark of 4% of household income. The estimates of WTP for water quality improvements are comparable to the monthly cost of two common in-home treatment techniques, chemical treatment and filtration. Results suggest that WTP for improvements in supply consistency (\$3 to \$6 per month) are lower than WTP for improved water quality. The estimates of WTP for these improvements in water supply are more reasonable for households currently on groundwater than they are for piped water households, for whom we estimate negative mean WTP.

Lahore is one of many underserved cities in the developing world where most households have basic water service through piped networks and private wells, but improvements in drinking water quality and supply consistency may have significant value. In one survey of consumers of water utilities in 50 Asian cities, two of the most frequent consumer complaints were poor water quality and frequent interruptions in supply (McIntosh and Yñiguez 1997). Thus, our results for Lahore may be useful in assessing similar situations in other Asian cities.

2 Study Area and Background

Pakistan is an arid country, with available freshwater resources of 1,384 cubic meters per capita per year, putting it into the category of a "water-stressed" country (Falkenmark and Rockstrom 2005; World Resources Institute 2007). Lahore is Pakistan's second largest city, with an estimated population of about 10 million, growing at about 3.3% per year (Lahore City Government 2007). Lahore households rely on three major water service modes: the piped supply network of the Lahore Development Authority's Water and Sanitation Agency (WASA), the piped supply network of the various Cantonment authorities, and household groundwater wells. Groundwater is easily accessible in Lahore, thus the two piped-water suppliers treat and distribute groundwater from deep wells, using centralized local pumping stations.

Approximately 87% of households within WASA's service area are connected to the piped system, a service coverage fraction that has been constant since 2000, but represents an increase from about 57% since 1967 (Lahore Development Authority, Water and Sanitation Agency 2007; McIntosh and Yñiguez 1997).[1] Information on the quality of piped drinking water in Lahore is difficult to find. One recent analysis suggests that source water aquifers

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[1] In 1995, WASA served about 84% of households within its service area, so the growth in service connections appears to have occurred before the mid-1990s (McIntosh and Yñiguez 1997).

are contaminated, although in the small number of samples (16) analyzed, piped water meets World Health Organization guidelines for most contaminants (Aziz 2005). A more recent government-funded study tested 16 water sources in Lahore and identified unsafe bacteriological contamination in one-half of these sources, and arsenic contamination in all of them (Kahlown et al. 2007).[2] When surveyed in the mid-1990s, 77% of households obtaining water from WASA said that they drink the tap water (McIntosh and Yñiguez 1997). In the mid-1990s, one survey of WASA's residential customers suggested that water service was available, on average, about 17 h per day; only 6% of households reported 24-h supply (McIntosh and Yñiguez 1997). Households currently pay a fixed monthly, bi-monthly, or annual fee for piped water service. The fee varies by household but not with water consumption, as households do not generally have water meters. The billing rate is fixed by WASA or the Cantonment Board, based on the number of faucets and other fixtures in the household.

3 Methodology

We use contingent valuation (CV) to collect the data in this study. The basic architecture of a CV survey is: (1) a description of the service/amenity to be valued and the conditions under which the policy change is being suggested; (2) a description of the link between a participant's response and the decision rule for the policy change; (3) a set of choice questions that ask the respondent to place a value on the service/amenity; and (4) a set of questions assessing the socioeconomic characteristics of the respondent that will help in determining what factors shift the value placed on a particular service/amenity (Young 2005; Mitchell and Carson 1989).

There is considerable debate as to the ability of CV to provide accurate results, particularly for non-use values of natural resource amenities (Hanemann 1994; Diamond and Hausman 1994). The methodological issues that arise in CV study design are well-known.[3] A National Oceanic and Atmospheric Administration (NOAA) Blue Ribbon panel on contingent valuation developed a set of guidelines generally recognized as "best practices" in the conduct of CV surveys (Arrow et al. 1995). CV has been used extensively to value improvements in public services in developing countries, such as the provision of health clinics, vaccination, and water service, as well as to value mortality risk. When employed to estimate use value in contexts like these, the results from stated preference methods including CV are comparable to results from revealed preference methods, such as travel cost models and hedonic wage studies (Carson et al. 1996).

3.1 Survey Design and Implementation

Our survey had three segments. In the first segment, we collected household demographic information. The second segment established the water services the household was employing, the perceived quality of that service (in terms of cleanliness and interruptions), whether the household treated water, and the cost of the current service bundle. The third and final

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[2] According to Pakistan's national water quality standards, drinking water entering the distribution system should have a total coliform count of zero in any 100 ml sample. Water in the distribution system should be free of *E. Coli* in any sample and have total coliform counts of no more than 10 per 100 ml sample. Coliform bacteria should not be detectable in any two consecutive 100 ml samples, or in more than 50% of samples collected per year. Zero total coliform and zero *E. Coli* are allowable in potable water. Pakistan's arsenic standard allows 10 ppb in potable water (Kahlown et al. 2007).

[3] For a succinct description, see Young (2005), p. 137.

segment evoked households' willingness to pay for improved water services, and is included here as Appendix A.

The survey assessed WTP for two different aspects of water service. Both options involved in-home piped water access. Option 1: "water quality improvement" was defined as piped water clean enough to drink straight from the tap, but with current levels of interruptible flow and pressure drops. Option 2: "water supply improvement" was defined as piped water of current perceived cleanliness, but with uninterrupted supply and no drops in pressure. The method used to evoke WTP was a dichotomous choice, close-ended CV question relating a price to each water service option.[4]

We asked different WTP questions of respondents currently billed for piped water use and respondents using groundwater as a primary source. Respondents currently connected to the piped water system were first asked the amount of their current monthly expenditure on piped water.[5] We then asked whether they would be willing to pay 1.5 times, 2 times, or 3 times their current monthly water expenditure if their piped water service improved as defined for each option. We assigned households to these price multiples in order of the survey (the first household was offered a price of 1.5 times their current bill, the second household 2 times, and so on). Because household water expenditures vary significantly, the absolute amounts of offered prices varied substantially; the surveyor calculated the absolute amount represented by the relevant price multiple for each household, and this was actually the offered price.

Respondents currently using private groundwater wells were asked whether they would be willing to pay one of a set of three absolute amounts monthly—$2.63, $3.62 or $5.43.[6] For the piped water households, we offered the lowest price to the first household, the middle price to the second, and the highest price to the third, proceeding repeatedly in order through the three price brackets with the remaining surveys.[7] Since we are not estimating WTP for an actual water service expansion policy, we do not consider the connection charge that groundwater households would need to pay in order to establish a connection to the piped system. This has been shown to be an important barrier to service expansion in other contexts (Pattanayak et al. 2006).[8]

The survey was field-tested in June and conducted in July–August 2007. To identify low-income households for the sample, we gained access to the established social network of a micro-finance organisation, the Kashf Foundation (KF). KF's network offered a number of advantages: (1) an established network of trust which minimized time spent locating and

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[4] The close-ended referendum format of WTP question was popularized by Hanemann (1984), was recommended by the Report of the NOAA Panel on Contingent Valuation (Arrow et al. 1995), and has largely replaced open-ended questions in CV studies (Haab and McConnell 2002). Unlike open-ended WTP questions, close-ended questions require households to exercise the kind of judgment familiar to them from typical consumption decisions (Mitchell and Carson 1989; Werner 1999).

[5] None of the sample households had water meters. They are billed monthly or bi-monthly by WASA, or annually by their Cantonment Board.

[6] Corresponding to PKR 160, PKR 220, and PKR 330, respectively. These amounts were established based on focus groups conducted prior to the survey, in which we determined that households currently connected to the piped water network paid, on average, just under PKR 110 per month for water (note that this is about 25% lower than the average water bill among households in our eventual sample). We then multiplied this average amount by 1.5, 2.0 and 3.0 to obtain our offered prices. Currency conversion was done at a rate of 60.73 PKR/USD—the rate on June 1, 2007 from http://www.exchangerate.com/past_rates_entry.html.

[7] T-tests indicate that there are no statistically significant differences in the means of household characteristics across the resulting price groups for either piped or groundwater households, so we are satisfied that our assignment of households to offered prices was random.

[8] Average connection fees in Lahore in the mid-1990s were $7.38 to $29.51, depending on the size of the connection (McIntosh and Yñiguez 1997).

Fig. 1 Picture of tap icon

recruiting sample households, (2) access to low-income households, the clientele of KF, and (3) a good spatial spread, as KF operates across the city. The main drawback to this approach is sample selection—households that have selected into KF may be different from average Lahore households in their perception of water service quality, WTP for improvements, and other characteristics. For example, average household income in the city of Lahore has been estimated at $2,280 per year (Westfall and Villa 2001). KF's new client households, on average, earn $580 to $1,800 per year (Kashf Foundation 2006). But KF clients, presumably, increase their incomes through access to this credit source. We do not have sufficient information to determine whether and how our sample households differ from the full population of Lahore households. This should be considered when interpreting results.

The authors conducted all interviews in person. Respondents were interviewed individually and in private.[9] On average, about 25 interviews were conducted per week, taking approximately 15–30 min each. A total of 197 households were surveyed. Of these, two households were dropped because they used both piped and groundwater. An additional two households failed to answer our questions about household education and are dropped from statistical models in which education is included, leaving a total of 193 completed surveys.[10] Pictures were used to help explain water service improvements. For instance, an image of a filtration device was used in conjunction with an image of a tap when conveying the idea of "filtered water of drinkable quality from the piped water network connection" (see Figs. 1, 2, 3).

In order to clearly set out for respondents that their information would be protected, we included an introductory statement that set out: (1) the interviewer's status as a researcher affiliated with an educational institution; (2) a guarantee that information provided by respondents would be anonymous and confidential. Respondents were told that the study's immediate use was academic, but that these kinds of studies might eventually contribute to local water policy. This raises the issue of "hypothetical bias"—respondents' estimates of WTP may have been biased upward if they felt that their response would not have much impact (Hensher et al. 2005). To preserve incentive compatibility, the survey should have informed participants that

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[9] Since interviews were conducted using the network of KF clients, groups of KF clients tended to gather at an interview site. In the initial survey tests, non-respondents interrupted interviews with "advice" for respondents, and respondents seemed uncomfortable divulging personal information in front of others. Thus, private, individual interviews were used for the survey.

[10] This is smaller than sample sizes in related literature (235 in Whittington et al. 1991, 1500 in Whittington et al. 2002, 1800 in Pattanayak et al. 2006).

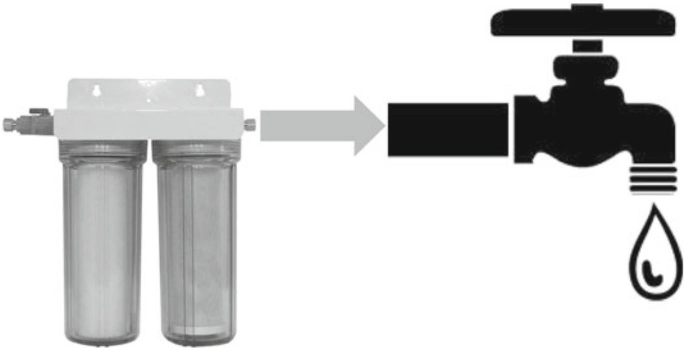

Fig. 2 Picture of water filtration placed before tap icon

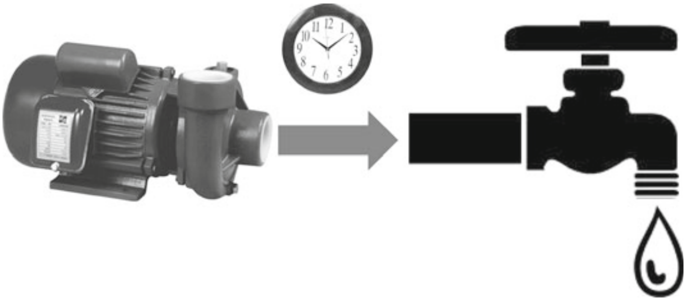

Fig. 3 Picture depicting constant flow and pressure placed before tap icon

if more than 50% of respondents said "yes" to our WTP questions, our recommendation to authorities would have been to carry out a project that improved water services as per the survey description, resulting in payment increases. Readers should interpret results with this potential hypothetical bias in mind.

3.2 Models of WTP for Water Quality and Supply Improvements

The primary purpose of a CV study is to obtain information about the distribution of WTP and use this information to estimate measures of central tendency, such as the mean or median. We take two classes of approach, parametric and non-parametric, to obtain estimates of the central tendency of WTP. Combined, the two approaches provide a rich level of descriptive detail, and each acts as a robustness check on the other.

It is also common practice to estimate the relationship between WTP and covariates, for two main reasons. First, economic theory suggests that the demand for a good is a function of the offered price, income, the prices of substitutes and complements, and preferences. Obtaining "reasonable" statistical estimates of the relationships between WTP and these covariates (where socioeconomic characteristics proxy for preferences) can increase our confidence that WTP estimates represent the marginal benefit to households of the described water service improvement, rather than random numbers. Second, if the results of such studies are to be used to inform water supply policy, it is useful to know how WTP varies with income, whether it differs among households currently tapping different primary water supplies, and whether households are willing to pay more for some types of service improvements than for others.

3.2.1 Parametric models

Following Cameron (1988) and Cameron and James (1987), we estimate parametric models of the probability that households were willing to pay for each water supply improvement option, controlling for price and the other covariates of interest (1).

$$\mathbf{Pr(WTP} = 1) = \mathbf{X}'\boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{1}$$

We estimate probit models (2), assuming ε is normally distributed (Φ is the standard normal cumulative distribution function), and obtain parameter estimates by maximizing the corresponding log-likelihood function.

$$\Pr(\mathbf{WTP} = 1|\mathbf{X}) = \Phi(\boldsymbol{\beta}'X) \tag{2}$$

In models that pool together piped water and groundwater users, **X** comprises the covariates: offered price (*price_quality* or *price_supply*), monthly household income (*income*), number of people living in the household (*number of residents*), fraction of adults living in the household who have had any formal education (*fraction of adults educated*), whether the household perceives its current water supply to be clean enough to drink without treating (*perceives current supply as clean*), whether the household uses piped water (*piped water*) or a groundwater well, whether the household treats its drinking water chemically or with a filter (*treats drinking water*), as well as interactions between *piped water* and the other covariates. We estimate models in which price enters both linearly and logarithmically.

We also separate the sample, simultaneously estimating probit coefficients and standard errors for groundwater and piped water users using seemingly unrelated regression (SUR). SUR is commonly used to estimate demand for the same commodity among different households. This approach is useful for a number of reasons. First, piped water and groundwater households are quite different in their socioeconomic characteristics, as demonstrated in the discussion of Table 1, so they may have different WTP functions. The interaction terms in the pooled models account for this, but separate equations are another alternative. Second, there are some characteristics specific to each supply type. For example, groundwater households must spend time pumping water from a well, using electricity and some household labor, while piped water households do not. Piped water users may experience different levels of supply inconsistency (interruptions and pressure drops); groundwater users lack a piped water connection and do not experience these problems. Taking a two-equation approach allows us to use different covariates for each household supply type. In our SUR models, we use subsets of the full **X** for each sub-sample and add two additional covariates: *frequency of supply problems* for piped water households, which measures on a scale of 0 to 3 the level of current difficulties with water pressure and supply interruptions (with 0 equivalent to no problems, and 3 very frequent problems); and *time spent pumping water* for groundwater households, which measures the number of minutes households spend each day pumping groundwater.

Estimating the two probit equations using SUR allows errors to be correlated across the two groups. For example, in our case, common exogenous neighborhood characteristics or other factors may affect demand similarly among piped and groundwater households. SUR increases the efficiency of estimation relative to the approach of estimating two separate models.

We test some hypotheses about the parameter estimates, $\boldsymbol{\beta}$. Economic theory suggests that demand should fall with price and increase with income. For groundwater households, *time spent pumping water* represents the price of a substitute (continuing to pump groundwater using electricity and household labor), so the coefficient for this parameter should be

Table 1 Descriptive statistics, household characteristics

Variable	Obs.	Mean	SD	Min.	Max.
Number of residents	193	7.69	3.19	2	25
Piped water households	129	7.50	3.37	2	25
Groundwater households	64	8.09	2.78	2	15
Income ($US/month)	193	298.75	227.50	32.94	1317.60
Piped water households	129	324.55	248.98	57.65	1317.60
Groundwater households	64	246.74	166.35	32.94	1235.25
Fraction of adults with any formal education	193	0.64	0.35	0	1
Piped water households	129	0.74	0.30	0	1
Groundwater households	64	0.44	0.35	0	1
Perceives current source as "clean"	193	0.44	0.50	0	1
Piped water households	129	0.30	0.46	0	1
Groundwater households	64	0.70	0.46	0	1
Currently treats drinking water in home	193	0.45	0.50	0	1
Piped water households	129	0.54	0.50	0	1
Groundwater households	64	0.25	0.44	0	1
Frequency of supply problems					
Piped water households	129	1.37	1.18	0	3
Monthly household water bill ($US/month)					
Piped water households	129	2.43	2.01	0	9.88
Time spent pumping water (min/day)					
Groundwater households	64	65.96	49.94	0	247.50

positive.[11] The remaining parameters capture household preferences. We expect that *number of residents* and *fraction of adults educated* will be positively correlated with Pr (WTP=1). A larger number of people in the households suggests larger benefits from water quality and consistency of supply. Well-educated respondents may know more about the health implications of water quality. Since groundwater households receive an extra "benefit" (a piped water connection) relative to piped water households, we expect *piped water* to be negatively correlated with WTP. The literature suggests that the higher the perceived quality of their status quo source, the less a household will be willing to pay for improving source quality (Whittington et al. 1990a), thus the coefficient for *perceives current supply as clean* should be negative. Households currently experiencing interruptions and pressure changes with a piped water connection should be willing to pay more for supply improvements, thus we expect *frequency of supply problems* to be positively correlated with WTP (Whittington et al. 2002). We have no prior expectation about the sign of *treats drinking water*. Households treating water likely do so because they perceive their source to be unsafe for drinking, which implies a positive sign on *treats drinking water*; however, households treating water may have adapted to their current water supply relative to other households (making investments in treatment systems, filters, etc.) and may be willing to pay less for system improvements.

In addition to interpreting our estimates of $\boldsymbol{\beta}$, we use the parameter estimates and the data to estimate WTP from the parametric models as in Cameron (1988) and Cameron and James

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[11] The value of time spent hauling water in developing countries can be approximated by the wage rate for unskilled labor (Whittington et al. 1990b).

(1987). We estimate WTP for each household using (3), in which β_1 is the price coefficient estimate from Eq. (2), with the remaining coefficient estimates and the constant represented by β_m and β_0, respectively. We then report the mean and median of the resulting distribution of WTP.

$$E(WTP_i) = (-1/\beta_1)*\left(\beta_0 + \sum_{m=2}^{M} \beta_m X_{mi}\right) \tag{3}$$

3.2.2 Non-parametric models

We also estimate mean and median willingness to pay using non-parametric methods, free of the distributional assumptions of the parametric models, but less useful for describing the relationship between WTP and the covariates. Our first non-parametric approach is the Turnbull estimator, originally attributable to Ayer et al. (1955) and Turnbull (1976), but first applied to CV by Carson et al. (1994).[12] The Turnbull model calculates the parameters of the empirical distribution of WTP by: (1) creating a list of offered prices in order from smallest to largest; (2) estimating the percentage of households who accepted each offered price; (3) smoothing the prices so that the fraction of "yes" votes decreases monotonically as the offered price increases (while assuming that all households would accept an offered price of zero, and none an infinite price); and (4) using the smoothed distribution function of "yes" votes to estimate the lower bound on willingness to pay ($E_{LB}(WTP)$) (Haab and McConnell 2002). Median WTP in the Turnbull model is simply the price at which the distribution function of WTP passes 0.50; because the estimator only estimates probabilities at a discrete number of prices, the median is defined within a range and is not a point estimate.

We also estimate a related non-parametric model due to Kriström (1990). The Turnbull estimate of mean WTP is a lower bound estimate, because it assumes that for each pair of prices that define a range of WTP, the full mass of the distribution function falls at the lower price. The Kriström estimator instead assumes the distribution function is piecewise-linear between each price—here we assume WTP is distributed uniformly between prices. Of the two non-parametric approaches, the Turnbull estimator is more conservative.

Obtaining the WTP estimates from both parametric and non-parametric models provides a richer, more robust description of WTP than a single class of model can provide. And the parametric models allow us to interpret the influence of several descriptive independent variables on WTP, *ceteris paribus*. The non-parametric models can also be applied to describe the influence of covariates on the central tendency of WTP.[13] However, the drawback to this approach is that, unlike with the parametric models, we would not be controlling for other factors as we vary the ranges of the independent variable of interest. Thus any differences across groups could not be reasonably attributed solely to the differences in the values of the variable on which we have selected.

4 Data

The total sample size is 193 households. About two-thirds of the sample use piped water, and one-third pump groundwater from private wells. Some households supplement these

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[12] The description of the Turnbull estimator and related methods is particularly clear in Haab and McConnell (2002), Chap. 3.

[13] The appropriate method is to apply the non-parametric estimator (Turnbull or Kriström) to sub-samples of the data, sorted by particular values or ranges of a single independent variable, and then test for statistical differences in sub-sample WTP estimates.

supplies, buying bottled water or obtaining water from local deep aquifer pumping stations, but piped water and wells are the primary sources.[14]

Table 1 presents summary statistics for household socioeconomic characteristics used in the statistical analysis, dividing the sample by primary water source.[15] Mean household size is about 8 people for both piped and groundwater users (on average, 5 adults and 3 children per household in both groups). The groups are quite different along other dimensions, however. Piped water households have higher monthly income ($325), on average, than groundwater households ($247). Consistent with lower incomes, groundwater households also have fewer assets, on average, including televisions, refrigerators, mobile telephones, and motorcycles (see Appendix B). Piped water households have relatively more formal education; almost three-quarters of adults in piped water households have some formal education, compared with less than half in groundwater households. About 70% of groundwater households perceive their household water source to be of safe, drinkable quality, compared with only 30% of piped water households.[16] Not surprisingly, more piped water households (54%) engage in in-home drinking water treatment than do groundwater households (25%).[17] Among households treating water, almost all use both chemical treatment and boiling, with a smaller fraction using filtration systems, alone or in combination with one of the other technologies. Asked to rate their problems with water pressure and supply interruptions on a scale from 0 to 3 (with 0 indicating no problems and 3 indicating very frequent problems), the average score among piped water households was 1.37. Households using groundwater spend, on average, just over one hour per day running electric pumps to collect water.

Table 2 presents descriptive statistics for binary WTP responses, by water supply type, as well as the prices from our WTP survey. Groundwater households were more likely than piped water households to be willing to pay our offered price for both improvements in cleanliness and in consistency of water supply. In raw form this is not surprising, as groundwater households do not currently have a connection to the piped water system, so this can be considered an extra benefit of each option, relative to the benefits piped water households receive for the same option. However, the fact that these services are bundled for groundwater households may also have the opposite effect, since these households, on average, perceive current water supplies to be cleaner than piped water. In addition, the prices offered to piped water households were higher, on average, than those offered to groundwater households—the multiples of current water bills offered to piped water households tended to be higher than the absolute prices offered to groundwater households.[18]

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[14] Just under one-fifth of piped water households in the sample use additional water sources, and only one groundwater household uses additional sources. Water trucks and other informal sector providers are uncommon in Lahore, in contrast to other developing country cities, perhaps due to the easy accessibility of groundwater (McIntosh and Yñiguez 1997).

[15] The survey collected information on many household characteristics not included in our models. These results are summarized in Appendix B.

[16] A far smaller percentage of households (30%) in our survey considered piped water from WASA to be of drinkable quality than the percentage reported in WASA's own consumer survey in the mid-1990s, reported earlier (77%). This may be due to differences in survey methods, changes in piped water quality over the past 15 years, or differences in the characteristics of surveyed households.

[17] The differences in means across groups are significant for monthly income (at .05), fraction of adults with some formal education (at .01), perceived water cleanliness (at .01), and household water treatment (at .01) by two-tailed *t*-tests for differences in means. Income includes all household income contributions from earning members, as well as foreign remittances.

[18] The differences in means across piped and groundwater users are significant by two-tailed *t*-tests, for Pr (WTP *quality*=1) at .10, for Pr (WTP *supply*=1) at .01, and at .05 for *price_quality* and *price_supply*.

Table 2 Descriptive statistics, WTP and prices

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Pr (WTP *quality* = 1)	193	0.67	0.47	0	1
Piped water households	129	0.63	0.49	0	1
Groundwater households	64	0.75	0.44	0	1
Pr (WTP *supply* = 1)	193	0.42	0.49	0	1
Piped water households	129	0.29	0.46	0	1
Groundwater households	64	0.67	0.47	0	1
price_quality ($US/month)	193	4.71	3.76	0	27.18
Piped water households	129	5.16	4.46	0	27.18
Groundwater households	64	3.79	1.19	2.64	5.44
price_supply ($US/month)	193	4.71	3.76	0	27.18
Piped water households	129	5.16	4.46	0	27.18
Groundwater households	64	3.79	1.19	2.64	5.44

Quality is the first service improvement option, “clean piped drinking water in the home,” holding water supply constant; and *supply* is the second service improvement option, “uninterrupted piped drinking water in the home,” holding water quality constant

5 Results

5.1 Parametric models of the determinants of WTP

Table 3 reports the marginal effects for our probit models of WTP in which the probability that households were willing to pay our offered price is the dependent variable. Marginal effects are estimated at the means of the independent variables, and are estimated for a discrete change from 0 to 1 for dummy variables. Reported standard errors are robust to heteroskedasticity and clustered by neighborhood. WTP models for water quality improvement—clean, drinkable piped water—are reported in columns 1 and 2, with prices entering linearly in column 1 and as natural logs in column 2. The results of the two models are quite similar. While neither the price coefficients nor those interacting price and *piped water* are individually significant in columns 1 and 2, they are jointly significant at 0.01 in both models; WTP is negatively correlated with price in both linear and log form, as expected.[19] Groundwater households appear to be more sensitive to price than households currently connected to the piped system. Additional household residents raise WTP. The effect of income on WTP is negative for groundwater users and positive for piped water users, though the effects are very small for both groups.[20] Education has no significant effect on WTP. Households that perceive their current source to be clean are less likely to be WTP for improved cleanliness, but whether a household currently treats drinking water has no statistically significant influence on WTP.

WTP models for water supply improvement—uninterrupted piped water supply to the household at current levels of piped-water quality—are reported in columns 3 and 4. The price coefficients and those interacting price with *piped water* are individually insignificant, but

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[19] For the test of joint significance of *price* and *piped water*price* in column 1, $\chi^2(2) = 17.61$ and $\Pr > \chi^2 = 0.0002$. For the test of *lnprice* and *piped water*lnprice* in column 2, $\chi^2(2) = 16.64$ and $\Pr > \chi^2 = 0.0002$.

[20] A significant, negative income effect was also observed in Whittington et al. (1991). It is possible that wealthier households on groundwater have already adapted to their current water supply by investing in filtration and other technologies, or are more likely to purchase bottled water for drinking and thus are WTP less than poorer groundwater households, who have not made such adaptations.

Table 3 Probit models of willingness-to-pay, pooling ground and piped water households

Variable	Model specification			
	Water quality linear price (1)	Water quality log price (2)	Water supply linear price (3)	Water supply log price (4)
Price	−0.066		−0.072	
	(0.045)		(0.055)	
Lnprice		−0.236		−0.267
		(0.170)		(0.209)
Number of residents	0.059***	0.059***	0.010	0.009
	(0.021)	(0.021)	(0.028)	(0.029)
Income	−0.001**	−0.001**	0.001	0.001
	(0.000)	(0.000)	(0.001)	(0.001)
Fraction of adults educated	0.283	0.281	−0.132	−0.135
	(0.196)	(0.199)	(0.257)	(0.257)
Piped water	−0.303	−0.281	−0.315	−0.444
	(0.231)	(0.270)	(0.412)	(0.421)
Perceives current supply as clean	−0.327***	−0.324***		
	(0.101)	(0.104)		
Treats drinking water	−0.102	−0.102		
	(0.152)	(0.153)		
Piped water*price	0.031		0.039	
	(0.045)		(0.058)	
Piped water*lnprice		0.050		0.120
		(0.176)		(0.223)
Piped water*number residents	−0.038	−0.038	−0.013	−0.006
	(0.025)	(0.025)	(0.031)	(0.031)
Piped water*income	0.002***	0.002***	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Piped water*fraction of adults educated	−0.344	−0.353	−0.056	−0.050
	(0.227)	(0.231)	(0.300)	(0.305)
Piped water*perceives current supply as clean	0.169	0.155		
	(0.121)	(0.130)		
Piped water*treats drinking water	0.063	0.052		
	(0.184)	(0.190)		
Number of obs.	193	187	193	187
R^2	0.15	0.14	0.15	0.17

Dependent variable is Pr(WTP = 1). All models include a constant and report marginal effects at the means of the independent variables. Standard errors, robust to clustering by neighborhood, are reported in parentheses. Asterisks denote statistical significance: * at 0.10, ** at 0.05, and *** at 0.01. Log price models have only 187 observations because six piped water households reported a water price of zero jointly significant (at 0.05 in this case).[21] Similar to the results for water quality improvement, the effect of price (linear and log) on WTP is negative, and groundwater households appear to be more sensitive to price than households currently using piped water. None of the other variables are significant determinants of WTP for water supply improvement.

In a second set of parametric models, we estimate WTP for piped water and groundwater households in separate equations. The results of two 2-equation models (for water quality improvement in column 1 and water supply improvement in column 2) are reported in Table 4. Consider the results for water quality improvement first. It is difficult to say whether the effect of the offered price on WTP is stronger for piped water households or for groundwater households. The two coefficients do not differ significantly because the groundwater estimate is noisy (recall that there are only 64 households on private wells), and the magnitude of the groundwater estimate is larger than the piped water price estimate. WTP increases with the number of people in a household, as before. We see explicitly the difference in the influence of income, with the expected positive effect for piped water households and a negative coefficient for groundwater households. The impact of *perceives current supply as clean* appears to be stronger for groundwater than piped water households, though the coefficients are not statistically different. Groundwater extraction time is an important determinant of WTP for groundwater households—households that currently spend more time pumping groundwater are willing to pay more for clean, piped water.

The price effects for water supply improvement are similar to those for water quality improvement. Both coefficients are negative, with the groundwater coefficient greater in magnitude but statistically insignificant. For groundwater users, the only significant determinant of WTP for consistent piped water supply is *time spent pumping water*. For piped water users, those with more frequent supply problems (service interruptions and pressure drops) are willing to pay more for supply improvements. We also obtain a negative and significant coefficient on *fraction of adults educated*.

5.2 Parametric and Non-parametric WTP Estimates

Having estimated the coefficients in Eq. (2), we use Eq. (3) to estimate *E(WTP)* for each household. We then calculate measures of central tendency of the resulting WTP distribution. The results of this process are reported in Table 5, with water quality models listed at the top and water supply models listed below.

5.2.1 WTP for water quality improvement

If we look at the three linear parametric models for water quality improvement (rows 1, 2 and 3), we obtain a mean household WTP of \$7.48–\$9.09 per month, and a median WTP of \$6.97–\$8.12 per month, with little difference between groundwater and piped water households. In the estimated distribution of *E(WTP)*, we observe a single groundwater household with a negative value (column 4). Negative WTP estimates are commonly observed in the analysis of dichotomous-choice referendum data and there is significant debate regarding their interpretation and statistical treatment (Bohara et al. 2001; Werner 1999; Haab and McConnell 1998, 1997). There are cases in which respondents may actually perceive a negative effect from the change being valued. For example, Bohara et al. (2001) describe CV surveys of WTP for changes in land management for environmental purposes (e.g., wolf reintroduction,

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[21] For the test of joint significance in column 3, $\chi^2(2) = 6.40$ and $\Pr > \chi^2 = 0.0409$; in column 2, $\chi^2(2) = 5.93$ and $\Pr > \chi^2 = 0.0515$.

Table 4 Two-equation probit models of willingness-to-pay

Sub-sample and variables	WTP for water quality	WTP for water supply
Piped water households ($N = 129$)		
Price	−0.099***	−0.096**
	(0.026)	(0.043)
Number of residents	0.060*	−0.015
	(0.037)	(0.030)
Income	0.002***	0.001
	(0.001)	(0.001)
Fraction of adults educated	−0.134	−0.682*
	(0.341)	(0.378)
Perceives current supply as clean	−0.441	
	(0.332)	
Treats drinking water	−0.114	
	(0.329)	
Frequency of supply problems	−0.056	0.307***
	(0.117)	(0.099)
Groundwater households ($N = 64$)		
Price	−0.198	−0.208
	(0.133)	(0.135)
Number of residents	0.160**	−0.008
	(0.070)	(0.079)
Income	−0.003**	0.002
	(0.001)	(0.001)
Fraction of adults educated	0.873	−0.544
	(0.719)	(0.883)
Perceives current supply as clean	−1.009***	
	(0.326)	
Treats drinking water	−0.469	
	(0.465)	
Time spent pumping water	0.009***	0.011***
	(0.002)	(0.003)

For both models, the dependent variable is Pr(WTP = 1). Both columns report marginal effects at the means of the independent variables. Standard errors, robust to clustering by neighborhood, are reported in parentheses. Asterisks denote statistical significance: * at 0.10, ** at 0.05, and *** at 0.01. Models include a constant. Cross-equation tests indicate no statistically significant difference in coefficient estimates between piped and groundwater models, except for a test in column 1 for differences in *income*, where $\chi^2(1) = 8.04$, and $\Pr > \chi^2 = 0.0046$

mining restrictions) in which losers from the policy may have true negative WTP. A second class of true negatives may be observed if the change being observed involves reductions in other non-market goods. Neither case seems relevant here. Negative WTP can also be reasonable if some respondents perceive negative effects of the change,for example, WTP for the irradiation of poultry to reduce the risk of food poisoning (Bohara et al. 2001). It is unlikely that any households we interviewed perceive negative effects from the improvement of piped water quality or consistency of supply.

For the distributions of WTP for water quality improvement, we are inclined to consider the single estimate of $E(WTP_i) < 0$ as a statistical artifact (a true zero). While linear-price models (which assume a normal distribution of WTP) have been demonstrated through Monte Carlo simulation to provide unbiased WTP estimates, even with a significant fraction of negative estimates (Bohara et al. 2001), we can also constrain WTP to be non-negative by

Table 5 Summary statistics, willingness-to pay (WTP) estimates, US$/month

WTP option and model	Mean	Median	Variance	N	%WTP<0
Water quality improvement					
Probit models					
1. Linear price, ground and piped water	7.48	6.97	12.97	193	0.01
2. Two-equation linear price, piped water	9.09	7.94	27.14	129	0.00
3. Two-equation linear price, groundwater	8.16	8.12	20.12	64	0.02
4. Log price, ground and piped water	12.68	6.97	240.17	187	0.00
Nonparametric models					
5. Turnbull, ground and piped water	8.77	9.26−11.53	0.84	193	0.00
6. Kriström, ground and piped water	11.63	9.26−11.53	0.84	193	0.00
Water supply improvement					
Probit models					
7. Linear price, ground and piped water	3.42	3.48	10.55	193	0.17
8. Two-equation linear price, piped water	−1.28	−1.58	19.18	129	0.65
9. Two-equation linear price, groundwater	6.39	6.32	7.78	64	0.00
10. Log price, ground and piped water	4.12	2.57	28.24	187	0.00
Nonparametric models					
11. Turnbull, ground and piped water	4.11	2.64−3.63	0.24	193	0.00
12. Kriström, ground and piped water	6.22	2.64−3.63	0.24	193	0.00

using a log-price model to estimate the distribution of WTP (row 4). Log-normal mean WTP estimates are known to have significant positive bias because mean WTP is an increasing function of variance, and the lognormal distribution has a fat tail (Bohara et al. 2001; Haab and McConnell 1998). This is clear here, as mean WTP in the log model is $12.68 per month for water quality improvement, about 28% higher than the upper estimate of means from the three linear models, and the variance is very large.

The non-parametric estimates of WTP for water quality improvement are similar to the linear parametric estimates. These models bound WTP at zero, which might be a more significant advantage were there more negative estimates. The Turnbull estimate of lower-bound mean WTP (row 5) is $8.77 per month, and the Kriström estimate is higher, as expected, at $11.63 per month.[22]

We can also use the parametric model parameter estimates from Tables 3 and 4 to understand the effects of changes in the independent variables on the WTP estimates reported in Table 5. For example, how does a household's perceived cleanliness of its current supply affect WTP for improved water quality? The probit marginal effects reported in Table 4 suggest that households that believe their current source is clean enough to drink are less likely to be willing to pay for improved water quality, controlling for price and other factors, and the effect is much larger and significant for households currently on groundwater, than it is for households connected to the piped water network. What if groundwater users did not perceive

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[22] In Monte Carlo simulation, the Turnbull model underestimates true WTP when the WTP distribution contains only a small number of negatives. However, with the fraction of negatives at 30% or more, the non-parametric estimators have smaller bias than log-normal models and are preferred if constraining WTP to be positive is desired (Bohara et al. 2001).

their current supplies to be clean enough to drink? We used the Table 4 parameter estimates to simulate the effects on WTP of moving all households currently on groundwater to *perceives current supply as clean* = 0. Mean household WTP for water quality improvement, for groundwater and piped water households combined, increases from \$7.48 per month to \$8.46 per month (a 13% increase), and median WTP increases 29%, from \$6.97 per month to \$8.98 per month.

5.2.2 *WTP for water supply improvement*

The linear estimates of WTP for water supply improvement (Table 5, rows 7–9) are much lower than for water quality improvement, and also very different for piped water than for groundwater households. Mean WTP from the pooled linear model is \$3.42 per month. The mean for groundwater households is \$6.39/month, and piped water households have a negative mean WTP in the linear model (−\$1.28/month). Using the probit model with the log of price on the right-hand side to predict WTP (row 10), constraining WTP to be non-negative, results in a mean WTP of \$4.12. The non-parametric estimates, which also eliminate the possibility of negative WTP, but typically with less bias, are \$4.11 for the Turnbull lower-bound estimate, and \$6.22 for the Kriström estimate.

We can think of no reason why piped-water households would legitimately have a negative WTP for more consistent piped water supply, holding water quality constant. It may be that the survey design was inadequate to determine true WTP for improvements in consistency of supply among piped-water households. Ideally, we would re-survey piped-water households to determine whether the negative WTP estimates in the linear models represent legitimate negative valuations or effective zeros. If true negative WTP was unlikely, we could then re-design the WTP questions in the survey (perhaps by adding follow-up questions for households who say they are unwilling to accept our offered price) to reduce the incidence of *E(WTP)*<0. Absent the ability to do this, we hesitate to interpret the mean WTP estimates for water supply improvement among piped-water households.[23]

5.3 Discussion and interpretation of results

Our estimates suggest that mean WTP for clean, drinkable tap water among Lahore households is between \$7.50 and \$9 per month, whether households are currently using piped water or groundwater. This is approximately 3 to 4 times the current average monthly water bill among our sample households with piped water connections (\$2.40) in Lahore. Though few such studies have been performed, households' willingness to pay much more than current expenditures for improved water supply services has been established for other Asian cities (Whittington et al. 2002). This suggests that the willingness of households to pay for water quality improvements may not be the most significant barrier to these improvements—capital constraints on the part of water suppliers and household fixed costs (such as potential connection fees for groundwater households) are likely more significant barriers (Olmstead 2003). This is important information, as it suggests that, for some types

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[23] If we move all piped water households up one step on the 0–3 scale of current problems with water supply (except those who are already reporting a "3", the maximum), we can use the parameters from column 2 of Table 4 to re-estimate WTP for water supply improvement among piped water households, and compare those to the results in row 8 of Table 5. Mean WTP increases from −\$1.28 per month to \$1.07 per month, and the fraction of negative WTP estimates falls from 65 to 33%.

of water service improvements, piped water systems may be able to recover significant costs from user fee increases. However, in our case, the magnitude of the estimates may also be biased upward due to the hypothetical nature of the survey—we did not directly link households' WTP responses with a decision rule for any change in water service policy.

Households in this study appear to be more likely to be WTP, and to be WTP a greater amount, for improved water quality than for improvement in the consistency of water supply (reduction in supply interruptions and changes in pressure). This is consistent with households' ability to adapt to supply interruptions (through storage, bottled water purchases, or water borrowed from neighbors, for example), which may be preferable to the expense of routinely treating water supplies (recall from Table 1 that while less than one-third of piped water households perceived their tap water to be clean and drinkable, only one-half actually engage in in-home treatment, thus treatment must be costly). This difference in WTP for water quality and consistency of supply is particularly large for piped water households, who may already have made such adaptations to supply interruptions and pressure drops, having become accustomed to them. In addition, since groundwater households generally perceive their water supply to be clean and drinkable, their interest in a piped water connection will likely be driven by their perception of tap water quality.

We have little definitive information about how our WTP estimates compare to the expected costs of improving water service in Lahore. One estimate suggests that WASA's annualized capital expenditure per connection in Lahore in the mid-1990s, including groundwater extraction, treatment and distribution, was \$4.24 (in 2007 dollars), suggesting that the cost to the utility of providing additional connections within the city is quite low (McIntosh and Yñiguez 1997). This excludes the fixed costs to households of extending pipes from the street and installing indoor plumbing. In terms of the consistency of water service, estimates in a different, but perhaps comparable context suggest that Mexico City's piped water utility can provide households currently experiencing interrupted service with water at regular, equally-spaced intervals with no additional infrastructure and no price increases, implying very low costs, if any (Baisa et al. 2010). In Mexico City, as in Lahore, households hedge against irregular supply by using rooftop storage tanks, but there are very significant welfare gains from reducing uncertainty over when interruptions will occur and with what frequency. Comparing our benefit estimates to the costs of improving water quality and the consistency of water service in Lahore is an important area for future research.

How do the WTP estimates compare to the costs to Lahore households of alternative options for improving water quality through in-home treatment? Our CV survey did not collect household water treatment cost data. However, it is possible to estimate the costs to Lahore households of improving drinking water quality through chemical treatment and filtration, two common technologies used in our sample.[24] We assume households require about 12 liters of treated water per day (1.5 l per day per person, times eight people per household, on average). Chemical treatment of 12 l per day would have cost about PKR 593, or \$9.76, per month in 2007.[25] The fixed cost of installing the technology necessary for the cheapest common water filter in the Lahore market in 2007 was about PKR 2538, and

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[24] Ideally, we would also compare our WTP estimates to the monthly cost of boiling water. However, the largest component of boiling costs is the cost of household labor, and we do not have a good estimate of the local wage rate with which to estimate time costs.

[25] A package of 28 chlorine tablets in 2007 was approximately PKR 230, and each tablet treats 5 liters of water. We include no labor costs for chemical treatment, since the tablets must simply be dropped into storage containers in the appropriate ratio.

the replaceable filters approximately PKR 334 per month.[26] The monthly cost of filtration depends on the expected lifetime of the filter system—for example, if this is 3 years, the total cost is about PKR 404, or $6.65 per month.[27] Our back-of-the-envelope monthly cost estimates for chemical treatment ($9.76) and filtration ($6.65) are within the range of the WTP estimates for water quality reported in Table 5.

Haab and McConnell (1997; 1998) suggest that reasonable estimates of WTP should be bounded by zero and income. We have already discussed the lower bound of estimates, and some of our models constrain WTP at zero. Though we do not explicitly constrain WTP to be less than monthly household income, none of our models predict a monthly WTP for water service that exceeds household income, for any household, for either water service improvement option. If mean WTP for improved water quality ranges from $7.50 to $9 per month, this is 2.5–3.0% of average monthly household income in our sample; a slightly smaller fraction (2.8%) for piped water households, if we divide the row 2 estimate in Table 5 by average income among our piped water households, and slightly larger (3.3%, dividing Table 5's row 3 estimate by average income among sample households on groundwater) for groundwater households. If WTP for improved water supply ranges from $3 to $6 per month, this is approximately 1.0–2.0% of average household income in the sample. The World Bank suggests that 4% of household income is a benchmark ceiling for affordable expenditures on water service in developing countries (Fujita et al. 2005). All of our estimates lie below that benchmark.

6 Conclusions

We survey 193 low-income households in Lahore, Pakistan to estimate their willingness to pay for water service improvements. Using both parametric and non-parametric estimators of WTP, we find that households are willing to pay about $7.50 to $9 per month for piped water supply that is clean and drinkable directly from the tap, about three to four times the average monthly water bill in our sample for households that currently have a connection to the piped water system. This adds to a growing literature suggesting that households in developing countries would be willing to pay substantial amounts for safe drinking water, suggesting that the ability of water system customers to support the user fees necessary for service improvements may not be a substantial barrier to financing such improvements. Our WTP estimates are also well under what is typically considered "affordable" by the World Bank, a benchmark of 4% of household income. The estimates of WTP for water quality improvements are comparable to the monthly cost of two common in-home treatment techniques, chemical treatment and filtration.

We also estimate household willingness to pay for improved consistency of piped water supply (eliminating supply interruptions and pressure drops). Results suggest that WTP for improvements in supply consistency ($3 to $6 per month) are lower than WTP for improved water quality. This is consistent with households' ability to adapt to supply interruptions (through storage, bottled water purchases, or water borrowed from neighbors, for example),

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[26] The filter system uses ultraviolet light (to eliminate microbial contaminants), a carbon filter for fine particles, and a coarse filter for large particles. The carbon filter requires replacement every two months (we divide this cost in half for our monthly cost estimate). As for chemical treatment, the monthly labor costs for this kind of filtration system are negligible.

[27] Obviously, assuming a longer lifetime for the in-home filtration system will result in lower estimates of monthly cost, bringing the estimated cost below our WTP estimates for water quality improvements. However, the fixed cost of the technology, itself, may simply make it unaffordable to some households.

which may be preferable to the expense of routinely treating water supplies. The estimates of WTP for these improvements in water supply are more reasonable for households currently on groundwater than they are for piped water households, for whom we estimate negative mean WTP.

Our estimates, like all CV estimates, are specific to a particular place and point in time, and readers should exercise caution in transferring our estimated benefits from improving water quality and water supply in the Lahore piped water network to other urban areas in developing countries. Recall that Lahore's WASA customers have water service, on average, about 17 h per day, and that only 6% of customers report a 24-h supply (McIntosh and Yñiguez 1997). When we simulate greater household dissatisfaction with supply interruptions in our sample, we obtain higher estimates of WTP for supply improvements. Were a similar survey to be conducted in a city where supply interruptions were even more frequent, estimates of WTP for supply improvements might be higher. Similarly, when we simulate greater concern among households about the quality of their current source for drinking, WTP for water quality improvement increases. Thus, a CV survey in a city where water quality is perceived to be lower than in Lahore might result in higher estimates of WTP for water quality improvement. Depending on relative perceptions of quality versus supply problems, our finding that WTP is higher for water quality improvements than for water supply improvements might well be reversed in a different setting.

There are important differences in our estimates among households currently connected to the piped water system, and those who are not. Some of this difference is likely due to the fact that groundwater households stand to obtain an extra benefit (a connection to the piped water system) from each water service improvement option we offered in our survey, relative to piped water households. It may also be due to the fact that groundwater households currently perceive their water quality to be quite good, relative to piped water households. Nonetheless, we might expect demand for piped water, and for piped water connections, to increase significantly were piped water providers in Lahore to improve services. Developing a better understanding of the demand responses of different types of households to water service improvements is an important area for further research.

The Millennium Development Goals seek to halve the proportion of people without access to safe drinking water by 2015. This is an ambitious goal, and achieving it would generate very substantial welfare improvements by reducing human morbidity and mortality, particularly among children in developing countries. Achieving this goal will also be costly. Thus, additional research on the various mechanisms through which water service improvements might be financed (including through water tariffs) can play a critical role in designing policies to expand access to clean drinking water.

Appendix A. Willingness-to-pay Questions from Annotated Survey Instrument

The willingness-to-pay questions described below were preceded by a pre-interview statement, the first segment of the survey (which collected household sociodemographic data), and the second segment of the survey (which collected information on current water usage practices), and followed by concluding remarks, as well as an opportunity for respondents to ask questions. While not included here, these sections of the survey are available from the authors on request.

Survey Segment 3: WTP Questions

Prior to asking the WTP questions, respondents were told that what was going to happen next was a hypothetical exercise and that this was not being planned by the local government, Kashf Foundation or any other agency. Quite often, there followed a brief exchange, where respondents would try to ascertain what the impacts of this hypothetical exercise would be, upon which it would be conveyed to them that this exercise had no immediate impact. Then, depending on the primary water source of the household, WTP questions were pursued.

Respondents were asked two separate questions, whether they: (1) would be willing to pay 1.5 times, 2 times or 3 times what they were currently paying for clean water (in the case of those respondents who were not paying anything for their water, one of a set of three pre-fixed monthly billing amounts was used—PKR 160, PKR 220 or PKR 330 (US$2.63, US$3.62 or US$5.43, respectively)[28]; (2) would be willing to pay 1.5 times, 2 times or 3 times what they were currently paying for uninterrupted water supply (again, US$2.63, US$3.62 or US$5.43 respectively, for non-paying respondents).

The choice of which bracket to use was based on sequence—the first respondent would have the 1.5 multiplier applied to both WTP questions; the second respondent would have the 2 multiplier applied to both questions; the third respondent would have the 3 multiplier applied to both questions; and the sequence started over for the fourth respondent.

These households had their "new" WTP amounts conveyed to them in two forms (or as two separate calculations): as a monthly bill (i.e. their current bill multiplied the appropriate multiplier, divided by the appropriate unit of time to translate it into a monthly bill) and in terms of the original billing cycle (two-monthly, yearly) multiplied by the appropriate multiplier.

WTP Questions for Piped-water Households

A picture of a tap was placed in front of the respondent (see Fig. 1) and they were told that this represented their water supply and that they paid the amount earlier reported by them for it. After this, the respondent was asked the two WTP questions, as follows.

WTP question 1: "Suppose that [insert local water authority name] began providing you with clean, straight-from-the-tap drinkable water, would you be willing to pay them [insert monthly bill calculation] per month or [insert bill calculation for original billing cycle] per [insert unit of time for original billing cycle]? The authority will not provide you with a filter, but they will use filtration technology at their end to provide you with clean water (See Fig. 2). Would you be willing to pay them [insert monthly bill calculation] per month or [insert bill calculation for original billing cycle] per [insert unit of time for original billing cycle] if you got clean, straight-from-the-tap drinkable water? Note that this is not going to happen but I am simply asking you to imagine this scenario. What is your response to the amount suggested—accept or reject?"

WTP question 2: "Suppose that [insert local water authority name] began providing you uninterrupted water service without any reduction in pressure. This water is of the same quality you get at present i.e. imagine that [insert local water authority name] is not promising to

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[28] All discussion of money in household surveys was done in PKR—for brevity, we use only US$ for the remainder of Appendix A, to keep the discussion consistent with the tables and text of the paper.

filter the water like I had just asked but instead to provide uninterrupted water service without any reduction in pressure (see Fig. 3); would you be willing to pay them [insert monthly bill calculation] per month or [insert bill calculation for original billing cycle] per [insert unit of time for original billing cycle]? Again, to remind you, this is not actually going to happen but I am simply asking you to imagine this scenario. What is your response to the amount suggested—accept or reject?"

WTP Questions for Groundwater Households

Households using groundwater did not have any form of regular water billing and relied on their own groundwater pumps. There were a few households on piped-water that did not receive a water bill and these exceptions were also asked the WTP questions under this method. Here a fixed amount, that was determined during the focus groups, was used in conjunction with the multipliers. The base amount was set at US$1.83: this amount was multiplied by 1.5, 2 or 3 in the same way described for piped-water households above. Figure 1 was placed in front of the respondent. The enumerator then stated: "We've spoken a little bit about your current water situation. Now, I want you to imagine/suppose that [choose WASA or the LCB, depending on which one's jurisdiction is closer] can provide piped water to your household."After this, the respondent was asked the two WTP questions, using Figs. 2 and 3 as above.

WTP question 1: "Suppose that [insert water authority name], along with connecting you to the piped water grid they could provide you with clean, straight-from-the-tap drinkable water, would you be willing to pay them [insert: pre-fixed amount (i.e. US$2.63, US$3.62 or US$5.43)]? The authority will not provide you with a filter, but they will use filtration technology at their end to provide you with clean water (see Fig. 2). Also, this will not affect your usage of groundwater. Would you be willing to pay them [insert: pre-fixed amount (i.e. US$2.63, US$3.62 or US$5.43)] if you got clean, straight-from-the-tap drinkable water? Note that this is not going to happen but I am simply asking you to imagine this scenario. What is your response to the amount suggested—accept or reject?"

WTP question 2: "Suppose that [insert local water authority name] began providing you uninterrupted water service without any reduction in pressure (see Fig. 3). This water is of the same quality you get at present i.e. imagine that [insert local water authority name] is not promising to filter the water like I had just asked but instead to provide uninterrupted water service without any reduction in pressure; would you be willing to pay them [insert: pre-fixed amount (i.e. US$2.63, US$3.62 or US$5.43)]? Again, to remind you, this is not actually going to happen but I am simply asking you to imagine this scenario. Also, this will not affect your usage of groundwater as you currently do. What is your response to the amount suggested—accept or reject?"

Appendix B

See Table 6.

Table 6 Summary statistics for all household survey variables

	Piped water users ($n = 131$)					Groundwater users ($n = 64$)				
	Mean	SD	Median	Max.	Min.	Mean	SD	Median	Max.	Min.
Household socio-economic characteristics										
Composition										
Number of people in household	7.55	3.55	7.00	25.00	2.00	8.09	2.78	8.00	15.00	2.00
Number of heads of household	1.57	0.91	1.00	6.00	1.00	1.55	0.50	2.00	2.00	1.00
Adults	4.77	2.81	4.00	19.00	2.00	4.77	2.19	5.00	10.00	2.00
Children	2.78	2.09	3.00	11.00	0.00	3.31	2.20	3.00	8.00	0.00
Education										
Fraction of heads of household with max primary education	0.40	0.44	0.00	1.00	0.00	0.39	0.43	0.25	1.00	0.00
Fraction of heads of household with max secondary education	0.34	0.43	0.00	1.00	0.00	0.09	0.25	0.00	1.00	0.00
Fraction of heads of household with max tertiary education	0.03	0.16	0.00	1.00	0.00	0.03	0.16	0.00	1.00	0.00
Fraction of heads of household with any education	0.77	0.39	1.00	1.00	0.00	0.50	0.51	0.50	2.00	0.00
Fraction of adults with max primary education	0.34	0.33	0.33	1.00	0.00	0.29	0.29	0.20	1.00	0.00
Fraction of adults with max secondary education	0.34	0.31	0.29	1.00	0.00	0.12	0.22	0.00	1.00	0.00
Fraction of adults with max tertiary education	0.06	0.18	0.00	1.00	0.00	0.03	0.14	0.00	1.00	0.00
Fraction of adults with any education	0.74	0.30	0.83	1.00	0.00	0.44	0.35	0.45	1.00	0.00
Fraction of children with max primary education	0.54	0.37	0.50	1.00	0.00	0.50	0.38	0.50	1.00	0.00
Fraction of children with max secondary education	0.16	0.31	0.00	1.00	0.00	0.08	0.20	0.00	1.00	0.00
Fraction of children with max tertiary education	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00	0.67	0.00
Fraction of children with any education	0.70	0.34	0.75	1.00	0.00	0.60	0.37	0.67	1.00	0.00
Infrastructure and utilities										
Mean monthly household income (PKR)	325.69	247.45	246.99	1317.31	57.63	246.69	166.32	210.77	1234.97	32.93

Table 6 continued

	Piped water users (n = 131)					Groundwater users (n = 64)				
	Mean	SD	Median	Max.	Min.	Mean	SD	Median	Max.	Min.
Earning members in household (∗ = not specified)	2.53	1.63	2.00	9.00	1.00	3.38	2.12	3.00	8.00	1.00
Rented house (0: own; 1: rented)	0.20	0.40	0.00	1.00	0.00	0.02	0.13	0.00	1.00	0.00
Rent paid (monthly)	10.63	24.06	0.00	131.73	0.00	0.26	2.06	0.00	16.47	0.00
House size (marla)	4.03	2.17	3.50	12.50	1.00	5.72	2.93	5.00	22.50	1.50
Water bill (monthly)	2.40	2.01	1.81	9.88	0.00	0.00	0.00	0.00	0.00	0.00
Electricity bill (summer monthly)	29.56	22.64	24.70	148.20	2.88	18.94	10.08	16.88	57.63	3.29
Electricity bill (winter monthly)	14.41	12.13	10.70	65.87	1.07	10.39	6.58	9.06	37.05	0.91
Gas bill (summer monthly)	5.17	4.59	4.12	27.99	0.00	4.57	8.52	0.00	49.40	0.00
Gas bill (winter monthly)	13.82	11.98	9.88	61.75	0.00	6.61	10.66	0.00	49.40	0.00
Other fuel (wood or bottled gas)	0.82	4.14	0.00	32.93	0.00	5.42	9.80	0.00	49.40	0.00
Assets										
Owns television	0.94	0.24	1.00	1.00	0.00	0.88	0.33	1.00	1.00	0.00
Owns radio	0.05	0.21	0.00	1.00	0.00	0.09	0.29	0.00	1.00	0.00
Owns computer	0.26	0.44	0.00	1.00	0.00	0.09	0.29	0.00	1.00	0.00
Owns air-conditioner	0.17	0.38	0.00	1.00	0.00	0.03	0.18	0.00	1.00	0.00
Owns refrigerator	0.82	0.39	1.00	1.00	0.00	0.45	0.50	0.00	1.00	0.00
Owns telephone	0.37	0.49	0.00	1.00	0.00	0.22	0.42	0.00	1.00	0.00
Owns mobile-phone	0.89	0.32	1.00	1.00	0.00	0.78	0.42	1.00	1.00	0.00
Owns music system	0.40	0.49	0.00	1.00	0.00	0.31	0.47	0.00	1.00	0.00
Owns iron	0.95	0.23	1.00	1.00	0.00	0.70	0.46	1.00	1.00	0.00
Owns washing machine	0.84	0.37	1.00	1.00	0.00	0.55	0.50	1.00	1.00	0.00
Owns cycle	0.20	0.40	0.00	1.00	0.00	0.22	0.42	0.00	1.00	0.00
Owns motorcycle	0.55	0.50	1.00	1.00	0.00	0.20	0.41	0.00	1.00	0.00
Owns rickshaw	0.08	0.27	0.00	1.00	0.00	0.03	0.18	0.00	1.00	0.00
Owns car	0.06	0.24	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

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