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Mobilising private resources for public services: The transition to private water sources in rural Bangladesh

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Mobilizing private resources for public services: the transition to private water sources in rural Bangladesh
Final report

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Abstract

Across countries and history, most currently high-income areas have transitioned from community water sources to private, household-level water sources. In doing so, they have also transitioned from dependence on government or donor subsidies to a more sustainable funding model based primarily on user fees. Developing countries face a dilemma: when and how should they make this transition? We estimate the willingness-to-pay for household-level connections in two communities in rural Bangladesh and combine these estimates with pipeline costs to identify the currently most cost-effective pricing strategy. We show that economies of scale in infrastructure provision strongly dominate revenues raised by user fees so that the most cost-effective price is zero.

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1 Introduction

Across countries and history, most high-income areas have transitioned from community water sources to private, household water connections (OECD, 2009; UNICEF & WHO, 2011), largely eliminating morbidity and mortality associated with poor quality water and sanitation (Alsan & Goldin, 2019; Cutler & Miller, 2005). Recognizing the importance of this transition, Sustainable Development Goal (SDG) 6 aspires to universal and equitable access to safely managed drinking water—defined as located on premises, available when needed and free from contamination—by 2030. With this deadline looming, however, one quarter of the world's population, or two billion people, still lack access to safely managed drinking water as defined in SDG 6 (WHO & UNICEF, 2021). Most of these people (about 70%) live in rapidly developing lower-middle-income countries, such as Bangladesh, the context for this study. If present trends continue, just under a fifth of the world's population will still lack access to safely managed drinking water in 2030, falling far short of the SDG 6 target.

Importantly, the transition to private sources has also historically been accompanied by a transition away from dependence on government or donor subsidies to a more sustainable funding model based to a greater degree on user fees (OECD, 2009). Today's developing countries face a dilemma: when, and how, should they adopt such an approach?

A key policy unknown is how much more households of different income levels are willing to pay for household drinking water connections than for community sources, the status quo for much of the world (UNICEF & WHO, 2011). This study conducts an incentive-compatible willingness-to-pay elicitation to measure how households in rural Bangladesh value private connections.

Our empirical design is based around the construction of a real piped water network. Water is pumped from a deep borehole that draws water from a safe aquifer to elevated storage in a water tower. Water then flows by gravity through a pipeline network. The pipeline network has both community taps and the potential to connect individual households to running water. A price lottery generates random variation in whether or not households connect to the network. Our design allows us to measure how much households vary household connections compared to community connections, keeping water quality constant.

We estimate a demand curve that declines steeply in price. Estimated demand for a piped water connection declines to 75% of households at a price of 1 US$ and about 24% at 10 US$. The cost of the system as implemented is approximately 101 US$/household. Combining these data with information on the construction costs of the pipeline network, we estimate that the most cost-effective price of a household connection is zero. This is because economies of scale in the piped water networks are a substantially stronger driver of cost-effectiveness than revenues raised via user fees.

Real-world take-up diverges from the behaviour implied by the estimated demand curve in important ways that we are yet to fully understand, possibly driven by unfamiliarity with the product on offer. Even with a more optimistic scenario for demand based on observed take-up, the most cost-effective price remains zero.

Previous evidence about how households value access to safe drinking water is limited. Studies that simply ask households how much they are willing to pay may not be reliable. Households may understate their willingness-to-pay, if they believe that truthfully revealing a high willingness- to-pay will lead them to be charged higher prices, or overstate their willingness-to-pay, if they believe that provision of water infrastructure depends on their reporting a high willingness-to-pay. The few existing studies that use experimental methods to elicit truthful valuations of safe water do so for household water treatments, water delivery, or for community safe sources, none of which meet the definition of safely-managed drinking water in SDG6 (see Ashraf, Berry, & Shapiro, 2010; Berry, Fischer, & Guiteras, 2020; Burlig, Jina, & Sudarshan, 2024; Null et al., 2012). This study is the first to provide incentive-compatible measures of willingness-to-pay for safe household water connections.

The paper proceeds as follows: section 2 describes the context, and section 3, the piped drinking water intervention. Section 4 describes the data collection and design of the willingness to pay elicitation. Section 5 describes willingness-to-pay for a pipeline connection and compares it to observed demand. Section 6 combines estimates of demand with information about the cost of the intervention to evaluate the most cost-effective pricing strategy. Section 7 concludes.

2 Context

The context for this research program is the safe drinking water crisis in Bangladesh. Access to safe drinking water remains persistently low, despite years of effort by the Bangladeshi government and other organizations. Progress has been extremely limited over the last 20 years (UNICEF and WHO 2023). The most recent systematically-collected data (BBS & UNICEF, 2019) suggest that 61% of the Bangladeshi population—around 100 million people—lack access to a safely-managed source of drinking water, as defined by the SDGs (free from contamination and available, on premises, when needed). In rural Bangladesh, the vast majority of people (92%) use hand-pumped tubewells either belonging to their own household or a close neighbour or relative. Among those who lack access to a safely-managed source, 30 million people use sources that are contaminated with arsenic, a naturally-occurring pollutant in groundwater. Because drinking water can also be contaminated between transport from the source and the point of use, or during storage, an even greater number have bacterial contamination in their drinking water (82% of the population or 136 million people).

Both exposure to fecal contamination in drinking water and arsenic contamination have potentially severe health effects. Exposure to faecal bacteria in drinking water increases the risk of diarrheal disease (Khan, Hossain, Chakraborty, & Mistry, 2022; Luby et al., 2015), which is linked to long-term health and child development (Piper et al., 2017; Prüss-Ustün et al., 2014) and is still the third-leading course of child mortality worldwide (Paulson et al., 2021). Bangladesh has one of the world's highest rates of stunting (Bank, 2018), to which water-borne disease likely contributes (Humphrey, 2009).

Long-term exposure to arsenic also leads to a number of serious health impacts (Hong, Song, & Chung, 2014). Daily use of arsenic-contaminated water at the Bangladeshi standard of 50 parts per billion (ppb) is associated with an additional 1 in 100 lifetime risk of cancer, rising to more than 1 in 10 for higher contamination levels (Smith, Lingas, & Rahman, 2000). There is also evidence of health impacts from exposure at lower levels, including levels below the more conservative WHO standard of 10 ppb (Rahman, Ng, & Naidu, 2009). The epidemic of arsenic-related disease in Bangladesh has been called "the largest poisoning of a population in history" (Smith et al., 2000).

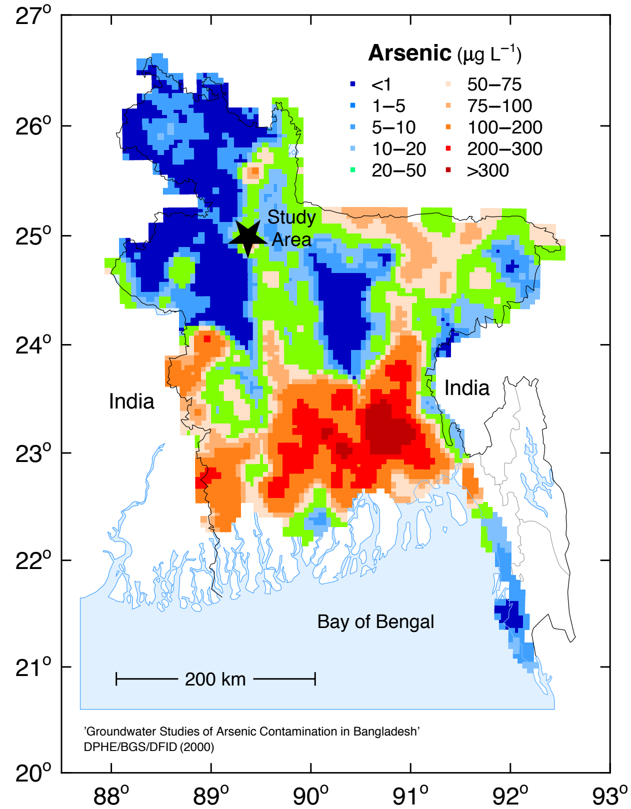
The immediate context for our study is Shibganj Upazila in Bogra District in north-western Bangladesh (Figure 1). Although outside the epicentre of the arsenic contamination problem, government officials and national media reported high levels of arsenic in scattered pockets. The area had received few interventions to address the arsenic problem before a prior experiment we conducted (Cocciolo, Ghisolfi, Habib, & Tompsett, 2023; Cocciolo, Ghisolfi, Habib, Rashid, & Tompsett, 2021). In 2015, before interventions we implemented during this experiment, 63% of households in a sample of communities from arsenic-affected areas were exposed to arsenic in their primary source of drinking water, corresponding to an additional 4 deaths from cancer in every community. Fecal contamination in drinking water was also widespread: 65% of sample households had fecal contamination in their drinking water before the intervention.

We selected two communities from the control group of our previous experiment. We previously collected data from these communities in 2015 and again in 2018, and we also provided information about water quality to households within the communities at this time. However, we had not conducted any previous interventions in these communities. The selection criteria for the communities were that they be sufficiently large (more than 150 households) to ensure that building a pipeline would be reasonably cost-effective and that they have an internal geography that was amenable to the construction of a single pipeline system, i.e., with clusters that were not too geographically distant from one another and with a potential site for the water tower.

3 Intervention

The physical intervention we consider is a piped water network that provides households with individual water connections (taps). The network has three key features: 1) a borehole to a safe aquifer—an underground layer through which groundwater flows—that is sufficiently deep to be isolated from sources of both bacterial and arsenic contamination; 2) a motorized

Figure 1: Arsenic contamination in Bangladesh



Notes Arsenic contamination map reproduced with permission from BGSDPHE2001.

electric pump to overhead storage; and 3) a simple gravity-fed pipeline distribution system. A water sensor in the overhead tank detects when water levels are low and automatically initiates pumping, so that the level of water in the storage tank should always be sufficient to allow water to flow continuously through the pipeline network. Flow meters in the pipeline are monitoring flow, allowing us to track how successfully the pipeline provides drinking water in future. Water began flowing through the pipeline on 28th November 2024. Figure 2 shows the water tower.

The network has a maximum capacity of 200 households, each of whom can be served with their own private tap. As constructed, the system currently serves 135 households. Pipelines are laid to connect a total of 176 households. The total installation cost was US$17,818 at current exchange rates, or approximately US$101 per household physically connected. Approximately, this breaks down to a cost of US$4795 for the borehole, pump, and overhead storage system (the fixed costs of the system) and a per household cost of the pipe network of US$74 (the variable costs).[1] The fixed costs create economies of scale whereby the cost per household falls with increasing numbers of connected households (Figure 3).

[1] While our realized costs are a useful benchmark for such systems, we note that the optimal scale for a pipeline network is around 400 households, likely with lower per household costs.

Figure 2: Water tower for pipeline network

Notes Photo credit: Md. Ahasan Habib.

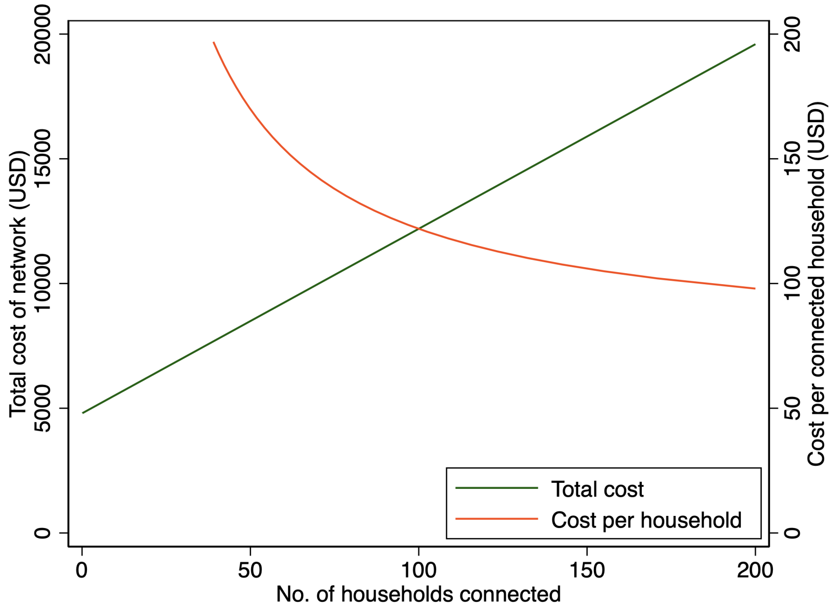
Figure 3 results from assuming that total variable costs increase linearly with the number of households connected. In practice, this assumption probably underestimates economies of scale. When more households connect, it is likely that the distance between the connected households reduces. (Strictly, an economy of density). If the distance between connected households reduces, the average variable cost also reduces, because shorter pipelines and less excavation are required.

Managing the piped water system will require monthly water fees from tap owners, but these costs are relatively small compared to the costs of installing the system.

In addition to the household connections, the pipeline network has three community taps, one in each cluster. This design ensures that any household living in the community can access drinking water from the system.

Compared to safe community sources, the potential advantages of a piped water network from an engineering and public health perspective are twofold. First, taps are less susceptible to the introduction of contamination than are tubewells, and few households use each water point. The risk of introducing contamination into the system is lower and the health consequences of any introduced contamination are also less likely to be severe, because of

Figure 3: Costs of pipeline



Notes Graph shows total costs and costs per household connected of a local pipeline network, up to a maximum capacity of 200 households. The graph of cost per household is truncated at US200$forreadability$.

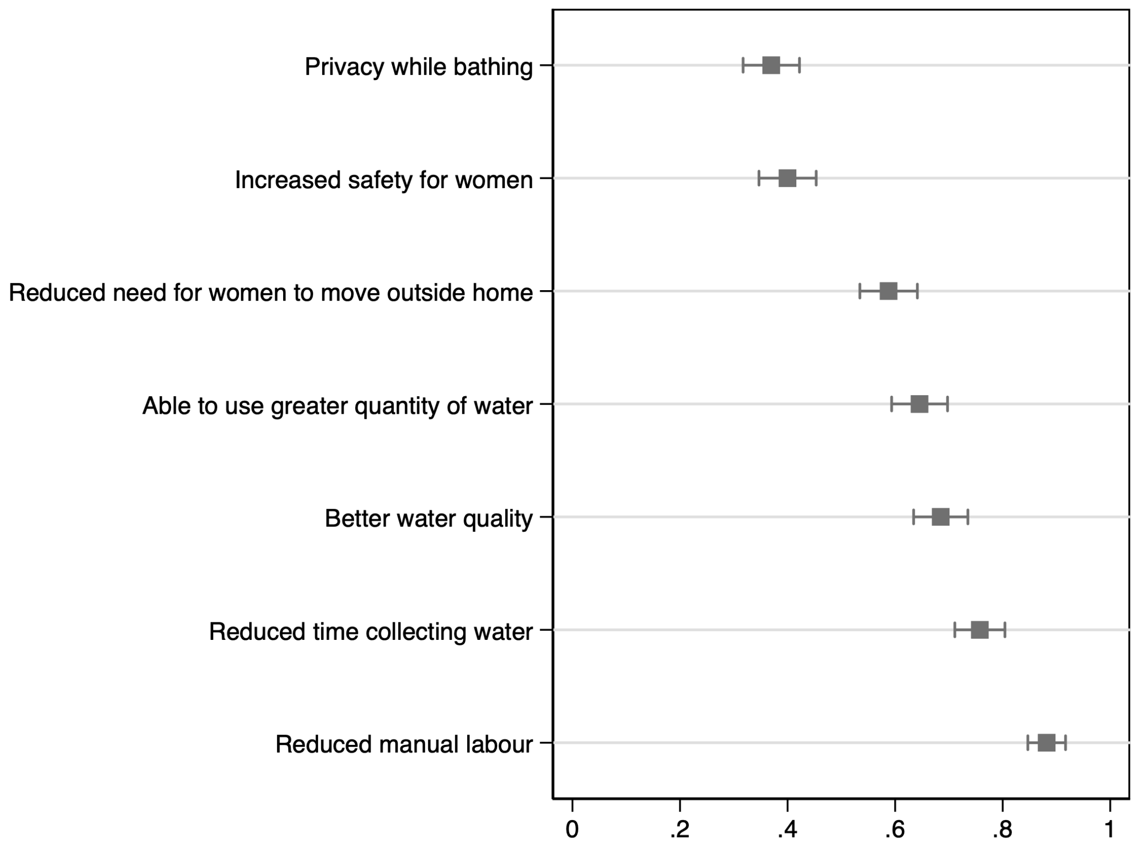
the reduced risk of cross-contamination across different households: exposure to one's own household's bacteria carries less risk of disease transmission than exposure to bacteria from other households. Second, individual water connections are likely to reduce the distances over which households transport water as well as the likelihood that they store water in the house before drinking it. Both transport over greater distances and storage over longer time periods increase the risk of contamination.

A piped water connection to an individual household also offers advantages beyond its health benefits. A large share of households (78%) in our study communities express interest in a household piped water connection. These households cited, on average, 4.4 potential benefits of a piped water connection. Among the advantages cited, households emphasised the labour-saving nature of a household connection. In addition, a substantial share of households cited the reduced need for women to move outside the home to collect water, a striking feature of the data given the emphasis in the policy literature on the idea that better access to water empowers women (Figure 4).

4 Methods

We collected baseline data in October-November 2023, and we are collecting preliminary endline data in November-December 2024.

Figure 4: Advantages of a pipeline connection



Notes Graph shows share of respondents giving listed advantage when asked about the relative advantages of a household piped water connection. Sample includes only households interested in a piped water connection in study communities (330/422). 90% confidence intervals reflect robust standard errors (Long & Ervin, 2000).

4.1 Baseline data

Household census We first conducted a household census during which we updated administrative household lists first assembled in 2015. Of 488 households listed on the administrative lists from 2015, we confirmed that 439 were present in the study communities. Of those not living in the study communities: 27 had migrated; in 17, all household members had passed away; and 5 were mis-listed. We also registered 17 new households and updated information about the household head for 41 households.

Water source census During our earlier studies, we collected a census of all water sources in the community in 2015. For a sample of households in each community, we updated this list with new water sources built between 2015 and 2018. We conducted a water source census to update this list. Of the 369 water sources previously identified, 58 no longer existed, and we identified 77 new water sources. We assembled an updated list of water sources as well as images of each water source, allowing us to match individual households to the water sources they use.

Baseline household survey We attempted to interview all households in each study community at baseline. Among the 456 households we had identified during the household census, we established that a further 8 had migrated and 3 households had merged with another household, for example, an elderly relative had moved in with a younger relative. Out of the remaining 445 households, we excluded a further 23. These households lived outside the area that we had preliminarily established as feasible to connect with a pipeline network. We sought consent to interview the remaining 422 households, among whom 37 households declined to participate and 385 households (91%) agreed to participate in the household survey.

The main module of the baseline household survey comprised a roster of household members, a roster of all water sources used by the household, and questions about knowledge about safe drinking water, the health of household members, participation in community decision-making, and an inventory of household assets used to construct an asset index. We also individually interviewed one male and one female household member, asking them questions about their social networks and physical mobility.

Water quality testing We offered to test water quality in a sample of household drinking water for each household and to test a sample of water collected directly from each source used by any household. To test household drinking water, we asked households to provide a glass of drinking water in the same way they would do if someone in the household wanted to drink. We offered households the opportunity to participate in the water quality testing program separately from the household survey. In practice, no household who declined to participate in the survey consented to the water quality testing program. One household who consented to the survey declined to participate in the water quality testing program.

We used IDEXX Colilert kits to measure both total coliforms and *Escherichia coli* in both household drinking water and samples collected from sources. We used an arsenic field test kit to measure arsenic contamination in samples collected directly from sources. Arsenic field tests are less accurate than laboratory testing (Reddy et al., 2020) but they are quick and inexpensive, and they obviate the need to send samples to external laboratories where we have only limited control over tracking procedures. We do not test household drinking water samples for arsenic because of the problem of passive removal: arsenic in stored drinking water oxidizes to an undetectable form and may precipitate out and accumulate in sediments in the drinking water vessel (Ahmed, 2001; Roberts et al., 2004). Arsenic in this form may not be detectable in samples of drinking water but can still enter the food chain when water in the bottom of the vessel is emptied or used.

In total, we collected baseline water quality data for 384 households out of the 385 households that consented to participate in the survey (bacterial contamination only) and 353/355 water sources used by any household at baseline (arsenic and bacterial contamination). The two missing observations arise from an incorrect matching of water source data to households, which is rare. Among water sources, 59% tested positive for arsenic at or above the WHO threshold of 10 ppb and 7% did so at the less conservative Bangladeshi threshold of 50 ppb; 57% tested positive for any coliform bacteria and 13% tested positive for *E. coli*. Among samples of household drinking water, 81% tested positive for any coliform bacteria and 31% tested positive for *E. coli*.

WTP elicitation To measure demand for an individual private connection, we use a Becker-Degroot-Marschak (1964) or BDM design to elicit truthful revelation of the maximum price households are willing to pay for a piped water connection. We designed the BDM elicitation to be incentivized by a household-level price lottery. Respondents answer a series of eight yes or no questions that iteratively narrow in on the maximum amount a household is willing to pay for a connection. The dynamic price list ensures that we can pin down willingness-to-pay (WTP) in a narrow interval (±US$0.42) while keeping the format of the questions we ask simple and straightforward to comprehend. After confirming the WTP, respondents select one of five envelopes containing different price vouchers. The vouchers can list prices between zero and a maximum of just above US$107, in intervals of approximately US$7. The distribution of price vouchers was close to uniform with slight excess mass for at zero and slightly skewed towards lower prices. If the price voucher was equal to or below the stated WTP, the household kept the voucher. The voucher could then be redeemed if a piped water network was constructed in the community for a household piped water connection at the listed price. The vouchers were personalized and non-tradable, and could only be redeemed for a piped water connection on the named household's land.

We only constructed a piped water network in one of the two communities. We held a public lottery to draw the name of the community that would receive the network at random. We explained to households during the elicitation process that they would only be able to redeem their vouchers if we constructed a pipeline in their community and that their community had a 50% chance of being selected to receive the pipeline.

To ensure that households understood the WTP elicitation, we first conducted a separate WTP elicitation for a familiar good, a bar of soap. To check that participants had correctly understood the rules, we coded dynamic questions to first confirm the WTP and then to ask them what would happen, after drawing the voucher, if they drew a price just above and just below their stated WTP. Among the 118 households who drew a price below their WTP for the soap, 98% purchased the soap at the voucher price, consistent with good understanding of the mechanism.

Because the price vouchers are drawn on the fly, one might be concerned about whether the random assignment of prices to households occurred as intended. As a manipulation check, we confirm that the prices drawn do not correlate with household wealth for either the soap elicitation or the piped water elicitation (Appendix Figures A1 and A2), and that the prices drawn for soap are orthogonal to the prices drawn for the piped water connection (Appendix Figure A3).

We sought consent separately for the WTP elicitation and the household survey, i.e., households who did not wish to participate in the survey were still offered the opportunity to participate in the WTP elicitation. However, no household who declined to participate in the household survey chose to participate in the WTP elicitation. Among households who consented to participate in the household survey, 55 declined to participate in the WTP elicitation.

Although the BDM approach is widely implemented, it was unclear ex ante how households would experience the WTP elicitation. To shed light on this, we asked households either immediately before or after the elicitation whether any household members were currently experiencing stress or emotional distress. We randomly assigned households to either be asked the question before or after the elicitation. Households asked the question immediately after the elicitation were less likely to report distress than households asked the same question immediately before the elicitation (Appendix Figure A4). We interpret this as suggesting that households broadly experienced the WTP elicitation in a positive way.

Willingness to pay for a good should partly reflect household characteristics that are common to demand for all consumer goods, such as wealth. As such we would normally expect WTP for different goods to be positively correlated. We confirm that WTP for a piped water connection is positively correlated with WTP for the bar of soap (Appendix Figure A5).

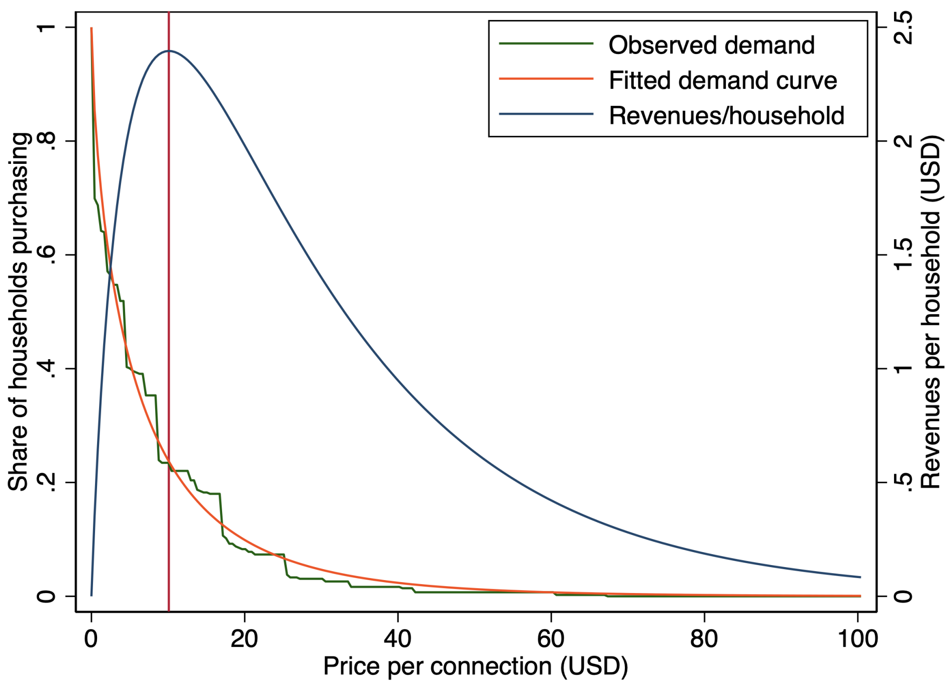
4.2 Endline data

An endline survey is in the field at the time of writing this report. We plan to resurvey all households from baseline and to collect data on water sources used, behaviour with respect to water collection and storage, household health, and to retest all water sources used by households and samples of household drinking water. After the pipeline has been in operation for a year, we hope to be able to return and collect a more complete endline survey considering a wider range of outcomes, including effects on social networks and physical mobility.

5 Willingness to pay

Figure 5 shows the results of the willingness to pay (WTP) elicitation. The raw data are shown in green. Around 22% of households declined to participate in the WTP elicitation, which we interpret as implying a WTP of zero. A further 8% participate in the elicitation but declare a WTP of zero. The median household has a WTP of around US$4.2. The maximum WTP declared by any household is US$67, but this is the extreme of a skewed distribution: the 90th percentile is around US$17. The demand curve is quite well-approximated (R^2 = 0.986) by a Weibull function with equation $e^{-0.0104887\,price^{0.6935161}}$ (shown in orange).

Figure 5: Demand and average revenue



Notes Raw data from willingness-to-pay elicitation shown in green.

A policymaker wishing to set a fixed price for a connection to maximize revenue, faced with this demand curve, would optimize revenues by setting a price of approximately US$10.1. How revenue per household varies as a function of price is shown in blue. For low prices, relatively many households connect, but each connecting household contributes little in revenue. For high prices, each household contributes a greater amount, but few households connect. At the optimum, however, only around a quarter of households would connect, a classic equity-efficiency trade-off.

Observed demand Demand revealed in the WTP elicitation fell faster than we expected when we designed the elicitation (Appendix Figure A6). In itself, this is not surprising: the objective of this pilot study was to learn about the demand function. But a consequence of this was that only 33 households retained a voucher after the WTP elicitation. Building a pipeline to serve only thirty households would be very inefficient. Households also expressed concern about potential unfairness if households paid very different amounts for the same good. As a result, we decided to offer connections at a maximum price of US$8.4 (1000 BDT). Households with a voucher below this value could purchase at the voucher price; all other households could purchase a connection at this the maximum price.

In principle, since this threshold was not affected by any individual's response to the WTP elicitation, this approach does not invalidate the incentivized design. One could reasonably object, however, that our decision was influenced by the aggregate demand function we estimated. But even if an individual anticipated that the community's aggregate response could influence the final price we set, their individually optimal response would still be to reveal something very close to the truth. This is because the benefits of understating their willingness to pay accrue to everyone; the benefits of telling the truth only to themselves. The temptation to free ride, in this case, helps incentivize truthful revelation.

In total, 135 households to date have connected to the pipeline network. Among these households, 6 were from households not included on our household lists—typically, new households formed from the division of other households—and 8 were from households not deemed eligible at the start of our household survey, who finally we were able to connect. Among the households in our original sample, 121 connected out of 222 (the sample of eligible households in the treated community). Most connecting households paid 1000 BDT (US$8.4), the maximum price. Twenty households who drew a voucher for a free connection during the WTP elicitation received a connection for free (100% take-up). Five households who drew a voucher for a connection at 800 BDT could in principle have redeemed this voucher but these households in practice also paid 1000 BDT.

Our elicitation data predicted take-up of 37% at a price of 1000 BDT. Observed take-up at a price of 1000 BDT was 50%.[2] Unexpectedly, however, predicted take-up based on responses to the WTP elicitation has very little predictive power over final take-up.[3] Take-up at a price of 1000 BDT is 47% in households with a WTP of less than 1000 and 56% in households with a WTP of 1000 or higher, a difference that is not statistically significant at conventional levels ($p = 0.216$). Excluding the households who chose not to participate in the WTP elicitation, the difference is even smaller: observed take-up is 53% in households who reported a WTP of less than 1000, statistically indistinguishable from the 56% take-up among households a WTP of 1000 or higher ($p = 0.761$).

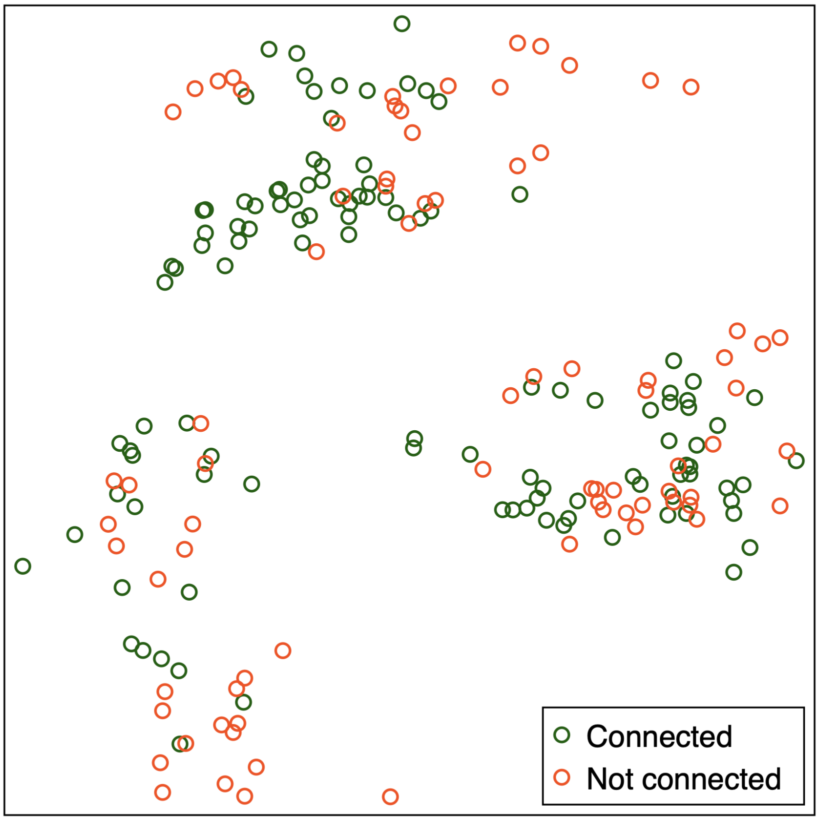
No conclusive patterns emerge as yet to explain the difference between behaviour expected based on responses to the WTP elicitation and observed take-up. Examining the distribution of take-up suggests local clustering of take-up along pipeline routes (Figure 6). Take-up is higher in parts of the community with more extensive arsenic contamination at baseline

[2] We exclude households who drew a zero price in the price lottery. Since only households who participated in the WTP elicitation and price lottery could draw a zero price, we reweight the remaining households who participated in the price lottery by a factor that accounts for this.

[3] One could be concerned that this results from a mismatch of the observed take-up data to the household survey data, but when we complete the matching we correctly match the 20 households who drew a price of zero in the price lottery to their take-up data, suggesting that this cannot explain the lack of correspondence.

(Appendix Figure A7). That eventual take-up differs from behaviour in the WTP elicitation may reflect genuine uncertainty over the value of the good on offer.

Figure 6: Map of connections

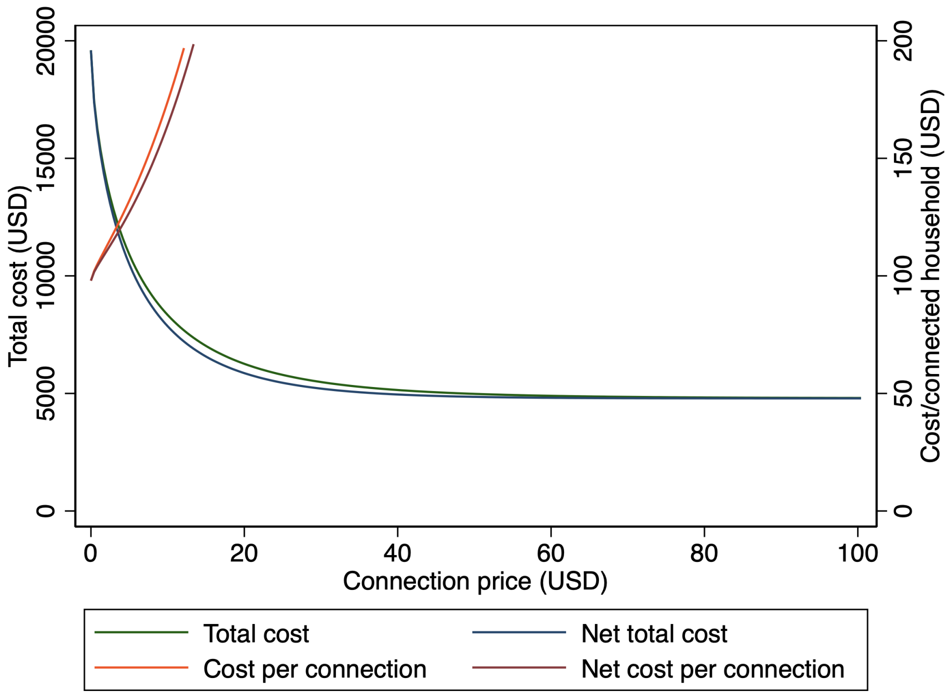


Notes Household location data based on GPS coordinates collected at baseline. Background imagery and geographical identifiers are not shown to preserve the anonymity of the study community.

6 Cost-effectiveness

Combining these data with information on the costs of the pipeline network, we can determine the optimal strategy for a policy-maker who wishes to maximize cost-effectiveness in their intervention, that is, to serve the greatest number of households at the lowest possible price. Figure 7 shows total costs of the system and costs per household, both before and after accounting for revenues raised by households paying to connect. The graph assumes demand for connections as a function of price as shown in Figure 5. Strikingly, the most cost-effective approach is to offer connections for free. This is because economies of scale strongly dominate the revenue-raising effect of charging for household connections. In fact, given the demand curve implied by responses during the WTP elicitation, revenues raised by user fees are almost irrelevant in determining costs per household.

Figure 7: Costs as a function of connection price



Notes Graph shows total cost of the piped water network as a function of the connection price (green) and total cost net of revenues raised by households paying to connect to the network (blue). Costs per household shown in orange; costs per household net of revenue shown in red. Costs per household are truncated at US$ 200 for readability. Demand based on preferences reported during WTP elicitation.

This result is not driven by the coarseness of a flat fee as a policy instrument. A hypothetical policy-maker who could perfectly differentiate user fees based on willingness to pay would be able to implement the program at a cost of US$91. This policy-maker would be able to charge individual households their willingness to pay, resulting in an average user fee of US$7. Implementing the program with free connections would cost US$98, only 7% higher than the ideal benchmark.

Nor is the result sensitive to different assumptions about demand. Observed take-up suggests higher demand than revealed during the WTP elicitation, but we in practice only observe take-up at prices of zero and 1000 BDT (US$8.4). This is insufficient to pin down the distribution of a Weibull function, but we can numerically select the Weibull function that passes through the observed demand at 1000 BDT and minimizes the distance to the demand function observed during the WTP elicitation (Appendix Figure A8). Whether this projected demand curve is realistic or not is unknown, although interestingly it is strikingly close to the estimated demand curve we used to design the original pricing experiment. This projected demand curve would radically alter the revenue maximizing price, pushing it all the way out to US$87 but sharpening the equity-efficiency trade-off: at this price, only 12% of households would connect. However, even with this much more optimistic demand curve, the most cost-effective price remains zero (Appendix Figure A8).

One could reasonably ask whether the low average willingness to pay reveals that the intervention is simply too expensive for the context. How cost-effectively rural drinking water pipelines improve health is largely unknown, but we can make some initial estimates. Given baseline fecal contamination rates, every five households connected would avert exposure to fecal contamination in drinking water for four households, assuming the pipeline successfully delivers safe drinking water. On average, about one in three households have a child under 5 at any one time (Cocciolo et al., 2023). Rural under five mortality in Bangladesh is 41 per 1000 live births (BBS & UNICEF, 2019), and access to clean water reduces all-cause mortality by around 24% (Kremer, Luby, Maertens, Tan, & Więcek, 2024). Combining these numbers suggests that you would need to connect 381 households to save one child's life, most likely an infant. Assuming around 80 disability-adjusted life-years (DALY) saved (WHO, 2020) gives an approximate cost of around US$461 per DALY loss averted. While not inconsiderable, this number is quite similar to a conservative opportunity cost-based willingness-to-pay threshold for Bangladesh of US$381 (Chew, Painter, Pan-ngum, Day, & Lubella, 2024; Woods, Revill, Sculpher, & Claxton, 2016). This threshold acknowledges that spending on a new health intervention should be evaluated in the light of the counterfactual health improvements that could be realized by spending the same money on an alternative intervention.

7 Conclusion

Rural piped drinking water networks present a potentially viable alternative for meeting Sustainable Development Goal 6 in rural Bangladesh, otherwise unattainable if present trends continue. A key question for policy-makers is how to design pricing of household connections to ensure the most cost-effective rollout of infrastructure. To make progress, policymakers need to know how households would respond to different pricing scenarios. To shed light on this, we implemented an incentivized willingness-to-pay elicitation to measure demand for household connections. Our approach specifically measures the additional amount households are willing to pay for a household-level connection, conditional on having access to a community source of the same quality.

Using our estimated demand function, we then investigate the most cost-effective pricing strategy for a policymaker who wishes to serve the greatest number of households at the minimum cost. We show that economies of scale in infrastructure provision strongly dominate the potential to raise revenues from user fees, such that the price that maximizes cost-effectiveness is zero. This conclusion is not driven by policymaker's limited ability to tailor prices to individuals nor is it sensitive to more optimistic assumptions about demand.

Economies of scale that are sufficiently strong remove the efficiency-equity trade-off in pricing decisions.

A free price for all is not necessarily the optimal strategy. Alternative, more sophisticated pricing strategies might be even more cost-effective. For example, one could provide a basic level of service provision for free with optional, paid-for upgrades. Indeed, we saw some evidence of demand for these types of upgrades in the field. However, our results suggest that free provision of at least a basic level of service is likely to be a feature of any cost-effectiveness maximizing strategy.

Our results are limited to the case of piped water networks in rural Bangladesh. Whether these systems exhibit unusually high economies of scale or not is an open question. Systematic evidence on the existence of economies of scale in public service provision is scanty, but what evidence there is suggests moderately increasing to constant returns to scale (Gómez-Reino, Lago-Peñas, & Martinez-Vazquez, 2023). Our central recommendation is that policymakers should carefully consider the possibility of economies of scale when they evaluate how to fix user fees for infrastructure.

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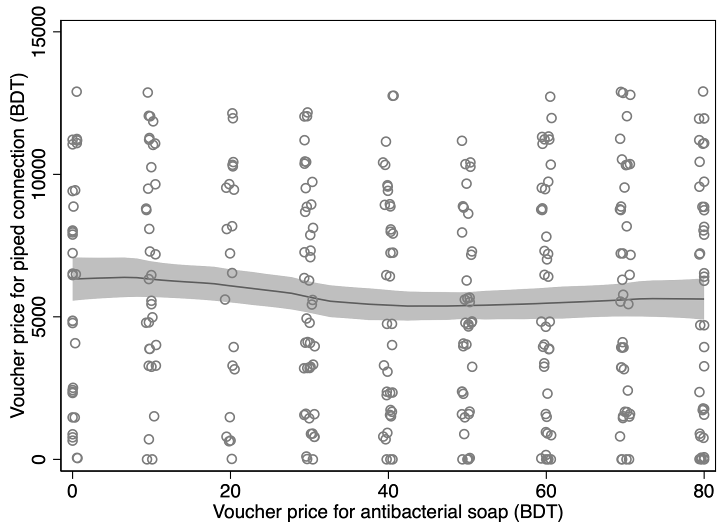
Appendices

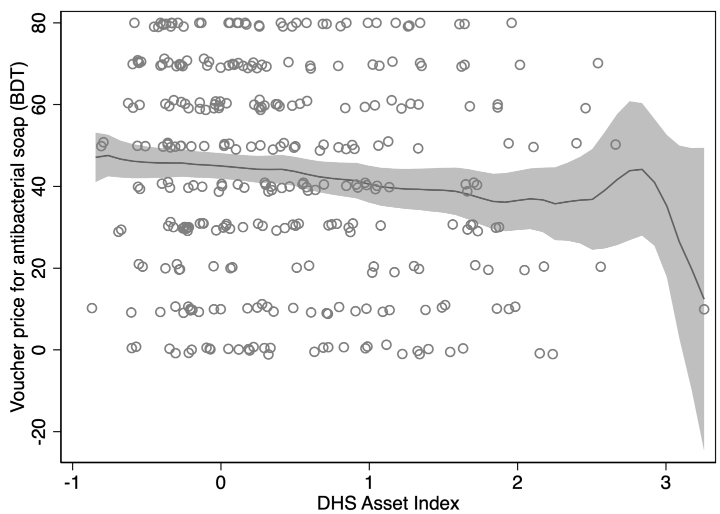
A Appendix Figures

Figure A1: Voucher lottery manipulation check: soap price vs piped water price



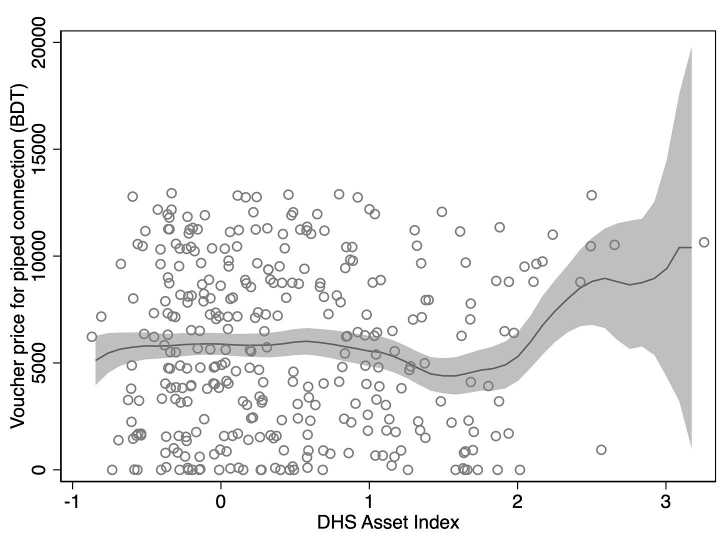
Notes Graph shows randomly drawn price in Bangladeshi taka (BDT) for a piped water connection against randomly drawn price for a bar of antibacterial soap. Individual observations shown as hollow circles, jittered for readability. Line and shaded interval show the non-parametrically estimated relationship between the two prices with 90% confidence interval and bandwidth set to 10. If the price lottery occurred as designed, we should observe no correlation between the two.

Figure A2: Voucher lottery manipulation check: soap price vs assets



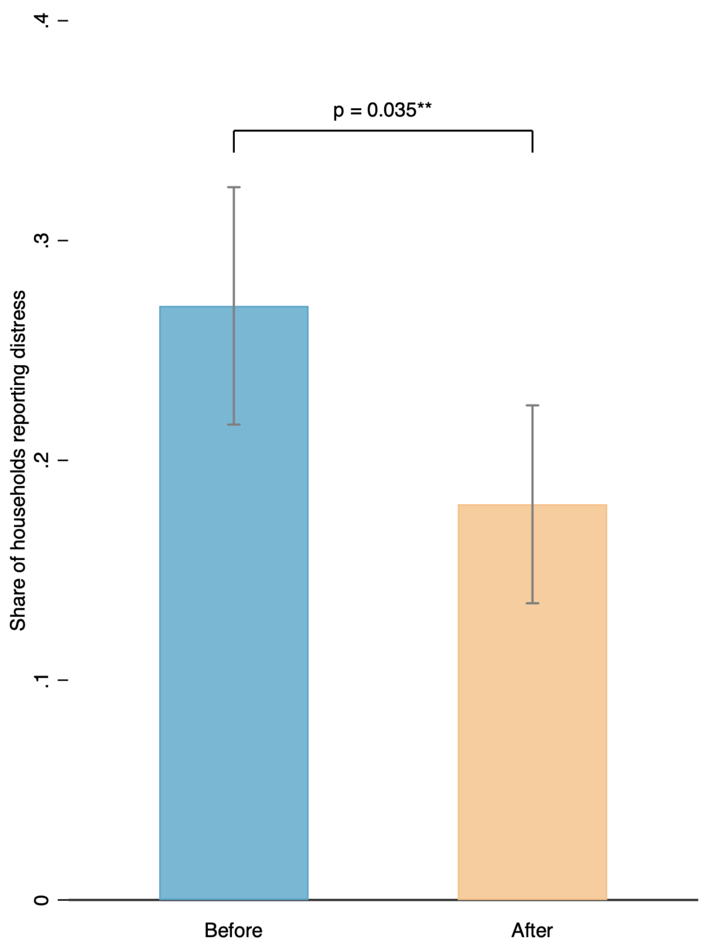
Notes Graph shows randomly drawn price in Bangladeshi taka (BDT) for a bar of antibacterial soap plotted against a household-level asset index constructed using weights from the DHS surveys. Individual observations shown as hollow circles, jittered for readability. Line and shaded interval show the non-parametrically estimated relationship between the voucher price and the asset index with 90% confidence interval. If the price lottery occurred as designed, we should observe no correlation between the two. Note the sparsity of observations at very high wealth levels and the corresponding width of the confidence interval.

Figure A3: Voucher lottery manipulation check: piped water price vs assets



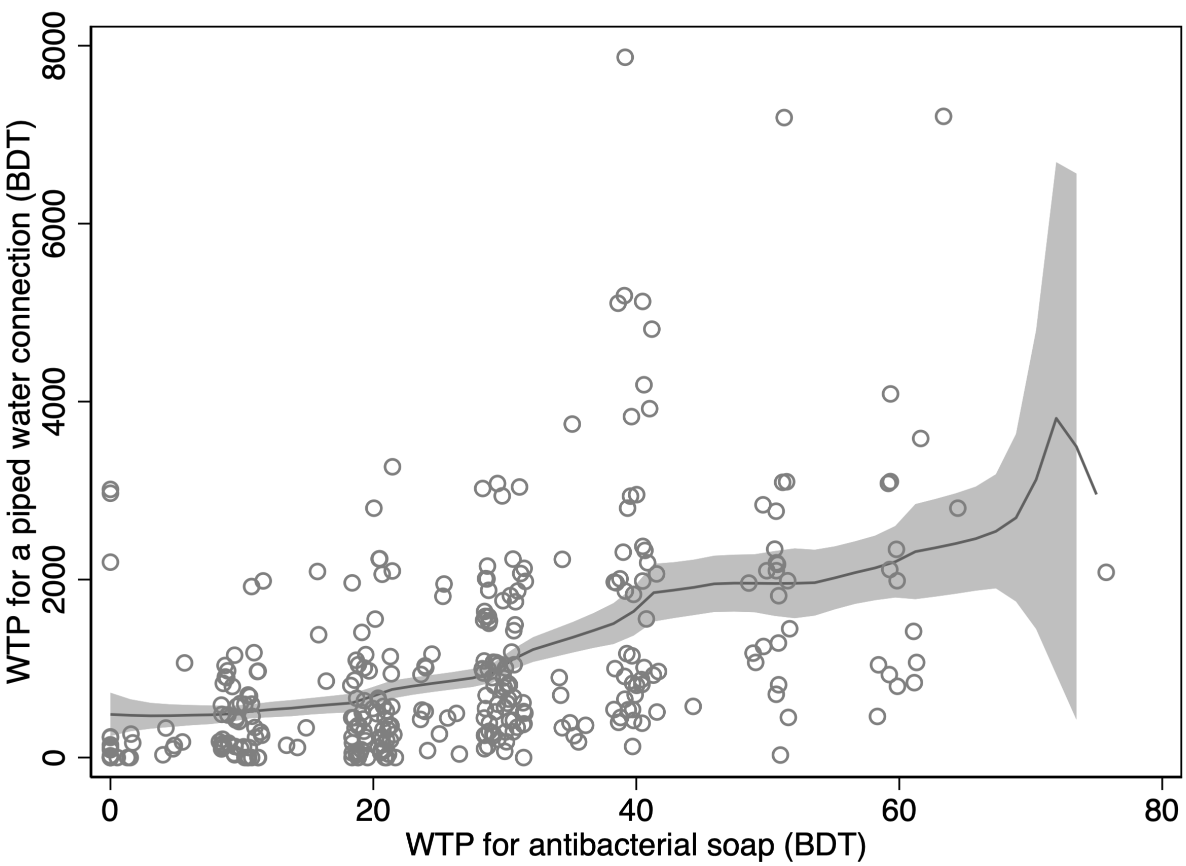
Notes Graph shows randomly drawn price in Bangladeshi taka (BDT) for a piped water connection plotted against a household-level asset index constructed using weights from the DHS surveys. Individual observations shown as hollow circles, jittered for readability. Line and shaded interval show the non-parametrically estimated relationship between the voucher price and the asset index with 90% confidence interval. If the price lottery occurred as designed, we should observe no correlation between the two. Note the sparsity of observations at very high wealth levels and the corresponding width of the confidence interval.

Figure A4: Share of households reporting distress



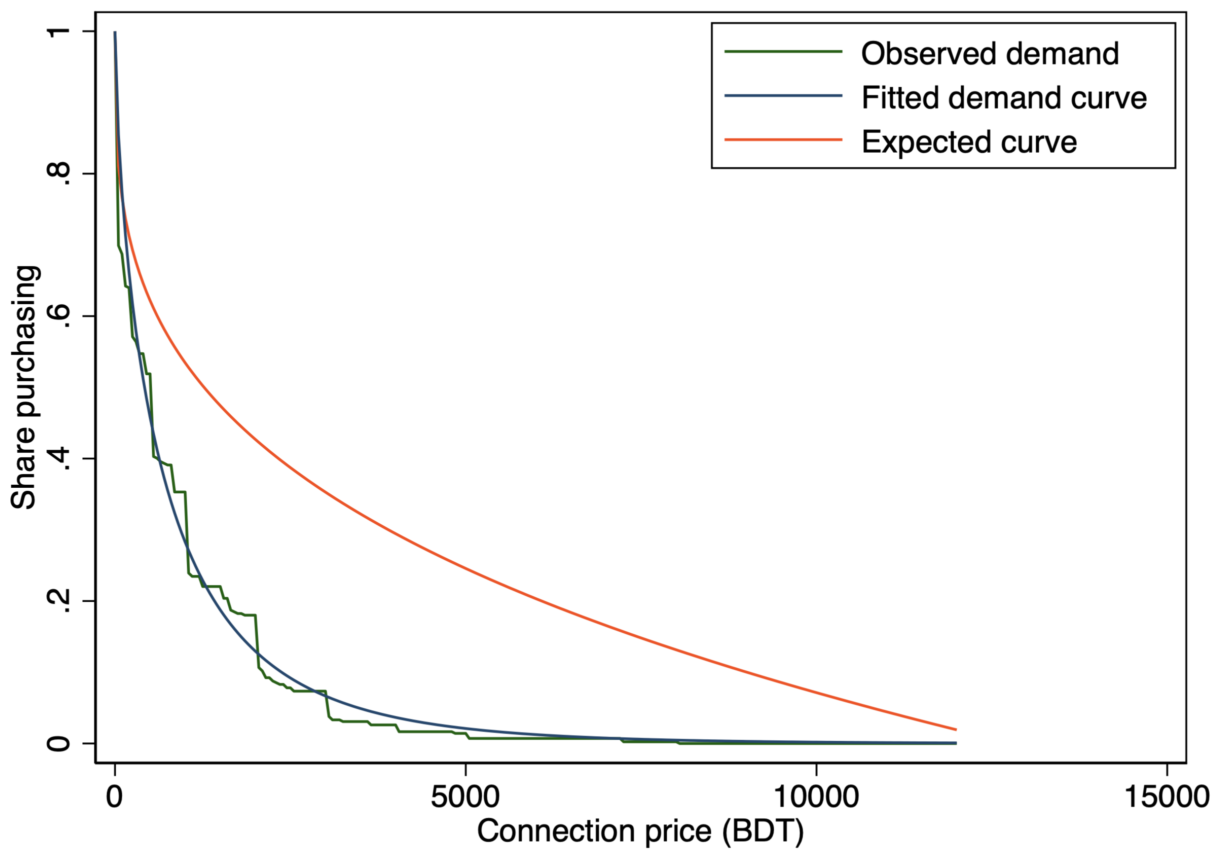
Notes Graph shows share of respondents replying in the affirmative when asked whether anyone in the household was currently experiencing a high level of stress or any emotional distress. Households randomly assigned to be asked the question immediately before or after the willingness to pay elicitation. Question was asked to all households who consented to participate in the survey, independent of their decision to participate in the WTP elicitation. 90% confidence intervals reflect robust standard errors (Long & Ervin, 2000).

Figure A5: Willingness to pay comparison



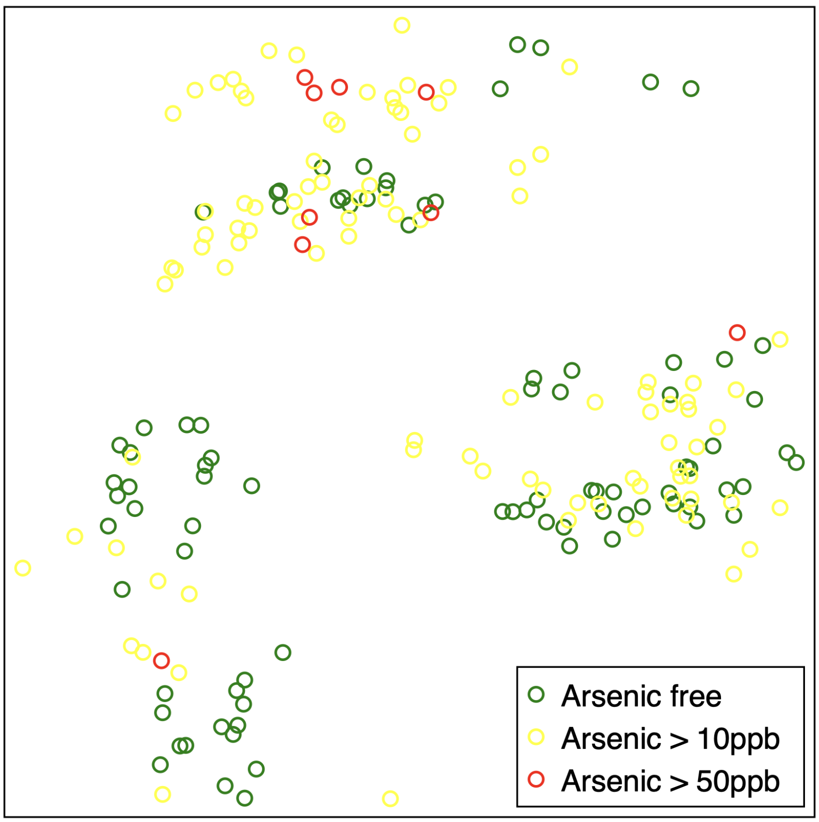
Notes Graph shows willingness to pay (WTP) in Bangladeshi taka (BDT) for a bar of antibacterial soap and a piped water connection to the household. Both WTP elicitations were incentivized. Individual observations shown as hollow circles, jittered for readability. Line and shaded interval show the non-parametrically estimated relationship between the two WTP valuations with 90% confidence interval.

Figure A6: Willingness to pay: observed vs expected



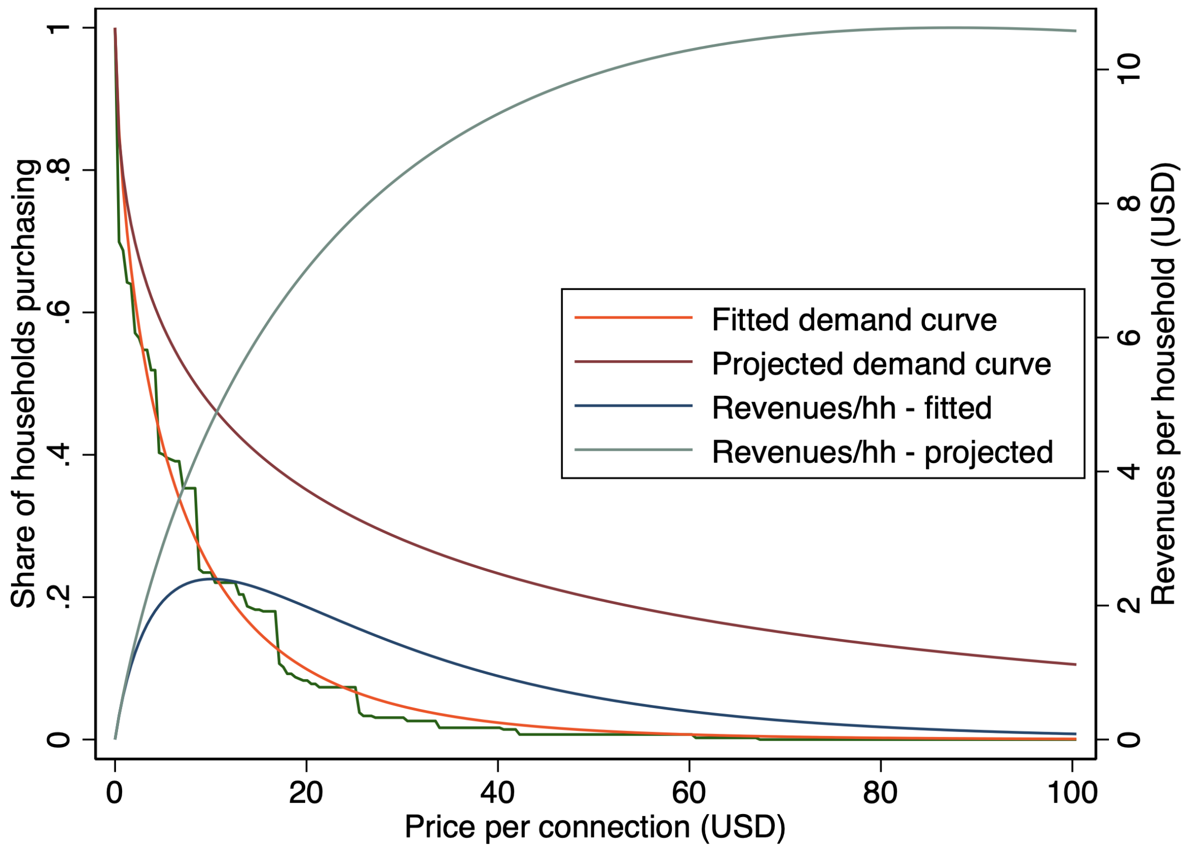
Notes Graph shows willingness to pay (WTP) in Bangladeshi taka (BDT) for a bar of antibacterial soap and a piped water connection to the household. Both WTP elicitations were incentivized. Individual observations shown as hollow circles, jittered for readability. Line and shaded interval show the non-parametrically estimated relationship between the two WTP valuations with 90% confidence interval.

Figure A7: Map of arsenic contamination in treated community



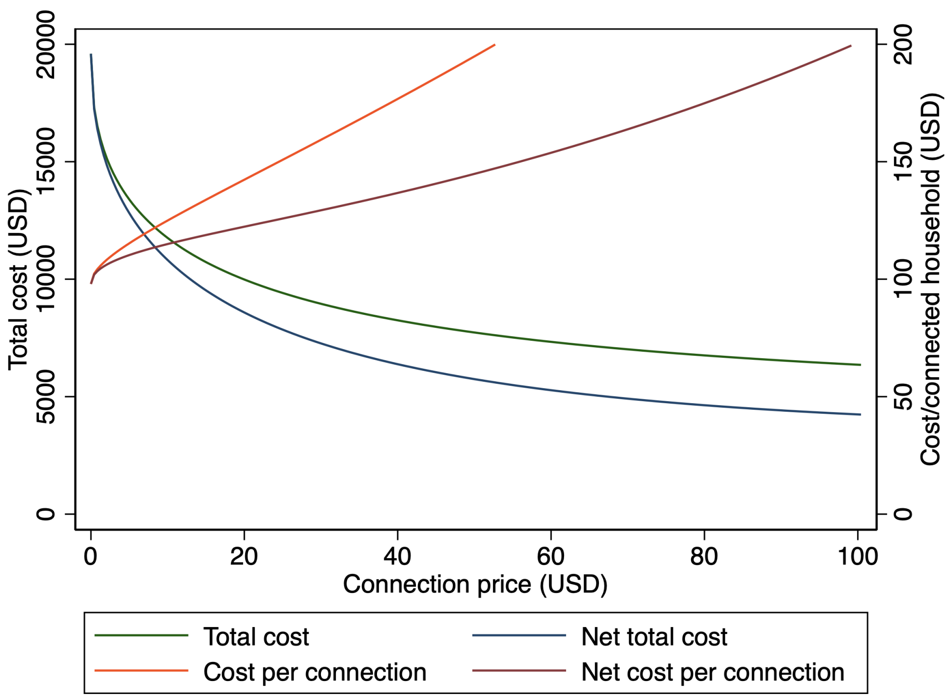
Notes Household location data based on GPS coordinates collected at baseline. Background imagery and geographical identifiers are not shown to preserve the anonymity of the study community.

Figure A8: Demand and average revenue: observed and projected



Notes Graph shows demand based on preferences inferred from the WTP elicitation (orange) and from projecting demand using observed take-up behaviour (red). We project this demand curve by i) limiting our search to Weibull functions with the equation $y = e^{-ax^b}$; ii) limitiing our search to functions that pass through observed take-up; and iii) among these parameters, identifying the function that minimizes the distance from the demand curve inferred from the WTP elicitation. We simulate revenues per household using the fitted demand curves for both the demand curve inferred from the WTP elicitation (blue) and from the projected demand curve based on observed take-up (blue-grey).

Figure A9: Costs as a function of connection price: projected demand



Notes Graph shows total cost of the piped water network as a function of the connection price (green) and total cost net of revenues raised by households paying to connect to the network (blue). Costs per household shown in orange; costs per household net of revenue shown in red. Costs per household are truncated at US$ 200 for readability. Demand based on projected demand curve shown in Appendix Figure A8.

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