Cost of services and willingness to pay for reliable urban water supply: a study from Delhi, India

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Abstract The provision of safe and universal water supply in an equitable and efficient manner is extremely important for urban water reform programs currently being carried out in developing countries. The sector reform not only requires a significant amount of working capital, but also people’s willingness to pay for the improved infrastructure. This paper serves two purposes – first, it explains the meaning of ‘full-cost of water services’ in urban areas and attempts to provide a framework to value economic and environmental externalities for the urban water supply and use through a case study of India’s capital city – Delhi. The second part uses contingent valuation method to establish people’s willingness to pay from a survey of 1,100 households for water supply with better quality and reliability. Policy implications are subsequently discussed, keeping in mind cost of provision of water supplies. Also included is the assessment of the cost of unreliable supply (coping cost), which otherwise households are spending in the absence of a reliable supply. The paper shows several instances of reciprocal externality wherein the residents themselves absorb the cost of over-extraction, in terms of declining water tables, and cost of salinity in terms of decentralised treatment cost.

Keywords Externalities; pricing; urban water supply; willingness to pay

Introduction
Reliable water supply with higher levels of quality is attainable through higher costs and hence higher prices to customers. To determine the appropriate level of service improvements, information is needed on full-cost of water provision, what customers want and how much they are willing to pay. This information is important for making explicit decisions about appropriate mix of service quality and price (Whittington and Swarna, 1994). However, there is some confusion about the exact meaning of some of the articulated principles of “full-cost pricing”, like environmental damage cost. In particular, it is not clear at many places how to value environmental externalities for the urban water supply and use. Though economists have tried to calculate this cost (Munasinghe, 1990; Bhatia et al., 1994; Briscoe, 1996; Bowers and Young, 2000; Zhang, 2003), there appears to be some bias in the methodology adopted like over estimation of the damages.

A review of the existing literature on marginal cost pricing for urban water showed that this area has not been fully examined and hence, further research is needed. Ebarvia (1997) suggested setting the optimum price equal to the marginal opportunity cost (MOC). The principle of MOC pricing outlines three major components for the supply of a natural resource: (a) marginal production costs (MPC), (b) marginal user costs (MUC), and (c) marginal environmental costs (MEC). According to the researchers, the socially optimal price should equal the sum of these components. The measurement of each of them is briefly discussed below from a case study of Delhi’s water utility. Subsequently, the paper examines how much people are willing to pay to support a policy of providing them a reliable water supply that meets World Health Organization (WHO) standards.
The alternate scenario emphasizes two aspects of the proposed improved services:
(i) longer hours of service that would gradually move towards continuous supply, and (ii) good quality water with no health risk of contamination.

**Marginal production cost**
Marginal value reflects the economic value of water but it is difficult to implement it. Difficulties in implementation arise because it is difficult to define and estimate marginal cost in quantitative terms needed to determine appropriate user charges. Because of capital indivisibility problem of a typical water supply system, costs will be marginal at certain times and non-marginal at other times. This results in significant fluctuations in price. Studies by Saunders and Warford (1977) indicate that when the problem of capital indivisibility exists, computing the marginal cost as the average unit cost of incremental output becomes more appropriate. This necessitates the calculation of average incremental cost (AIC) as given below. The numerator in the formula is the present value of the least-cost investment stream plus the incremental operating and maintenance costs while the denominator is the present worth of the incremental volume of water produced over the period considered (Warford, 1994):

\[
AIC = \frac{\sum_{t=1}^{T} (I_t + M_t - M_0)/(1 + r)^t}{\sum_{t=1}^{T} (Q_t - Q_0)/(1 + r)^t}
\]

where,
- \(I_t\) is the investment cost in year \(t\),
- \(M_t - M_0\) is the operations and maintenance cost in year \(t\) due to incremental consumption of water in year \(t\) or \(Q_t - Q_0\), and
- \(r\) is the discount rate.

Using this, the AIC for per m³ of water comes out to be 13.18 Rs (0.30 US$) (Figure 1).

**Marginal users cost**
The cost of future use foregone due to the depletion of a resource may be estimated as the cost of replacing the depleted asset at some future date (if substitutes are available). The MUC can, therefore, be estimated by getting the difference between the present

![Figure 1](https://iwaponline.com/ws/article-pdf/5/6/135/417856/135.pdf)

**Figure 1** Total production cost and revenue for Delhi’s water utility – total revenue per m³ is 4.63 Rs while total expense is 13.18 Rs (2003–2004 data; 1 Rs = 0.023 US$ at 2005 price level, 1 Crore = 10 million Rs)
value of the MPC of the substitute or replacement technology and the present value of
the MPC of existing technology.

\[ MUC = \frac{(P_b - C)}{(1 + r)^T} \]

where,

- \( P_b \) is the price of replacement technology,
- \( C \) is the price of existing technology,
- \( r \) is the discount rate, and
- \( T \) is the time at which the replacement technology comes in or the switch to the back-
  stop occurs.

Following strategies are considered for Delhi’s water supply augmentation: (a) supply
augmentation through leakage reduction; (b) surface water augmentation through con-
struction of dams; and (c) augmentation through groundwater development. Currently
42% (1,279 million litres a day, MLD) of treated water is lost due to leakages. The pre-
sent level of 42% system losses could be reduced to 25% in the short term (by 2011)
with a long-term target of 15% (by 2021) through upgradation and replacement of distri-
bution network. The total investment for this is set at 32 million US$ (2005 price
level) for a total augmentation of about 819 MLD including 187 MLD from recovery
of water at the four water treatment plants. For surface water augmentation from dams,
Tehri dam (728 MLD at 161 million US$), Kishau dam (1,683 MLD at 255 million
US$), Renuka dam (1,251 MLD at 185 million US$) and Lakhwar Vyasi dam (614
MLD 140 million US$) are considered totaling 741 million US$ for augmenting 4,277
MLD of water. Plans for dams at Kishau, Renuka and Lakhwar Vyasi are at a very pre-
liminary stage only, and these dams would take at least a decade and half to be
realised. The third option of augmenting through groundwater development is not con-
sidered for the future, as there is hardly any scope for further groundwater development
due to falling water table. Only a small fraction of the water demand is being met by
the groundwater and these are already overexploited in the current scenario. Using the
above figures at a discount rate of 12% and 20 years timeframe, the MUC comes out to
be 14.31 Rs/m³ of water (0.32 US$/m³).

Marginal externality cost

Economic externalities

This consists of estimating the cost of bad quality unhygienic and unreliable public water
supply termed as the “unreliability cost”. Due to water agency’s inability to provide effi-
cient and reliable supply, customers spend a significant amount of money to make the
supply reliable in terms of both quality and quantity (see Table 1). The indirect cost of
unreliable supply to customers in Delhi is found to be 259 Rs (2.97 US$) per month per
household – 4.6 times the average monthly water bill paid to the public water utility. An
increasing proportion of urban customers are already making their own investments to
simulate ‘24 × 7’ water supply at the household level – borewells, surface and overhead
storage tanks, booster pumps, tankers suppliers, etc. These investments are supplemented
with water purification methods such as filtration and boiling.

Environmental externalities

Examples of environmental externalities in urban water systems include the decline in
natural water quality and quantity. When a wastewater stream pollutes a river or contami-
nates a groundwater aquifer, the condition of the water resource changes. The impact of such changed environmental conditions may decrease the society’s welfare as a whole. The environmental externalities cost can be calculated as indicated below (a, b and c).

(a) Due to river getting polluted by wastewater and effluents discharge:
- Lost scenic boat trips along the river side = estimate of total visitor days in a year × gross daily net revenue
- Lost fisheries = (Carrying capacity of river for fisheries at the current level – carrying capacity of river for fisheries at the target level) × unit market value of the species concerned × sustainable off-take percentage (50%)
- Lost wildlife and biodiversity = additional costs of achieving minimum target river water quality and flow level = cost of upgrading sewage treatment plants + cost of improving stormwater control + cost of importing water to the catchment.

Care should be taken to ensure that there is genuinely some lost value. Minor impacts are included in lost wildlife and biodiversity opportunities. Where wildlife and biodiversity objectives are poorly defined, the work may need to be underpinned by a series of studies to clarify the nature of public preferences for wildlife and biodiversity conservation. Alternatively, the impact of wastewater disposal can be indirectly measured in terms of the impaired ability of the river to produce potable water because of wastewater disposal. The investment and operating costs of wastewater collection and treatment up to the river’s receiving water quality can be taken as a proxy of the environmental cost of wastewater disposal (Warford et al., 1994). With respect to sewerage services in Delhi, around 73% of the population is connected to the sewer network. There are 17 wastewater treatment plants with nominal capacity of 2,330 MLD. This is more than adequate for an estimated present day volume of 1,847 MLD of wastewater for treatment. However, to meet the future demand, as well as reduce unsafe disposal of wastewater in the environment, 20% additional capacity would be required for year 2021 with

Table 1 Cost of unreliable supply borne by people in unplanned settlements in Delhi as measure of economic externalities

<table>
<thead>
<tr>
<th>Averting measures</th>
<th>% of households</th>
<th>Annualised capital cost</th>
<th>Recurring/O&amp;M cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage in buckets/drums</td>
<td>88.23</td>
<td>180 Rs</td>
<td>25 Rs</td>
</tr>
<tr>
<td>Overhead tanks</td>
<td>51.47</td>
<td>0.75 Rs/Litre</td>
<td>50 Rs</td>
</tr>
<tr>
<td>Use of private tankers</td>
<td>4.90</td>
<td>NA</td>
<td>200 Rs</td>
</tr>
<tr>
<td>Use of public handpumps</td>
<td>17.15</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Use of community standposts</td>
<td>14.70</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Use of bottled water</td>
<td>3.26</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Use of ceramic filters</td>
<td>16.99</td>
<td>141.50 Rs</td>
<td>200 Rs</td>
</tr>
<tr>
<td>Use of UV filters</td>
<td>12.25</td>
<td>1,061 Rs</td>
<td>400 Rs</td>
</tr>
<tr>
<td>Use of RO filters</td>
<td>0.32</td>
<td>2,743 Rs</td>
<td>1,500 Rs</td>
</tr>
<tr>
<td>Boilingb</td>
<td>12.74</td>
<td>NA</td>
<td>532 Rs</td>
</tr>
<tr>
<td>Use of boosting pumps</td>
<td>53.10</td>
<td>813.50 Rs</td>
<td>1,015 Rs</td>
</tr>
<tr>
<td>Use of borewell pumps</td>
<td>27.77</td>
<td>976 Rs</td>
<td>533 Rs</td>
</tr>
<tr>
<td>Cost of sickness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sickness due to diarrhoeal diseases</td>
<td>19.60</td>
<td>NA</td>
<td>704 Rs</td>
</tr>
<tr>
<td>Average annual coping cost per household</td>
<td></td>
<td></td>
<td>3,112 Rs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(72 US $)</td>
</tr>
</tbody>
</table>

Unreliability cost is calculated as annualized sum of money spent on drawing water from alternate sources, groundwater pumpage cost, household water treatment cost and cost on treating waterborne illness mainly due to diarrhoeal diseases.

For calculating cost of boiling, consumption of cooking gas for 25 min/d is taken. Considering gas consumption of 180 gm/hr and price of cooking gas cylinder (14.5 kg) at 282 Rs, the cost of boiling comes out to be 1.46 Rs/d. Data collected from 650 residential households.
a total investment of 70 million US$. The current cost of treatment is 2.80 Rs/m³. Using the formula for AIC, at a discount rate of 12% for 20 years’ annualized stream, the cost per m³ when additional capacity is built would be 8.50 Rs/m³ (0.19 US$).

(b) **Due to groundwater aquifer getting saline (external costs due to salt water intrusion):**
- Treatment cost to desalinise saline water: this can be measured as the cost to desalinise water to the potable standards.
- Reduced life span and productivity of wells: when the productivity of the wells declines, the operation and maintenance cost goes up. In some situations, one has to abandon the existing well and look for alternate sources of water.

In our study area, it was observed that many group-housing societies have installed Reverse Osmosis (RO) plant for treating the saline water in the absence of a reliable municipal supply. The cost of treating saline groundwater comes out to be 78 Rs (1.8 US$) to 48 Rs (1.1 US$) per m³ of water treated depending upon the membrane life and capacity of the plant (Figure 2). In the absence of reliable data, this cost estimate can be taken as the cost of groundwater getting saline due to excessive withdrawal. This is an example of reciprocal externality wherein the residents themselves absorb the cost of over-extraction, in terms of declining water tables, and cost of salinity in terms of RO treatment cost.

(c) **Due to groundwater aquifer getting depleted (external costs due to over-extraction):** This is calculated as cost of over-extraction in terms of declining water table, i.e., increasing pumpage cost. The basic equation relating pumpage to water table is (Gisser, 1983):

\[ A \cdot S \frac{\Delta H}{\Delta t} = R_n + \alpha W - W \]

where,
- \( A \) is the area of the aquifer,
- \( S \) is the storativity coefficient,
- \( H \) is the depth of water table,
- \( R_n \) is the natural recharge, \( \alpha \) is the return-flow coefficient, and
- \( W \) is the volume of water pumped from the aquifer.

During the period \( \Delta t \), the water table has been lowered by \( \Delta H \). The vertical distance between the water table, \( H \), and the pumping elevation, \( P_E \), termed the lift \( (P_E - H) \),
increases over time as the water level declines. Correspondingly, the pumping efficiency of wells declines as the lift increases. Thus, the falling water levels result in rising marginal cost of pumping. Let $c$ denote the marginal cost of pumping per cubic metre per metre of lift (i.e., cost of energy to lift water), then the operation cost (OC) can be expressed as:

$$OC = c(P_E - H)$$ (4)

In general, in the study area it was found that on an average for every one metre decline in water level, there is additional burden of 0.48 kWh of electricity on households.

**Willingness to pay for a reliable water supply**

Preferences for change versus status quo and consumer’s willingness to pay are estimated through discrete choice multinomial logit (MNL) and nested logit (NL) model with a linear utility function using maximum likelihood estimation technique (Haab and McConnell, 2002; Ahmad et al., 2005; MacDonald et al., 2005). In total a 1,100 household survey was completed spread over various planned and unplanned settlements through multistage stratified random sampling. Few of them were rejected due to non-response and missing data. Specifically, having presented a scenario and policy the respondents were asked their willingness to pay for improved ‘alternate scenario’ through a set of split bidding game valuation questions. The valuation section was finally concluded by respondent’s belief in the likelihood of improved water supply attributes and reasons for not willing to pay if any. The estimated parameters of the choice model define the utility functions for each alternative. Thus, the dependent variable is choice of water supply system. In making a choice, individuals are assumed to evaluate ‘alternatives’ on the basis of their ‘attribute profile’ and then choose the alternative that maximizes their utility. Theory and intuition suggest that preferences for improved water supply and WTP would differ across population groups with different socio-demographic characteristics, planning status, existing water situations, and opinions about water quality and public policy. Accordingly, in the model, respondent’s awareness, education, household size, etc. were taken as independent variables. Quality was defined in terms of single improved quality meeting WHO standards or dual quality supply with separate provision of potable and non-potable water. Reliability was defined in terms of increased supply hours (over and above current supply hours) that meet the customer’s end use demand. The upper bound level, representing potential reliability improvements that are considered to be technically feasible, is continuous supply. Thus three principal alternative specific factors influencing an individual’s utility are the quality, supply hours, and the bid amount. The mean WTP is calculated as:

$$E(WTP) = \frac{1}{\beta_y} \ln \left[ 1 + \exp \left( ASC + \sum_n \gamma_n ASC * S_n + \sum_k \beta_k Z_k + \sum_k \delta_k Z_k \right) \right]$$ (5)

where,

- $\beta_y$ gives the marginal utility of income and is the coefficient of the cost attribute or bid levels,
- $S_n$ represents socio-economic or environmental attitudinal variables for the nth individual,
- $Z_k$ is a vector of choice attributes,
- $\beta$ is a vector of coefficients of explanatory variables.
The effects of attributes in the scenario sets are captured by the \( Z \) variables, while the \( \text{ASC} \) captures any systematic variations in choice observations that are associated with an alternative that are not explained by either the attribute variation or respondent’s observed socio-economic characteristics (Train, 2003). It is possible to include socio-economic as well as attitudinal variables into the utility functions by estimating the variables interactively, either with the \( \text{ASC} \) or with any of the attributes from the choice set. As mean WTP is a non-linear function of model parameters (which are random variables), confidence intervals for mean WTP cannot be calculated conventionally. Therefore, 95% confidence intervals around the estimated mean WTP were calculated using the method given by Kanninen (1993) which approximates the asymptotic variance of the ratio of two random variables (Table 2).

From the discrete choice model, it is concluded that customers are willing to pay 295 Rs per month (6.78 US$) for dual quality supply and 189 Rs per month (4.35 US$) for single quality reliable supply. However, this cost is above the operation and maintenance cost of service provision, but does not cover the user’s cost and environmental externalities. This shows that customers are not willing to pay the “full-cost” of water primarily because (a) the full-cost of water is very high due to environmental and resource costs; and (b) the commonly held view that the provision of basic water and sanitation services is the job of the government, and the customers have a right to access such services at a low price, irrespective of their ability to pay for them. Based upon the model, customers are willing to pay higher amounts with increasing service hours, level of awareness, and education. Therefore, the public institutions that currently deliver water should increase their service standards to fully receive the customer’s willingness to pay and restructure the institutions to bring the cost to an economically efficient level (Table 3).

**Should externality cost be included in public pricing policy?**

Typically, the supply costs (incurred in financing and operating the abstraction, transmission, treatment and distribution systems) are considered to be relatively higher, while the opportunity costs (imposed on others as a result of use of the water) are lower than the supply cost. Accordingly, the priority issue for the economic management of urban water supplies relates primarily to the supply cost. However, researchers argue that adequate recovery of costs of water services has to be implemented into the pricing policy taking sustainable social, economic and environmental impacts into account. Nonetheless, it is ambiguous at many places how to internalise such impacts for the urban water supply and use. Therefore, designing an effective public externality pricing policy is challenging due to uncertainty involved in the measurement of externality cost. While the theoretically best approach to incorporate external costs in water price (i.e., charging each user the cost of external damage they generate) is not practical, another suitable

| Table 2 List of explanatory variables and their description used in the discrete choice model |
|---|---|
| Variable | Description |
| ASC | Alternate Specific Constant for Status Quo Option |
| PLANNING | Level of planning from A to H as classified by property class |
| EXTR_DUR | Total duration of supply demanded in hours |
| PAYMENT | Increment to monthly water bill in Rs (Bid levels) |
| AWARE | Respondent’s level of awareness |
| AGE | Respondent’s age in years |
| HEAD | Dummy for head of the household; 1 if yes, 0 otherwise |
| ENV | Dummy for water quality as major environmental problem; 1 if yes, 0 otherwise |
| EDU | Respondent’s total years of education |
Table 3: Estimation of WTP for two alternate scenarios using nested structure under multinomial logit model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Single Supply (Scenario 1)</th>
<th>Coefficient</th>
<th>t-ratio</th>
<th>Mean</th>
<th>Coeff. x Mean</th>
<th>Dual Supply (Scenario 2)</th>
<th>Coefficient</th>
<th>t-ratio</th>
<th>Mean</th>
<th>Coeff. x Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTRA_DUR</td>
<td>0.165237</td>
<td>11.876</td>
<td>8.21</td>
<td>1.356596</td>
<td></td>
<td>0.165237</td>
<td>11.876</td>
<td>5.58</td>
<td>0.222022</td>
<td></td>
</tr>
<tr>
<td>PAYMENT</td>
<td>-0.00413</td>
<td>-1.760*</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-0.00413</td>
<td>-1.760*</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ASC × PLANNING</td>
<td>-0.33562</td>
<td>-4.406</td>
<td>3.05</td>
<td>-1.02365</td>
<td></td>
<td>-0.22358</td>
<td>3.221</td>
<td>5.29</td>
<td>1.182516</td>
<td></td>
</tr>
<tr>
<td>ASC × AWARE</td>
<td>0.56249</td>
<td>3.723</td>
<td>3.03</td>
<td>1.704345</td>
<td></td>
<td>0.749801</td>
<td>5.684</td>
<td>2.11</td>
<td>1.58208</td>
<td></td>
</tr>
<tr>
<td>ASC × AGE</td>
<td>-0.03886</td>
<td>-3.700</td>
<td>39.6</td>
<td>-1.53903</td>
<td></td>
<td>-0.03292</td>
<td>-3.708</td>
<td>42.01</td>
<td>-1.38299</td>
<td></td>
</tr>
<tr>
<td>ASC × HEAD</td>
<td>0.414153</td>
<td>1.390*</td>
<td>0.43</td>
<td>0.178086</td>
<td></td>
<td>0.607752</td>
<td>2.414</td>
<td>0.61</td>
<td>0.370729</td>
<td></td>
</tr>
<tr>
<td>ASC × ENV</td>
<td>1.04899</td>
<td>3.197</td>
<td>0.24</td>
<td>0.251916</td>
<td></td>
<td>1.10176</td>
<td>3.826</td>
<td>0.246</td>
<td>0.271033</td>
<td></td>
</tr>
<tr>
<td>ASC × EDUC</td>
<td>0.26607</td>
<td>5.441</td>
<td>14.36</td>
<td>3.820722</td>
<td></td>
<td>-0.00666</td>
<td>-0.026*</td>
<td>10.78</td>
<td>-0.00716</td>
<td></td>
</tr>
</tbody>
</table>

Log likelihood function: -642.353
Chi-squared: 730.065
Pseudo R-square: 0.44996
No. of observations: 1,063
E (WTP): 295.05 Rs
95% confidence intervals: [304.50 – 285.60 Rs]
95% confidence limits: [198.77 – 179.87 Rs]

*Denotes acceptability below 95% confidence limits
approach that gives the right signals can be pursued. There are several instances of reciprocal externality wherein the residents themselves absorb the cost of over-extraction, in terms of declining water tables, and cost of salinity in terms of decentralised treatment cost. Environmental externality costs should only be included where they are actually incurred and paid by the water utility. It is not fair to charge for externalities that are incurred due to public water utility’s inefficiency. Water prices may be set so that revenues from water sales cover all operating costs, on-going maintenance costs, capital expenses necessary for ongoing operation, and costs of water use to the environment. The costs of water use to the environment may be included in the water bill by a “sewerage surcharge” that is required to treat the wastewater up to the stream’s receiving quality. In summary, to charge each water user for the exact external cost that their actions imposes on others is unworkable. This would require estimates of the environmental damage in monetary terms that additional increments of water use cause for each water user and development of a set of differential charges reflecting damage cost. This task is very complicated and purely site-specific. Quantifying appropriate charges to “internalise” the externality is thus a major research challenge.

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References
