Water for Sale[*]

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Abstract

This paper studies informal markets for drinking water in rural India, a setting marked by high reliance on groundwater to satisfy water needs, and rapidly falling water-tables. Concerns about depleting ground water have prompted an array of policy narratives ranging from taxing to completely banning water extraction in areas with acute water stress. Using an in-depth survey of water buyers and sellers, we estimate demand for water, obtain consumer price elasticities and use our structural estimates to compute consumer welfare gains generated by such markets. We find that these markets disproportionately benefit the poor households and the households where women spend longer time to collect water indicating that a ban on extraction affecting the supply would largely affect the welfare of these households. We also estimate the extent of market power in these informal markets implementing a test that uses our demand estimates and find strong evidence of collusion in those markets. In our counterfactual simulations, we evaluate two policies, first, taxing water extraction and second, allowing government entry into the market and compute welfare implications of those policies.

Keywords: Water Demand, Informal Markets, Market Power, Collusion, Women and Water
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1 Introduction

Fresh water reserves are rapidly declining in several parts of the world (Richey, Thomas, Lo, Reager, Famiglietti, Voss, Swenson, and Rodell, 2015). This can have far reaching consequences especially in the developing world where households rely directly on groundwater to satisfy drinking water needs. These concerns have prompted a set of policy narratives ranging from taxing water extraction to completely banning it in areas with acute water stress. In the long run, this may help to sustain the ground water level. However, in the short run such policies can have significant distributive consequences. This paper attempts to shed light on these short-run and long-term consequences of water access by studying informal markets for drinking water in rural India.

In India, 80 percent of the rural population relies on groundwater for meeting their drinking water needs. Like in many developing countries, the burden to collect water heavily falls on women (Travers, Khosla, and Dhar, 2011). Groundwater reserves are over-exploited (Rodell, Velicogna, and Famiglietti, 2009) and many states have imposed a ban on groundwater extraction. Against this background, informal markets for selling drinking water have emerged almost ubiquitously. In rural areas, vendors collect water from variety of sources and sell them to households. These markets play a salient role in providing drinking water especially in arid areas with water stress.

We study these informal markets with two aims in mind: One, we want to compute the willingness to pay for drinking water and quantify the welfare gains that accrue from these markets shedding light on the distribution of these gains. Two, we want to understand the market power in these markets so that we can inform policy using a structural estimation approach carrying out counterfactual exercises for a range of regulatory choices. To this end, we conducted a survey and collected a comprehensive data from Rajasthan India from around 1800 households across 180 villages. This rich dataset features seller and buyer characteristics, and transaction details spanning a year. Aside from the prices, participation in markets, quantity bought and sold, number of vendors operating in the market, their relations to buyers, the demographics of buyers, alternate water sources, and time use of women, we also collected detailed data on cost of providing water including fixed, and recurring costs.

These features of our data allow us to estimate demand for water and compute the elasticities. In our structural demand model, we estimate a model of differentiated products allowing consumer preferences for buying water to vary flexibly with income, number of households, contribution of women in the household work, other household characteristics as well as seller characteristics such as seller caste and availability of the seller over mobile phone, among others. The estimation procedure uses the discrete choices (choice of a specific seller) and continuous choices (quantity of water bought conditional on buying) observed in our data to estimate the preference parameters. Since a household's subjective assessment of water salinity affects the household's demand for water, we use it as an instrument to take care of price endogeneity. Our structural estimation reveals a mean elasticity of -3.4 and our reduced form IV estimate gives a mean price elasticity of -2.45 (statistically significant at the 1 percent significance level). In addition, our estimates reveal the presence of significant heterogeneity in willingness to pay for water across households depending on the household characteristics.

Using our estimates from structural model, we then examine how consumer welfare generated by the market varies by income (computed as total monthly expenditure) and time spent by women in fetching water (in minutes). Our estimates indicate that the welfare gains from the market are realized to poorer households who possibly do not have access to other means of meeting their drinking water needs. Additionally, households where women spend a significant amount of time (ranging from 20 to 150 minutes) collecting water benefit the most from these market operation. This exercise reveals that banning the vendors from procuring extracted groundwater can have regressive distributive effects and reduce the welfare of women who already spend a lot of time on the non-productive chore of collecting water.

We then use our structural estimates and our unique data-set to develop a test for measuring the degree of market power in informal markets.We follow the techniques developed in recent market structure literature (such as Ciliberto and Williams (2014), Backus, Conlon, and Sinkinson (2018), Miller and Weinberg (2017), Michel and Weiergraeber (2018)[1]) and

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[1] Other studies include Fan and Sullivan (2018), Eizenberg and Shilian (2019), Miller, Sheu, and Weinberg (2019)

implement a test of market power in those informal markets allowing for flexible cost and demand structure. We reject the null of no collusion and conclude the existence of some cooperation among sellers. The estimated index of market power (that varies between 0 and 1 with 0 being no collusion and 1 signifying joint profit maximization) comes out to be 0.394 and statistically significant at the 1 percent significance level. Intuitively, this parameter indicates that a seller values INR 1 profit of a rival seller as much as INR 0.394 of its own profits. Hence, we are able to reject the null hypothesis of competitive market structure. This parameter also refutes perfect collusion among sellers. Our findings indicate that, in this market sellers by offering differentiated services do possess some degree of market power and in addition, they also coordinate.[2] In our counterfactual exercise, we will utilize this exercise to shed light on the consequences of regulation. For example, we will evaluate how a tax on the sellers while extracting water would affect prices and consequently consumer welfare. Similarly, we also evaluate price response of the sellers and consumer welfare consequences when government enters the water market and provide water at a subsidized price. Coupling our estimates with water table data that we have obtained from the Central Ground Water Board of India, we can also assess how would this regulation affect groundwater extraction in the long run.

Our study makes contributions to two sets of research. We extend the nascent and relatively thin literature estimating the demand for water, shedding light on market structure, and optimal policy. Jacoby, Murgai, and Ur Rehman (2004) study groundwater markets for irrigation and find evidence of monopoly power in such spatially fragmented informal markets in rural Pakistan. Szabo (2015) ascertains the elasticity of household residential water demand in South Africa where drinking water is provided by a public utility which charges non-linear tariff schedules.[3] Similarly, Donna and Espín-Sánchez (2018) estimates a dynamic demand model for water markets in Spain to compare the welfare under auctions, quotas, and other market mechanisms. Our paper complements this work by estimating the demand in an informal market characterized by many suppliers. We extend this literature

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[2] As next steps, we will model flexible form of cooperation by heterogeneity in the internalization behavior of different sellers allowing for higher degree of coordination based on cultural affinity or geographical proximity.

[3] Olmstead (2009) provides a review of demand estimation for water with more formal market operations under non-linear prices.

and provide insights about the distribution of gains from this market. A novel innovation of our work is also the estimation of consumer surplus accruing from drinking water markets to households where women spend a large fraction of time collecting water. Our research sheds light on short-term gains of these markets to vulnerable populations viz., poor and households where women spend time collecting water.[4]

Another innovation of our paper is developing a test for market power in informal markets. While majority of current literature agrees that markets in developing countries are dominated by small and informal firms (for example see La Porta and Shleifer (2014) and Hsieh and Olken (2014)), not much is known about the degree of competition that exists in informal markets prevalent in different developing countries. Most of the existing literature on estimating market power in such settings has relied on evidence based on pass-through in the rural agriculture markets (for example see Bergquist (2017), Dillon and Dambro (2017), Casaburi and Reed (2017) among others). We however use a structural demand-side approach, allow for flexible preferences among buyers as well as cost heterogeneity among sellers and implement a test of market power in the context of an informal market. Such techniques can be easily extended to test market power in other similar informal market settings in the developing countries.

This exercise will enable us to test counterfactual policies for regulating this market. As a long-term conservation goal, policy makers in India are contemplating ways in which extraction of groundwater can be decelerated. A reduction in extraction could be efficiency enhancing in the long run. One way of doing this is to increase the cost of water in such markets by taxing the suppliers which would result in a decline in consumer welfare due to higher prices. We can shed light on optimal policy which facilitates the balancing of these two goals. We know of no other study that provides such insights from policy perspective.

Rest of the paper is organized as follows: Section 2 provides background information about the markets that we study. Section 3 discusses our data and section 4 the features of this market we observe in our data. In section 5, we show the correlates of the probability to buy water. Section 6 describes our instrumental variable estimation and its results.

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[4] Sekhri and Hossain (2019) document the consequences of water scarcity for women and find an increase in the incidence of violence against women during times of water stress. Devoto, Duflo, Dupas, Parienté, and Pons (2012) find that water access can reduce time spent on water collection and conflict.

Our model is described in section 7. Section 8 documents the results from our structural estimation. Section 9.1 sheds light on the value of water market and heterogeneity in this value. Section 9.2 proposes a test to ascertain degree of market power in informal markets and provides an application to our context. Section 10 concludes.

2 Water Markets in Rural Rajasthan

Vendors in these markets are micro to small scale business enterprises. A typical vendor uses a tanker for water delivery (See Appendix Figure 1 for an example). The tankers vary in sizes and conventionally are either 5,000 or 10,000 litres. Majority of the vendors use motorized means to haul the tankers though animals are not uncommon. Vendors procure water and deliver it to the households. The water vendors procure water from a source such as a tube well or pond or river which can be in the same village or a different one. The bulk of their operating cost comprises of fuel used in transportation. The commonly used fuel by tractor enabled vendors is diesel. Camels are also used to pull the tankers. However, they are much slower and take longer to collect and deliver the water. Water from ponds and rivers does not cost anything. Fuel costs for extraction are borne by the vendor if they use own or relatives tube-well. Farmers are willing to sell water from their wells.[5]

The consumer households are typically familiar with the vendors operating in their village. They approach the vendors and negotiate a price. The contracts are oral. Then the vendor provides water within a specified time of delivery. There are no forward or long term contracts. There is no regulation for entering this market. While most vendors have one tanker and tractor, there are vendors who have several such combinations and maintain accounts of their transactions. Such somewhat larger enterprises hire labor for procurement and making the deliveries. The consumers pay the vendor on delivery although some vendors also provide water on credit. There are no discounts offered. Only full tanker loads are sold. There are no divisible piece-meal sales of tanker water. Households store water in underground or surface storage units either made of plastic or concrete. These storage units

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[5] In India, there is no fee for extracting groundwater. Riparian rights allow anyone owning a land to extract water from beneath it. Fuel such as electricity is either free or highly subsidized. Hence, the marginal cost does not internalize the scarcity rents of groundwater.

have lumpy fixed costs. Appendix Figure 2 illustrates a storage unit. These are individually owned. Rarely, households also have jointly owned storage and buy taker loads of water and share. Households also tend to harvest rainwater. These contracts could be relational in nature. Households could have preference for specific vendors due to social affinity or other economic benefits offered in other markets.

Households may also rely on number of alternate source for meeting their drinking water needs. These include own taps, own wells or community taps and community wells. However, households may face various uncertainties while accessing water through those alternative sources.[6] A notable point is that the alternate sources including domestic piped water and government and community tap and well water is locally obtained usually extracted from the local micro-watershed. For instance, overhead tanks that provide piped water to households are maintained by Public Health Engineering Department (PHED) and water in these reservoirs are filled using a borewell tapping into local groundwater. The supply can be erratic and the quality of water is no different than that of handpumps which also extract local groundwater.

In some areas of Rajasthan due to depletion of groundwater, government sends water via freight trains to meet the drinking water needs. However, households need to walk to the train stations to collect the drinking water provided through those freight trains. While using these alternate sources, the chore of collecting water is mainly done by women of the household.

3 Data and Background

We collected a very comprehensive survey data to study the demand for drinking water in Rajasthan. The survey was administered in 8 districts of Rajasthan (Ajmer, Barmer, Churu, Jaipur, Jodhpur, Nagaur, Pali, Sikar), including 184 villages, and 1812 households. From each village, 10 households were randomly selected to be included in the survey.[7]

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[6] For example, the supply of tap water is highly unreliable and limited to only few hours per day. In some regions, the water in taps is released only for 1 hour a day. Government may also provide water extracted from different sources via taps in public places. This is also characterized by highly uncertain supply, in addition, the queues at such places tend to be long.

[7] Around 28 households data was not matched to the crosswalk.

The sampling design and roster making protocol is described in detail in the Online Data Appendix.

The survey had three modules: village, sellers, and households. The village module was administered to village leaders. The village questionnaire inquired about: socio-economic composition of the village, land-holdings, access to electricity, outcomes of two most recent village elections, legal reservations for women or lower castes, village meetings, availability of and distance to health centers, food distribution, bus connections, primary and middle schools, and water infrastructure projects completed with dates of completion, and number along with the type of water sources.

The water seller module was administered to every water seller serving the sample villages. This module inquired about water seller's business practices in their capacities as firms. The sellers were asked about: Destinations: number and location of villages where the seller operates,the number of sellers in each village ; Costs: cost of acquiring water, purchasing tanker to carry water, maintaining vehicles or animals to transport water, hiring a driver to transport water ; Quality: perceptions about quality of water from various sources, in terms of salinity and other contaminants ; Price: typical prices charged, availability of credit, interest rate on any credit, discussions about price with other sellers; Socio-economic characteristics: gender, age, demographic information, education, primary occupation, ration card status, and relationship with government officials.

The household module collected data from each household about the following: Socio-economic characteristics: age, gender, labor and schooling choices, and earnings of each household member; household's demographics; expenditures and farm/business income ; Water access: water sources used (out of list of sources that we created during the field work), quantity used from each source, cost per unit, travel and queuing time, identity of those obtaining water, availability and perceived quality of each source ; Water purchases from sellers: Quantity and price for all purchases over the previous 12 months, perceptions of price, quality, and reliability of all water sellers, relationship to water sellers ; Allocation of water: Fraction of water from sellers or from other sources allocated across drinking, cleaning/washing, and livestock ; Household members and individual labor supply.

4 Descriptive Analysis

4.1 Household Characteristics

Table 1 shows the distribution of the number of household members. In our sample, majority of the households have 8 or fewer members in the household although there is considerable heterogeneity in the size. Hence, drinking water needs exhibit considerable variation across our sample. Our sample is marked by significant arid conditions.

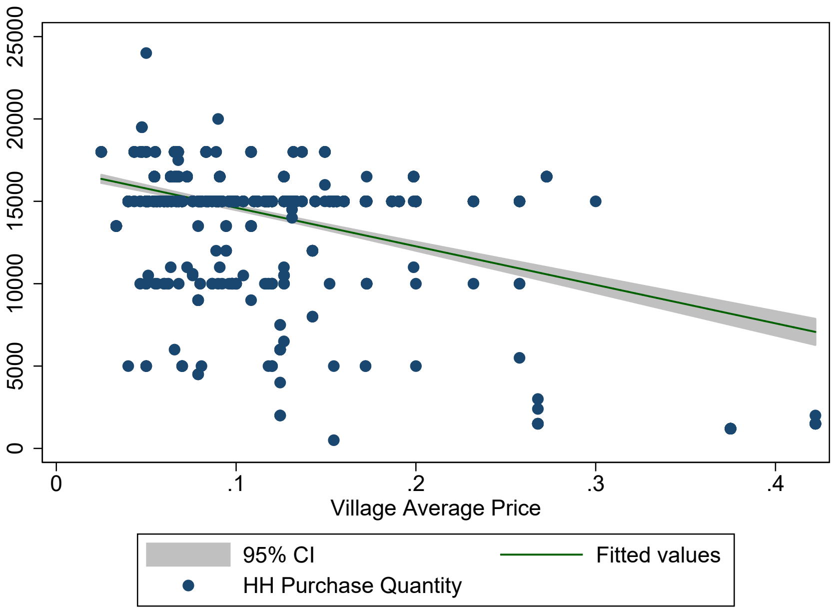
Most of the households spend an hour collecting water for drinking. Of the 1812 households in the sample, 529 do not collect water (Table 2). Most of water collection is done by females in the household (Table 3). We document sources of water collection in Table 4. These sources provide alternative substitutes for meeting drinking water needs. A total of 229 households get piped water at home, 61 rely on own tubewells, and 349 on large overhead public tanks to meet their drinking water needs. Water from overhead tanks can be purchased for INR 25 per month although supply is highly irregular and often limited to 1 hour a day. Households also have to pay for the pipes to connect to the source though majority just walk to the tanks.

4.2 Water Purchase Data

Table 5 shows the monthly variation in number of households buying water. Households demand varies seasonally. In March and April, the temperature rises with dry heat peaking in May and June. The monsoon season is July. Number of households buying water increase in March and peak in August. The demand again begins to taper in September. The cold season has very limited transactions. Water is typically purchased in 5000 L tankers. The mean price per litre is 13 paise which more than doubles in the hottest and driest month of May to around 30 paise per litre (Table 6). Total water transacted is 18,300 thousand litres. This peaks in August as well (Table 7). We observe majority (1,184 households) buying water in 3 months of the year.

Figure 1 illustrates the elastic nature of household demand for water. Quantity purchased falls as price increases. In summary, demand varies by month of the year and purchases are

Figure 1: Household Quantity Purchased by Prices



sensitive to prices.

4.3 Sellers and Market Transactions Data

In Figure 2, we plot the prices charged by vendors against the distance they travel to the most used water source for procuring water. Panel 2(a) shows this relationship for summer and Panel 2(b) for winter. Distance on x-axis is measured in kilometers. Tanker Price on y-axis is measured in Indian Rupees.[8] Each of the circles refer to a different seller and the size of the circles indicate the capacity of the tanker used by a seller while selling water. In both cases, the slope is positive indicating that as the cost of transportation increases, the prices charged by the sellers also go up on average. However, as the graphs reveal, even when a set of sellers incur similar collection and transportation costs, we observe some price spread across those sellers. This suggests that the differences in prices charged by the sellers can not be fully described by marginal cost differences, as sellers with similar marginal costs charge very different prices.

This implies that markups charged by sellers may vary and hence some market power may exist among the sellers in this market. Sellers in these markets not only differ in terms of

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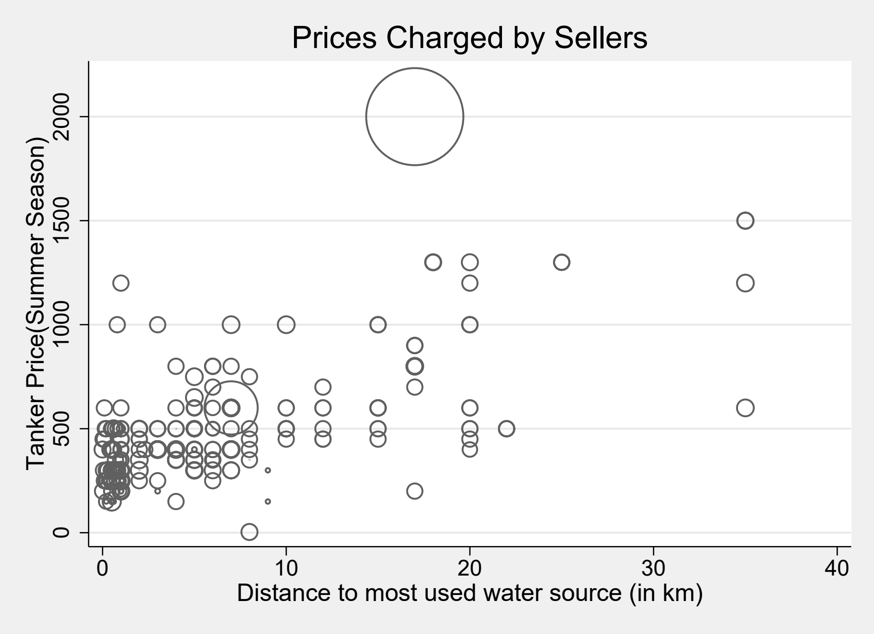
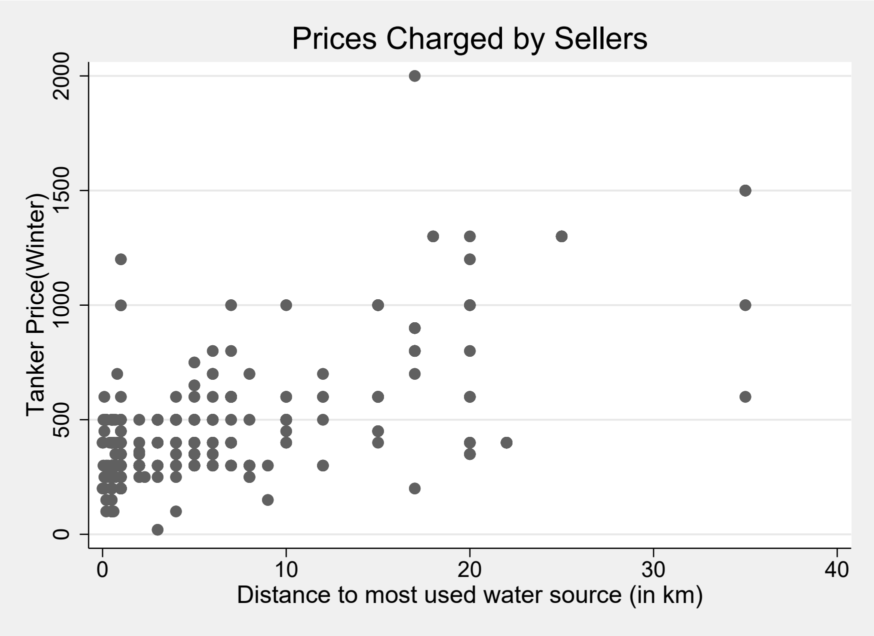
[8] 1 USD is equal to 70 rupees at current exchange rate.

Figure 2: Cost of transportation and prices charged



(a)

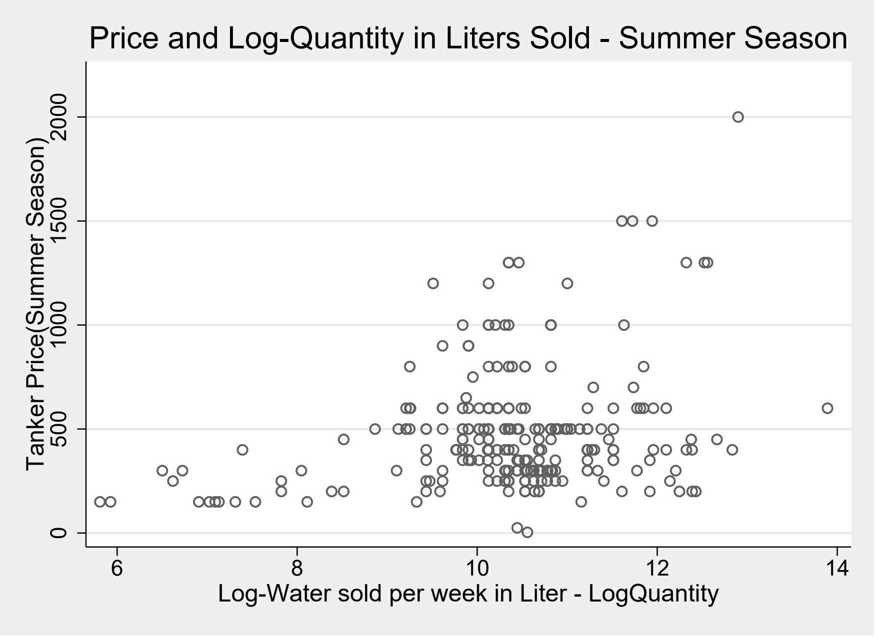


(b)

cost of water collection, but also in terms of other characteristics such as caste, connectivity (for example, some sellers use mobile phone to take orders), quality of sold water as well as experience as a seller. Additionally, as both sellers and buyers are part of the village ecosystem, other relational contracts are also going to play a role when buyers choose sellers.

We plot the tanker price charged against the log of quantity sold per week in liters in Figure 3 for the summer season during which the demand peaks. This too exhibits an expected positive slope.

Figure 3: Tanker Prices Charged by Quantity Sold



5 Regression Analysis: Correlates of Market Participation

In Table 9, we estimate the probability that a household purchases water as a function of average price in the village. In column 1, the linear probability estimate is negative and highly statistically significant as expected. A one paise increase in price is associated with an 11.5 percent decline in the probability of purchasing water. In column 2, we report the estimate from a probit specification and find a large negative correlation in prices and probability of purchasing water. In columns 3 to 6, we report the results from a linear specification for ease of interpretation. Number of household members is positively and significantly associated with likelihood of purchasing water. Having a substitute source of water (own pipeline) is negatively correlated with water purchasing. The coefficients in columns 4-6 are negative and highly statistically significant. While assets are not correlated with purchasing (column 5), average time exhibits a positive and significant correlation (column 6). Total spending does not correlate with purchasing, however total food spending has a positive and significant correlation. Clothes a negative and significant correlation indicating some degree of substitution in the probability of purchasing these goods. Number of sellers bears a large positive coefficient statistically significant at the 1 percent significance level. An interesting feature is the the likelihood to buy water is positive associated with the number of sellers a households knows.

6 Instrumental Variable Estimation

So far our data bears out the expected correlations between price and quantity purchased. In order to address endogeneity concerns, we proceed to estimate an instrumental variable specification. The salinity of drinking water effects its taste. People have a preference for non-saline water. Hence, we use individual assessment about the level of salinity in drinking water as an instrument.[9] Salinity is a categorical variable with choices: no salt, low level of salt, medium level and high level of salt. In Table 13 , we report the instrumental variable estimates. The first stage coefficients are reported in column 1. We construct indicators for each category of salinity and omit the indicator for high level as the reference group. Log of average price is negatively and statistically significantly (at the 1 percent significance level) correlated with no salt. In other words, when the household's water does not have salt, they are willing to pay a smaller price for purchasing tanker water. In column 2, we show the IV estimate of log of quantity purchased instrumenting log of village average price with the indicators for each category of salinity. We estimate an elasticity of -2.45% statistically significant at the 1 percent significance level. A one percent increase in price decreases the water demand by 2.45 percent.

A point to note is that the substitute water that households use included the piped water at home is from local sources typically groundwater. Hence, salinity does not correlate with

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[9] Sekhri, Hossain, Gonzalez, and Gupta (2019) show that the individual assessment of salt is quite accurate using another survey conducted in Rajasthan.

demand for piped water in our case unlike Bennet (2012) where local salinity in groundwater affects demand for cleaner water procured from the mountains and piped to households.

While the instruments do not pass the weak instrument test, we conduct weak instrument robust inference. The Anderson Rubin Wald test indicates the rejection of the null that the instruments are jointly insignificant and shows that the orthogonality conditions are valid.

7 Model

To evaluate the consumer surplus generated by the water sellers and to perform a test for market power, we develop a structural model of water market. We estimate the demand curve faced by the buyers and use the estimates to quantify the elasticity of demand for water. Using the estimated model, we compute the consumer surplus that the households generate from the water market. Using additional structures on the supply side, we develop a test of market power that helps us to quantify whether the sellers are operating in a competitive set up or whether there is some cooperation that exists among the sellers. Our estimated model helps us to evaluate alternative policies that can maximize consumer welfare while conserving the ground water resources, and hence would help us design the optimal regulations.

In a related study, Szabo (2015) analyzes demand for residential drinking water in South Africa. In her study, households get a free allowance upto a recommended minimum quantity and the prices are set by the government. However, in our setting, sellers are free to set their prices and the actual price setting behavior depends on the nature of competition faced by the sellers. We now describe the model of demand and supply side of water market in detail.

7.1 Model for Estimating Demand for Water

Our reduced form evidence suggests that consumers in different villages in Rajasthan, India crucially rely on water markets to fulfill their drinking water requirements. Since majority of the households in a village rely on local sellers to purchase water, we define each village as a separate market. The villages are denoted by $m = 1, \ldots, M$. We denote the set of potential sellers in a village m by $\mathbb{S}_m$. Each of the potential water-sellers ($\mathbb{S}_m$) for a village

m, decide whether to sell water in a village. Sellers would consider the market structure (the level of expected competition and expected profitability of the market) as well as cost of entry into the market to decide whether to operate in a village. Cost side factors include distance from water sources, distance travelled to procure and deliver water, cost of fuel and other operational costs. In our current estimation, we consider the entry decisions as given and treat the observed data as the equilibrium outcome from the entry decisions.[10] Our structural model consists of two stages.

- Given the number of sellers in the market, depending on market conduct, the sellers fix price of water. Compared to the demand analysis in Szabo (2015) where prices are fixed under government regulation, in our framework, prices are determined endogenously by the water sellers depending on the market structure and nature of competition.
- In the second step, households choose one of the available sellers to buy water from or choose not to buy water at all. If a household chooses to buy water, then they also decide on the quantity of water to buy depending on the budget constraint. Compared to Szabo (2015), where households choose only quantity of water to buy, in our model, households make both discrete (a specific seller) and continuous (quantity of water) choices while making consumption decisions.

While most of the existing literature in industrial organization assumes competitive oligopoly market structure, and use this assumption to estimate cost of operation, it is not clear if in our set up such an assumption would be valid. In particular, informal relationships among sellers may lead to cooperation among sellers resulting in collusive agreements.[11] Therefore, instead of assuming the nature of competition as given, we perform a test of market conduct in order to determine the nature of competition that the sellers face in this environment.

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[10] In our ongoing work, we plan to endogenize the entry decision as well in order evaluate welfare implications of policies like government entry in the water markets.

[11] Jacoby, Murgai, and Ur Rehman (2004) show monopoly power in irrigation water markets in Pakistan. Irrigation water markets are widely different from drinking water. Land allocation among farmers and spatial distribution affects these markets and as a consequence these markets are highly fragmented. Cost of entry is also much higher.

7.2 Demand Specification

We denote households by h, sellers by j and time periods by t. Household h at time t decides whether to purchase water and if so, then how much to purchase. We assume that the household h at time t chooses a purchasing quantity from seller j, q_{hjt}, and the outside good q_{0ht} to maximize its utility subject to budget constraints.

Water sellers differ in terms of their characteristics that include caste, price, quality, relational contracts as well as willingness to provide credit among others. The utility from purchasing water from seller j is represented by the following quadratic utility function:

$$u(q_{hjt}) = \frac{1}{\alpha_h}\left(d_{hjt}q_{hjt} - \frac{q_{hjt}^2}{2}\right) + q_{h0t} + \varepsilon_{hjt} \tag{1}$$

with the following constraints: budget constraint

$$y_{ht} = q_{h0t} + p_{hjt} * q_{hjt} \tag{2}$$

and

$$(q_{h0t}, q_{hjt}) \geq 0 \tag{3}$$

where d_{hjt} is specified as follows

$$d_{hjt} = \beta_h X_{jt} + \gamma_h M_{hjt} + \omega_{hjt} \tag{4}$$

In the above specification, X_{jt} represents the seller specific characteristics that are common across all households. M_{hjt} includes all the household-seller specific characteristics that include the observable factors such as relational contracts or being of the same caste, between the household and the seller. M_{hjt} also includes the household characteristics such as number of households, accessibility to other sources of water, spending on different items among others.

We write price as p_{hjt} suggesting that the price may vary between buyers even for a single seller. In this model, we assume that the unobservable shocks to quantity demanded shocks by households denoted by ω_{hjt} follow a normal distribution with mean 0 and standard deviation σ. ε_{hjt}, the unobservable preference demand shocks of household h for seller j in time period t, are assumed to follow a type 1 extreme value distribution. Similar models to estimate consumer demand using both discrete and continuous choices made by consumers have been used in marketing literature (for example see Chintagunta and Dube (2005), Dubé (2005), and Lambrecht, Seim, and Skiera (2007) for such applications).

Conditional on choosing seller j, household h's optimization problem while choosing quantity is given by

$$\begin{gathered} \max \quad \left[\frac{1}{\alpha_h}\left(d_{hjt}q_{hjt} - \frac{q_{hjt}^2}{2}\right) + q_{h0t}\right] \\ \text{subject to: } y_h t - q_{h0t} - p_{hjt} * q_{hjt} \geq 0 \end{gathered}$$

Setting up the Lagrangian and taking first order conditions, we have

$$\begin{aligned} \mathbb{L} : & \left[\frac{1}{\alpha_h}\left(d_{hjt}q_{hjt} - \frac{q_{hjt}^2}{2}\right) + q_{h0t}\right] + \lambda\left(y_{ht} - q_{h0t} - p_{hjt} * q_{hjt}\right) \\ FOC : \ & 1 - \lambda = 0 \ \ (\text{ w.r.t. } q_{h0t}) \\ & \frac{1}{\alpha_h}(d_{hjt} - q_{hjt}) - \lambda p_{hjt} = 0 \ \ (\text{ w.r.t. } q_{hjt}) \end{aligned}$$

Hence conditional on consuming positive quantity of q_{hjt}, the consumer's optimal choice is given by

$$q_{hjt}^* = d_{hjt} - \alpha_h p_{hjt}$$

Therefore, household h's optimal purchase quantity q_{hjt}^* (given quadratic utility) is given as follows,

$$q_{hjt}^* = \max[0, d_{hjt} - \alpha_h p_{hjt}] \tag{5}$$

Next we compute the expected utility of a consumer from consuming water

$$\frac{1}{\alpha_h}\left(d_{hjt}q_{hjt}^* - \frac{q_{hjt}^{*2}}{2}\right) + q_{h0t}^*$$

Note that,

$$q^*_{hjt} = d_{hjt} - \alpha_h p_{hjt}, \text{ and } q^*_{h0t} = y_{ht} - p_{hjt} * q^*_{hjt}$$

Using the optimal choices in the expression for utility, we can compute utility at the optimal water choice conditional on positive water consumption.

$$\begin{aligned}
u(q^*_{hjt}) =& \frac{1}{\alpha_h}\left(d_{hjt}(d_{hjt} - \alpha_h p_{hjt}) - \frac{(d_{hjt} - \alpha_h p_{hjt})^2}{2}\right) + (y_{ht} - p_{hjt} * q^*_{hjt}) \\
=& \frac{\left(d^2_{hjt} - \alpha^2_h p^2_{hjt}\right)}{2\alpha_h} + (y_{ht} - p_{hjt} * q^*_{hjt}) \\
=& \frac{\left(d^2_{hjt} - \alpha^2_h p^2_{hjt}\right)}{2\alpha_h} + (y_{ht} - p_{hjt}(d_{hjt} - \alpha_h p_{hjt})) \\
=& \frac{\left(d^2_{hjt} - \alpha^2_h p^2_{hjt} - 2\alpha_h(p_{hjt}(d_{hjt} - \alpha_h p_{hjt}))\right)}{2\alpha_h} + y_{ht} \\
=& \frac{\left(d^2_{hjt} - \alpha^2_h p^2_{hjt} - 2\alpha_h p_{hjt} d_{hjt} + 2\alpha^2_h p^2_{hjt}\right)}{2\alpha_h} + y_{ht} \\
=& \frac{\left(d^2_{hjt} - 2\alpha_h p_{hjt} d_{hjt} + \alpha^2_h p^2_{hjt}\right)}{2\alpha_h} + y_{ht} \\
=& \frac{(d_{hjt} - \alpha_h p_{hjt})^2}{2\alpha_h} + y_{ht}
\end{aligned}$$

Hence the expected utility (that captures consumer welfare is given by)

$$E_\omega(u(q_{hjt})) = E_\omega\left[\frac{(d_{hjt} - \alpha_h P_{hjt})^2}{2\alpha_h} | (d_{hjt} - \alpha_h P_{hjt}) > 0\right] * \Pr(d_{hjt} - \alpha_h P_{hjt} > 0) \qquad (6)$$

Our key parameter α_h, the price sensitivity of a household is flexibly modeled to vary across households depending on observable household characteristics such as income, number of household members and access to other water sources

$$\begin{aligned}
\alpha_h =& \alpha_0 + \alpha_1 * \text{income}_h + \alpha_2 * \text{Share of time devoted by women in HH}_h \\
&+ \alpha_3 * \text{No. of HH members}_h + \alpha_4 * \text{Time spent by women to collect water in the HH}
\end{aligned} \qquad (7)$$

Estimation is based on two observed decisions: the household's actual seller choice and the purchase quantity. We estimate the model parameters by maximizing the joint likelihood of these two observed outcomes.

Let I_{hjt} denote the indicator variable that takes value 1 if household h purchases from seller j at time t. Let $g(q_{hjt})$ denote the probability density of observing the purchase quantity q_{hjt}. The household h's contribution to the likelihood is given by

$$l_{ht} = \begin{cases} \prod_{j\in J} \Pr(I_{hjt} = 1) g(\hat{q}_{hjt} | I_{hjt} = 1, q_{hjt} > 0) & \text{if purchase in time } t \\ \sum_{j\in J} \Pr(I_{hjt} = 0) \Pr(q_{hjt} = 0) & \text{if not purchase in time } t \end{cases} \tag{8}$$

7.3 Price Endogeneity

In our market, a given seller may charge different prices to different buyers. Prices charged by a seller for a given buyer may be correlated with individual level unobservable (ε_{hjt}) and this may lead to endogeneity problem. We follow Petrin and Train (2010) and use control function approach to address the endogeneity issue in the estimation.

We write p_{hjt} as a function of all exogenous variables entering the utility function, instruments and a separable error term. Following the utility specfication in equation (1),

$$u(q_{hjt}) = \frac{1}{\alpha_h} \left(d_{hjt} q_{hjt} - \frac{q_{hjt}^2}{2} \right) + q_{h0t} + \varepsilon_{hjt} \tag{9}$$

where d_{hjt}, as specified in (4) is a function of the endogenous variable p_{hjt} and a set of exogenous characteristics. We assume price to be linear in instruments.

$$P_{hjt} = \gamma z_{hjt} + \mu_{hjt} \tag{10}$$

We use individual specific estimate of salinity of drinking water as an instrument for price. In our dataset, individuals provide assessment about the salinity level of drinking water where the options include no salt, low level of salt, medium level of salt and high level of salt. Note that, an individual's assessment of drinking water reflects the individual's willingness to pay for drinking water available in the market, that is a consumer who assesses higher salt content in water is also willing to pay higher price for water available in the market.

Using the notation in 4, we have

$$\begin{aligned} d_{hjt} &= \beta_h X_{jt} + \gamma_h M_{hjt} + \omega^1_{hjt} + \omega^2_{hjt} \\ \implies d_{hjt} &= \beta_h X_{jt} + \gamma_h M_{hjt} + \lambda\mu_{hjt} + \sigma_j \eta_{hjt} + \omega^2_{hjt} \end{aligned} \tag{11}$$

In the above specification, we allow μ_{hjt} and ω^1_{hjt} to follow joint normal distribution and independent over j. Using this specification, we derive the optimal consumer choice as given in 5 and proceed to likelihood estimation.

7.4 Supply Specification

We model the supply side as an oligopoly market with differentiated products. While demand parameters are estimated by exploiting the variations in the observed consumer choices, the additional structure on supply side helps us to develop a test of market conduct. Additionally, estimating supply side will enable us to evaluate counterfactual policy simulations such as of putting a tax on water extraction and its effects on prices as well as consumer welfare. Standard industrial organization literature assumes a competition structure and uses the supply side model to recover the marginal cost of selling a product (for example see Berry, Levinsohn, and Pakes (1995), Nevo (2000)). However, since we have detailed information on cost of operations, we do not assume a competition structure, rather we use this additional information to develop a test of market power (see section 9.2 for details).

We denote sellers by f. Each seller f sells in a set of villages given by V_f. In our current specification, we assume that the seller treats each village separately.[12] The total variable profit that a seller gets from selling water in market m is given by

$$\Pi_f(\vec{p}_m) = (p_f - c_f)q_f(\vec{p}_m)$$

where $\vec{p}_m$ denotes the vector of prices in market m offered by seller f and by its competitors. p_f denotes the price charged by firm f and c_f denotes the marginal cost of selling water. Finally, q_f denotes the quantity sold in the market by seller f.

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[12] We can easily extend this and allow the seller to take joint decision across villages.

Under competitive behavior, the profit-maximizing price of each firm should satisfy the following first-order condition:

$$q_f + (p_f - c_f)\frac{\partial q_f(\vec{p}_m)}{\partial p_f} = 0 \tag{12}$$

A price increase affects profits through three channels. First, it directly raises profits, proportional to current demand $q_f(\vec{p})$. Second, it lowers the product's own demand, which lowers profits proportional to the current markup. Third, it raises the demand of the other products in the firm's portfolio, which partially compensates for the reduced demand of the own product. If the first-order conditions (12) holds for all firms, then a Bertrand-Nash equilibrium obtains.

Given the F firms in the market, we write first-order conditions in vector notation. Define the $F \times F$ matrix θ^F as the firms' product ownership matrix,a block-diagonal matrix with a typical element $\theta^F(j,k)$ equal to 1 if j and k belong to the same seller, and 0 otherwise. Let $\vec{q}(p)$ be the $J \times 1$ demand vector, and $\Delta(\vec{p}) = \partial\vec{q}(p)/\partial(\vec{p})$ be the corresponding $J \times J$ Jacobian matrix of first derivatives. Let $\vec{c}$ be the $J \times 1$ marginal cost vector. Using the operator $\odot$ to denote element-by-element multiplication of two matrices of the same dimension, we have first order conditions given by:

$$\vec{q}(\vec{p}) + (\theta^F \odot \Delta(\vec{p}))(\vec{p} - \vec{c}) = 0$$

This can be inverted to give the expression:

$$\vec{p} = \vec{c} - (\theta^F \odot \Delta(\vec{p}))^{-1}\vec{q}(\vec{p}) \tag{13}$$

The above expression decomposes price into two terms: marginal cost and a markup, which depends on the own- and cross-price elasticities of demand.

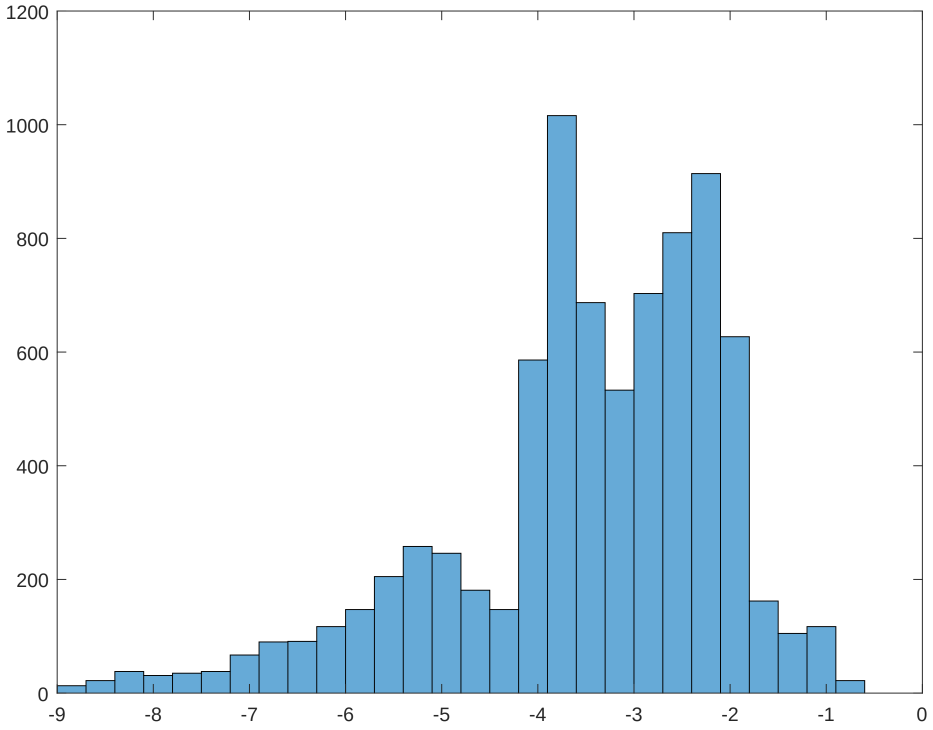
8 Results from Structural Estimation

We report the results from demand estimation in the table 11. Price coefficient across all specification comes out to be negative and statistically significant. This suggests that the demand curve is downward sloping, and that buyers derive negative utility from higher prices. Price variable interacted with consumer income level has a positive coefficient which confirms the common intuition that, as income increases, buyers are less responsive towards price. In majority of the households, women spend are the main collectors of water and spend a lot of time in collecting water. The estimated coefficient of price interacted with time spent by women to collect water is positive and significant suggesting that as the time to collect water by women member of a household increases, the price sensitivity goes down. This suggests that a household where women spend a lot of time in collecting water would care less for higher prices, and is likely to buy water with higher probability. Since higher number of household members also imply more help while collecting water, our estimates suggest that, with more household members households are more responsive to market prices and are less likely to buy water when prices go up. The coefficient of having own pipe is positive and significant which is a bit counter-intuitive as having own pipe would lower the probability of buying water while a positive coefficient actually suggests the contrary. However, in our sample the consumers who have own pipe do buy water in some instances. Since, those households have higher purchasing power, and these households have often consume high volume of water, our estimates are probably driven by those data patterns. The coefficient of average time to collect water is positive and significant suggesting that the probability to buy water goes up as water collection is more time consuming.

We use the demand estimates to compute the price elasticity of demand. The median price elasticity of demand comes out to be -3.1 while the mean elasticity comes out to be close to -3.4. Since we allow price sensitivity to vary across consumers, we also report the distribution of price elasticity among consumers in figure 4. The distribution of elasticity suggests that consumers are highly heterogeneous in terms of price elasticity. While some consumers are relatively inelastic with elasticity around to -1, a sizeable fraction of consumers have very high value of elasticity ranging upto -9. This suggests that, even in an informal village setting, the consumers are highly heterogeneous in terms of price sensitivity. Our model is able to capture this important aspect of the data by allowing flexible demand structure in the structural framework.

The results from allowing endogeneity of price is reported in column (IV) in table 11.

Figure 4: Distribution of Price Elasticity among Consumers



Notes: In this figure, we plot the histogram of price elasticities among consumers.

9 Using the Model Estimates to Understand the Gains from the Market

In this section, we use estimated model and answer several important economic questions related to the water market.

9.1 Value of Water Market

How much do buyers value the existence of the water market? How much surplus does the market generate for poor households and households where women spend majority of time collecting water? While these are important economic questions to understand, recent developments in India also make those questions extremely policy relevant. Due to lack of public water provision and insufficient availability of ground water, in various parts of India, private water tankers are being used to meet the demand and supply gap. In several instances,[13] to avoid over-extraction and exploitation of water resources, a blanket ban on extraction for commercial purposes has been imposed in several Indian cities. While imposing those bans is going to preserve the water resources, such bans can also result in negative utility reducing consumer welfare for households who rely on the tankers for their water needs. Therefore, quantifying how households value water markets and how such valuations are distributed across household characteristics is key while making those policy decisions.

To understand the surplus that households derive from water markets, we use our demand parameter estimates and compute the expected utilities from buying from a seller in the market. We use techniques developed in Small and Rosen (1981) to compute the consumer surplus. Note that the alternative option available to the household is to collect water from outside sources which requires resources, time and effort.

The distribution of surplus generated by water markets is plotted in the figure 5. The x-axis plots the monthly household income which ranges from close to 500 INR to around 10000 INR ($\sim$ 7 USD -140 USD). The y-axis plots the per liter surplus in INR generated by a household from buying water from a seller and it varies from 0.05 INR to 0.25 INR. Note that, the average per liter price is 0.07 INR per liter. It suggests that the water market generates significant positive surplus for the consumers. The histogram shows that most of the surplus accrues to the low income households where household income ranges between 1000-4000 INR. Higher income households typically possess other sources (such as own well or own piped connection) and hence may not rely on the water markets to fulfill their needs. Hence, while water markets generate significant overall positive value, low income households

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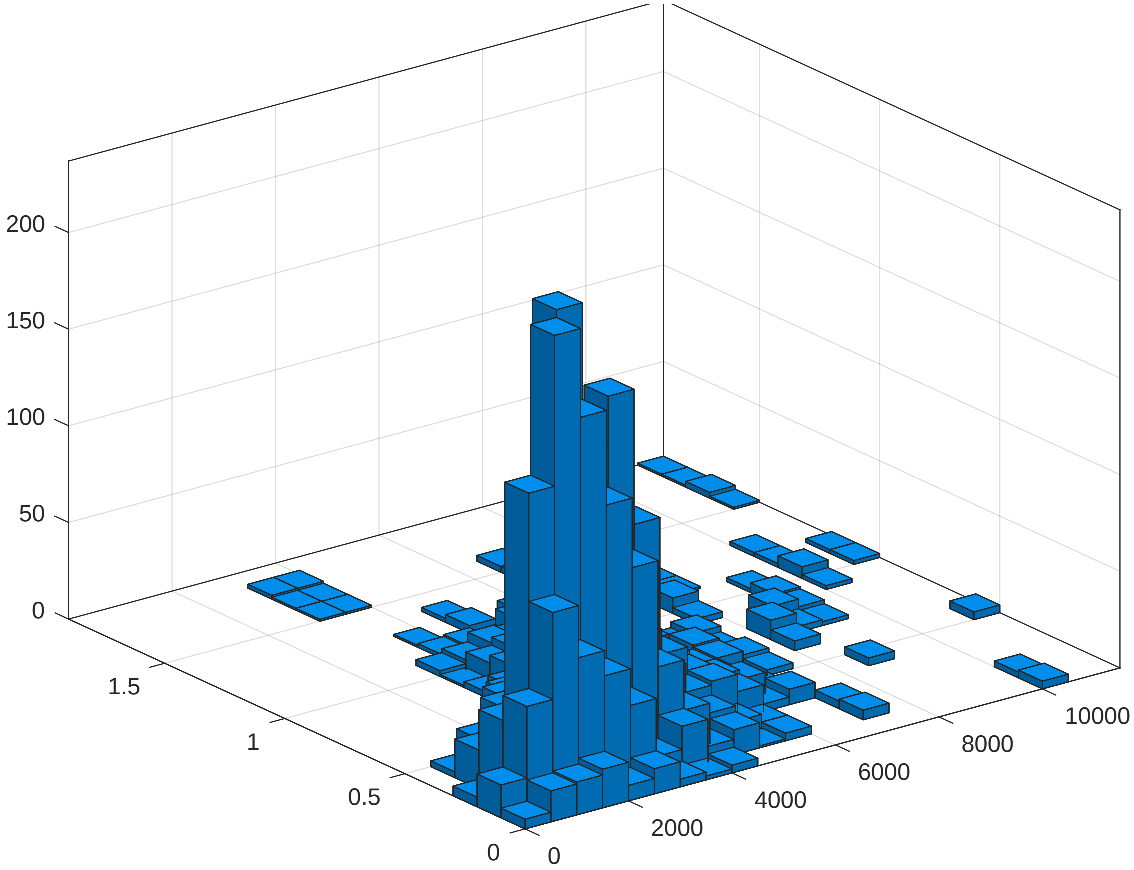
[13] For example, Madras High court imposed a tanker ban in Chennai, see the article in Times of India on Oct 17, 2018. (Link)

Figure 5: Distribution of Consumer Surplus generated due to Water Market

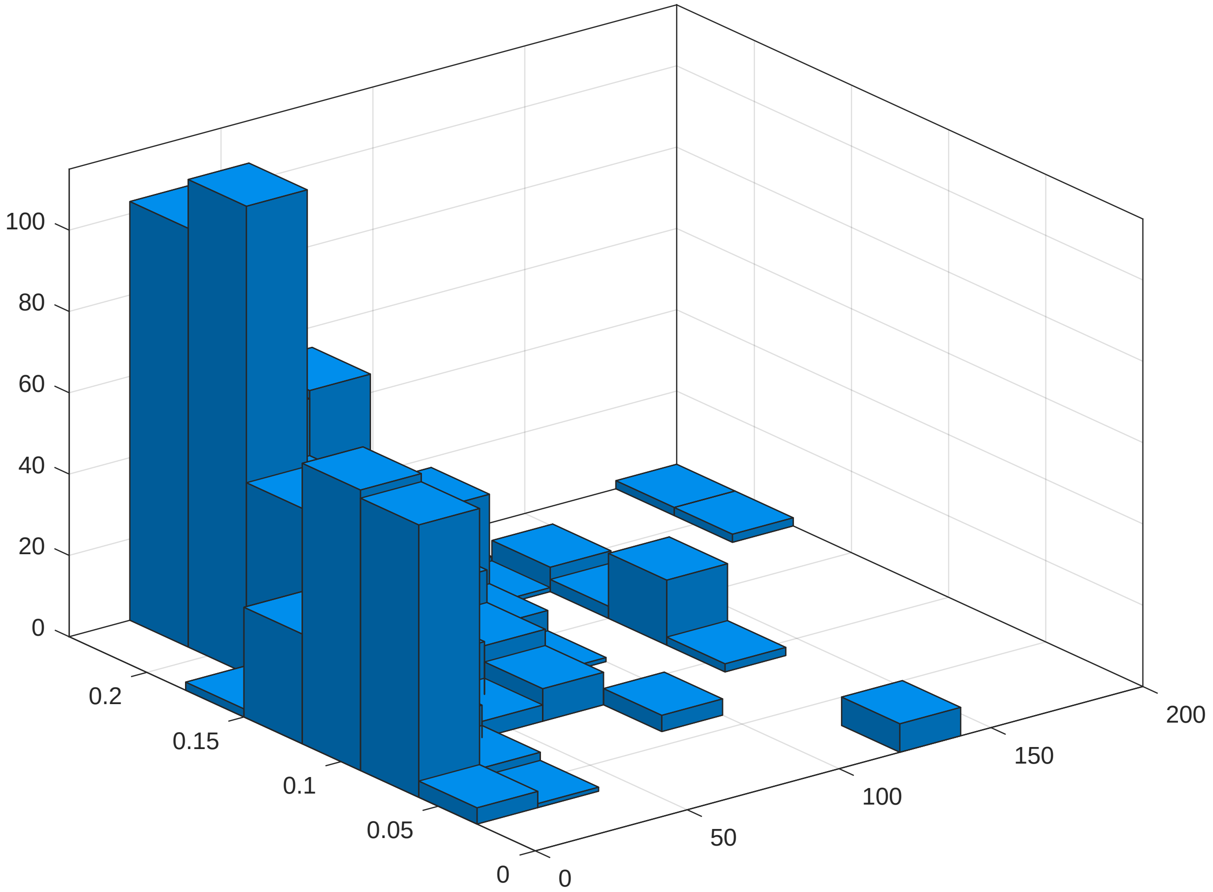


Notes: In this figure, in the x-axis, we plot the income level of the household. In the y-axis, we plot the consumer surplus in Indian Rupees (per a liter of water) generated due to water market for the consumer. The z-axis plots the frequency of consumers.

benefit the most from the existence of such markets. This suggests that a blanket ban on such tankers may generate significant negative utility for the poorest among all households.

In majority of the households, female members of the household are engaged in collecting water. Since demand for water can be fulfilled by presence of water sellers, presence of water markets may benefit the women in the households. To understand the surplus generated by the market and its relationship with women in the household, we refer to figures 6 and 7. In figure 6, we plot the time spent by female members of a household (in minutes) in the x-axis and the surplus generated by presence of water markets (in INR per liter) in the y-axis. In the figure 7, we plot the share of time spent by female members of a household (in minutes) in the x-axis and the surplus generated by presence of water markets (in INR per liter) in the y-axis.

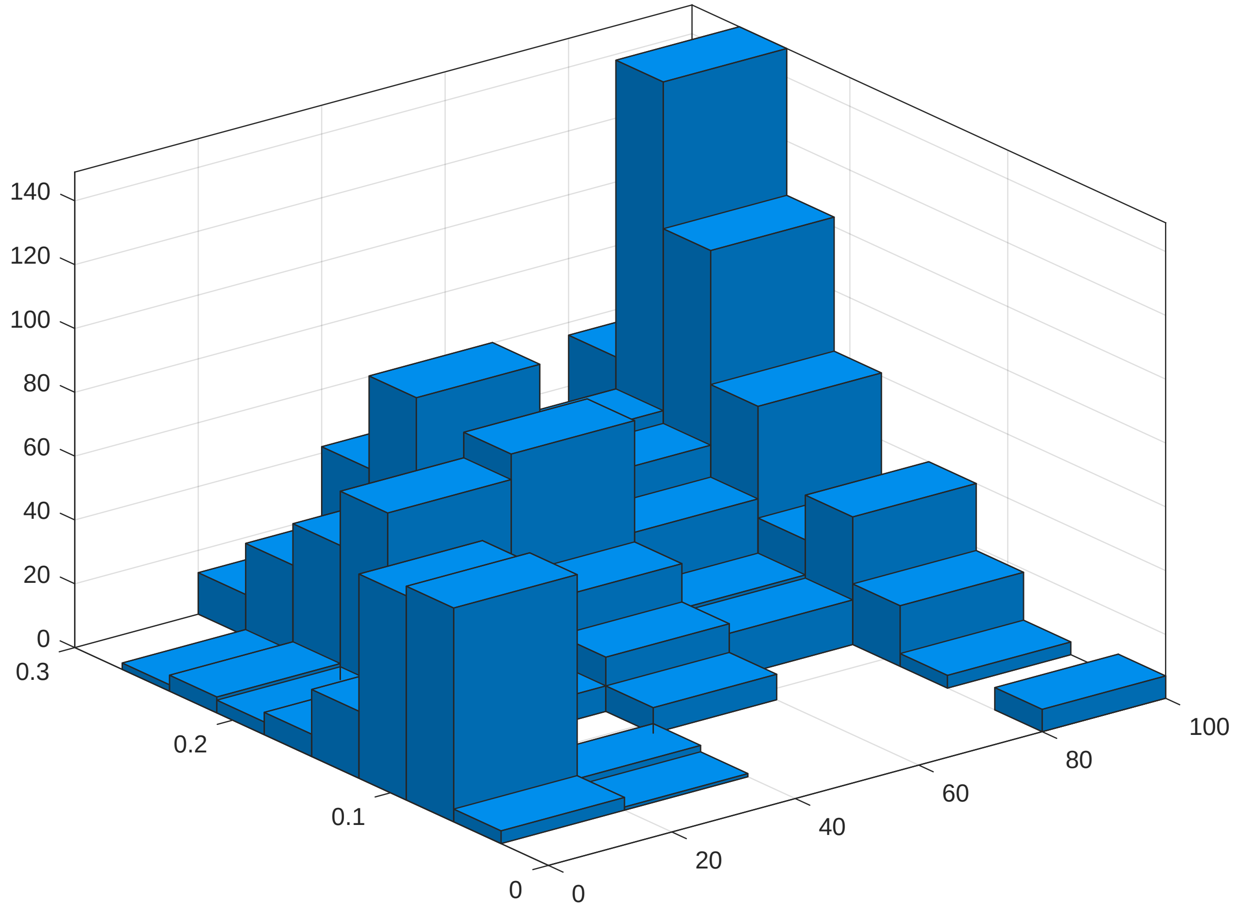
Figure 6: Distribution of Consumer Surplus due to Water Market and Women in the Household



Notes: In this figure, in the x-axis, we plot the time spent by woman member of a household to collect water. In the y-axis, we plot the consumer surplus in Indian Rupees (per a liter of water) generated due to water market for the consumer. The z-axis plots the frequency of consumers.

As can be seen from figures 6 and 7, presence of water markets generates positive surplus for households where women spend significant time to collect water. This also suggests that the blanket ban on water tankers sales will affect women members in the household negatively. Figure 6 suggests that the households where female members spend 50 minutes to an hour in collecting water benefit the most from presence of water markets. Similarly, figure 7, suggests that households where female members are the key contributors while collecting water (90-100% of the household time to collect water is devoted by female members), also benefit the most from presence of water markets.

Figure 7: Distribution of Consumer Surplus due to Water Market and Women in the Household



Notes: In this figure, in the x-axis, we plot the share of time taken by woman member of a household to collect water. In the y-axis, we plot the consumer surplus in Indian Rupees (per a liter of water) generated due to water market for the consumer. The z-axis plots the frequency of consumers.

9.2 Measuring the Market Power

The consensus from majority of current literature on firms is that developing countries are dominated by small firms. Additionally, most of the developing country markets are largely populated by informal firms (for example see La Porta and Shleifer (2014), Hsieh and Olken (2014)). While the presence of large number of small firms in the informal developing country setting is well documented, current literature has ignored the issue of presence of market power in such settings.[14]

We use our unique data setting and results from our structural model to develop a test of market power in this informal market. We follow the frameworks developed in in Industrial Organization literature to implement our test of market power in this context. Studies in Industrial Organization such as Miller and Weinberg (2017), Nevo (2001) and Ciliberto and Williams (2014) have used similar approach in a differentiated product world to measure market power in the beer market, cereal market, and airline market in the USA respectively. In the developing country context, Chaudhuri, Goldberg, and Jia (2006) uses a structural approach to measure market power in the pharmaceutical market in India. We use similar ideas to develop our test, and apply this to an informal market setting in a developing country.

We demonstrate our methodology in a simple two seller example, a more general framework follows similarly. Suppose in a market there are two sellers and the prices charged by the sellers are denoted by p_1 and p_2. Note that, if the sellers are competing (without coordination), then each of the sellers will fix price by maximizing its own profit taking other seller's action as given. Under cooperative/collusive behavior, each seller will internalize the effects of its action on its rival's profit. The degree of cooperation will lead to market power of a seller, if all sellers operate as a monopoly, then they can charge a higher markup compared to the case where the sellers compete with each other.

We denote the degree of cooperation as κ and model it as a function of seller characteristics. For example, sellers of same caste may be more likely to cooperate with each other. Similarly, sellers from same village or sellers who collect from same water source before selling the water may find it easier to cooperate compared to other sellers. To allow this we estimate different κ parameter for sellers of different castes and for sellers collecting water from different sources.

Given that a seller puts weight κ on its rival's profit, the profit maximization problems

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[14] In her NBER/BREAD address in summer institute 2018, Prof. Penny Goldberg also highlighted this, see the slide 6 in her talk `https://www.nber.org/programs/dev/slides/18Goldberg.pdf`

of firm 1 and 2 are respectively given by

$$\Pi_1 = \max_{p_1} \left[\underbrace{(p_1 - c_1) * q_1(p_1, p_2)}_{\pi_1} + \kappa * \underbrace{(p_2 - c_2) * q_2(p_1, p_2)}_{\pi_2} \right]$$
$$\Pi_2 = \max_{p_2} \left[\underbrace{(p_2 - c_2) * q_2(p_1, p_2)}_{pi_2} + \kappa * \underbrace{(p_1 - c_1) * q_1(p_1, p_2)}_{\pi_1} \right]$$

Note that we model the cooperation in a symmetric way. In our setting, $\kappa = 0$ implies that the sellers are perfectly competitive, while $\kappa = 1$ signifies collusion leading to monopoly. A value of κ between 0 and 1 signifies some level of cooperation.

The set of first order conditions are given by

$$\frac{\partial \Pi_1}{\partial p_1} = (p_1 - c_1)\frac{\partial q_1}{\partial p_1} + q_1 + \kappa(p_2 - c_2) * \frac{\partial q_2}{\partial p_1} = 0$$
$$\frac{\partial \Pi_2}{\partial p_2} = (p_2 - c_2)\frac{\partial q_2}{\partial p_2} + q_2 + \kappa(p_1 - c_1) * \frac{\partial q_1}{\partial p_2} = 0$$

Writing this in vector form, we have

$$\begin{bmatrix} q_1 \\ q_2 \end{bmatrix} + \left(\begin{bmatrix} \frac{\partial q_1}{\partial p_1} & \frac{\partial q_2}{\partial p_1} \\ \frac{\partial q_1}{\partial p_2} & \frac{\partial q_2}{\partial p_2} \end{bmatrix} \circ \begin{bmatrix} 1 & \kappa \\ \kappa & 1 \end{bmatrix} \right) * \begin{bmatrix} (p_1 - c_1) \\ (p_2 - c_2) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{14}$$

where $\circ$ denotes the element by element multiplication of two matrices.

Note that, under no coordination, $\kappa = 0$, and using the above first order condition, we have

$$\begin{bmatrix} q_1 \\ q_2 \end{bmatrix} + \begin{bmatrix} \frac{\partial q_1}{\partial p_1} & 0 \\ 0 & \frac{\partial q_2}{\partial p_2} \end{bmatrix} * \begin{bmatrix} (p_1 - c_1) \\ (p_2 - c_2) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{15}$$

Extending this framework to J sellers, the equation system (14) can be written as

$$\vec{q} + (\Delta \circ O_\kappa) * (\vec{p} - \vec{c}) = \vec{0} \tag{16}$$

where $\vec{q}$ denotes the vector of quantities, Δ denotes the $J \times J$ derivative matrix, O_κ denotes the $J \times J$ square matrix where all diagonal terms are given by 1 while the off-diagonal terms are denoted by κ. $\vec{p}$ and $\vec{c}$ denote the price and cost vectors respectively.

Our goal in the above setting is to estimate the parameters of κ that capture the level of coordination among sellers and also serve as a measure of market power. A value of κ that is closer to 0 signifies lower coordination and hence less market power while a value of κ that is closer to 1 signifies higher coordination, less competition and hence higher market power among sellers.

In the equation (14), we can derive the derivative matrix using the estimated demand model. Also, our dataset contains detailed information regarding the cost of water collection. Marginal cost of collecting and selling water includes cost of extracting water and the cost of transportation. Since we have information on fuel cost, mode of transportation as well as mode of water extraction, we can precisely compute the water collection cost for each seller from our data. Additionally, since our data contains information on distance between source of water collection and the village location, we can compute seller specific cost of transportation.

Given the cost information and the information on derivatives, we can use method of moments approach to estimate the parameters of κ. The estimation procedure is as follows: for a given starting value of a parameter vector κ, we can compute the left hand side of the equation (14) (and (16)). Given the model specification, in the population, the error vector should all be identically equal to zero. An estimate of κ vector is chosen to set the sample analog of the error terms as close to zero as possible. In practice, $\hat{\kappa}$ is chosen to minimize the quadratic distance measure given by the sum of squared errors.

We report the estimated value of κ_0 in table 12. Our estimate of κ_0 comes out to be 0.394 with standard error equal to 0.04. The value of κ is significantly different from zero at 95% confidence level. This suggests that the null of competition among the sellers is easily rejected. It seems the sellers have some degree of cooperation while operating in this informal market. Therefore sellers do possess some market power. We are in the process of extending our analysis to include more flexible form of cooperation by allowing higher coordination among the sellers of same caste or from same village. This will provide us further insights into the form of coordination that we find in this informal market.

In the above specification, we assume that we observe the actual marginal cost. However, a part of the marginal cost may be observable to the sellers which may be unobservable to the econometrician. In this specification, we allow for the unobservable shock and estimate the collusion parameter using the panel structure of the data. We observe prices and quantities in both summer and winter seasons. We assume that a seller's marginal cost may vary between summer and winter seasons, however this seller specific variation over time is observable to the econometrician. Therefore, the seller specific unobservable part of the marginal cost does not vary over time.

In a two firm world, using the derivations from (14), the first order conditions from summer and winter times are given by,

$$\begin{aligned}
&\text{For Summer Markets,}\\
&\begin{bmatrix} q_1^s \\ q_2^s \end{bmatrix} + \left(\begin{bmatrix} \frac{\partial q_1^s}{\partial p_1^s} & \frac{\partial q_2^s}{\partial p_1^s} \\ \frac{\partial q_1^s}{\partial p_2^s} & \frac{\partial q_2^s}{\partial p_2^s} \end{bmatrix} \circ \begin{bmatrix} 1 & \kappa \\ \kappa & 1 \end{bmatrix} \right) * \begin{bmatrix} (p_1^s - c_1^s - \varepsilon_1) \\ (p_2^s - c_2^s - \varepsilon_2) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}\\
&\text{For Winter Markets,}\\
&\begin{bmatrix} q_1^w \\ q_2^w \end{bmatrix} + \left(\begin{bmatrix} \frac{\partial q_1^w}{\partial p_1^w} & \frac{\partial q_2^w}{\partial p_1^w} \\ \frac{\partial q_1^w}{\partial p_2^w} & \frac{\partial q_2^w}{\partial p_2^w} \end{bmatrix} \circ \begin{bmatrix} 1 & \kappa \\ \kappa & 1 \end{bmatrix} \right) * \begin{bmatrix} (p_1^w - c_1^w - \varepsilon_1) \\ (p_2^w - c_2^w - \varepsilon_2) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}
\end{aligned} \tag{17}$$

In the above expression, the superscript s stands for summer time markets, and superscript w stands for winter time markets. Note that, we allow the same κ for both summer and winter markets indicating that the market conduct remains unchanged across time. Similarly, we allow ε_1 and ε_2 to remain unchanged over time.

Given the unobservables ε in the equation system, estimation of κ proceeds as follows.

1. We start with an initial value of κ.

2. Given the value of κ, we can estimate the vector of ε as a function of κ from summer time markets.

3. Given the value of κ and ε, we can compute the LHS of first order conditions in the winter markets.

4. Under the true value of κ (in the population) and given our model, the winter market equations must be equal to 0 given the values of ε derived from summer time markets.

5. In our sample during estimation, we minimize the objective function which is equal to the norm of the distance between the LHS of the first order conditions from winter markets and the vector of zeros. Estimation converges once the value of the objective function reaches its minimum value.

9.3 Counterfactual Exercise: Taxing water extraction

[To be updated]

9.4 Counterfactual exercise: Entry of Government

[To be updated]

10 Conclusion

In this paper, we use a unique dataset that we collected to assess the market for drinking water in rural Rajasthan in India. We estimate the demand for drinking water and relying on our estimates, we compute the welfare gains from the market. We show that highest consumer surplus per unit of water accrues to poor and households where women spend long time collecting water. These findings are indicative of regressive distributive effects that a ban on these markets can yield in order to conserve water resources. We also propose a test for estimating the extent of market power. In our context, we reject the null of perfect competition and find some degree of cooperation as well as market power among sellers. We intend to use these findings to determine how regulating this market via price instruments such as taxes affects the consumer welfare and what are its consequences for conservation of groundwater. Our counterfactual simulations from this exercise will be informative of optimal policy choice. While previous literature has focused on using pass through as a lever for measuring market power in informal markets, our procedure relies on a structural demand side approach. This test is easily portable to other informal markets characterized by several sellers. In future work, we also plan to model additional dimensions of the market and coordination among sellers to enrich our model and shed light on the coordination process.

Table 1: Number of Members in a Household

No. of members in the Household	Frequency
2	16
3	108
4	165
5	357
6	406
7	286
8	186
9	112
10	67
11	59
12	12
13	15
14	10
≥15	13
Total	1,812

Out of 1812 households in our sample, majority have less than 8 members in the household.

Table 2: Water Collection

No. of Members Collect Water	Freq	Time Spent (in Minutes) avg	min	max
0	529	0	0	0
1	307	59	10	410
2	592	53	10	240
3	266	47	10	180
4	86	45	18	143
5	18	35	20	54
6	8	38	30	55
7	4	43	24	61
8	2	48	34	62
Total	1,812			

Out of 1812 households in our sample, 529 households do not collect water. Most of the households spend close to an hour on average in collecting water.

Table 3: Water Collection by Females

Household collects Water	avg	min	max
Share of female members	71.2	0	100
Time Share of female members	74.2	0	100

Table 4: Source of Water

Source of Water	No of Households
Own Pipe	224
Own Tube	61
Community Pump	10
Community Well	7
Small Tank	14
Large Tank	349

Table 5: Month-Wise No of Households Purchasing Water

Month ID	No. of Households buying water
1	7
2	3
3	306
4	319
5	519
6	519
7	697
8	737
9	425
10	212
11	28
12	0
Total	3772

Table 6: Price per Unit by Months of the year

Month ID	mean	median	min	max	N
1	0.11	0.1	0.042	0.2	5
2	0.11	0.1	0.1	0.12	3
3	0.13	0.1	0.01	1.2	300
4	0.13	0.1	0.04	1.2	313
5	0.29	0.1	0.02	2	496
6	0.097	0.07	0.02	0.4	513
7	0.096	0.08	.02	.375	691
8	0.11	0.1	0.025	1	734
9	0.11	0.1	0.025	1	422
10	0.11	0.1	0.02	1	211
11	0.12	0.12	0.06	.14	28
12	-	-	-	-	0
Total	0.13	0.1	0.01	2	3716

Table 7: Total quantity sold (market size) over the months of the year

Month ID	Total Water Transaction (in ’000 liters)	Mean	Median	N
1	27	4550	5000	6
2	15	5000	5000	3
3	1475	4917	5000	300
4	1527	4879	5000	313
5	2202	4405	5000	500
6	2527	4916	5000	514
7	3484	5042	5000	691
8	3677	5002	5000	735
9	2137	5041	5000	424
10	1068	5037	5000	212
11	140	5000	5000	28
12	0	-	-	0
Total	18300	4905.813	5000	3726

Table 8: Household purchase patterns

No of Months	Freq
0	485
1	76
2	62
3	1,184
4	5
Total	1,812

Table 9: Reduced form Regression: Prob that a HH buys Water

	(Linear)	(Probit)	(Linear)	(Linear)	(Linear)	(Linear)
Price	-.115***	-0.38***	-0.114***	-0.100***	-0.100***	-0.143***
	(0.022)	(0.08)	(0.022)	(0.022)	(0.022)	(0.032)
Log(No. of Members in HH)			0.0364**	0.0343**	0.0307	0.0596***
			(0.0198)	(0.019)	(0.0197)	(0.024)
Have Own Pipe				-0.161***	-0.161***	-0.157***
				(0.022)	(0.022)	(0.032)
Have Car/Bike					0.0214	
					(0.018)	
Avg Time to Collect Water						0.00082***
						(0.0003)
Constant	0.876***	1.14***	0.817***	0.847***	0.838***	0.752***
	(0.009)	(0.04)	(0.034)	(0.033)	(0.034)	(0.047)
Observations	1,554	1,554	1,554	1,554	1,554	1,554
logL	-	-636	-	-	-	-

Table 10: Reduced form Regression: Prob that a HH buys Water

Prob(HH Buys)	(Linear)	(Linear)	(Linear)	(Linear)	(Linear)	(Linear)	(Linear)
Price	-0.118***	-0.152***	-0.146***	-0.141***	-0.140***	-0.0960***	-0.141***
	(0.0368)	(0.0317)	(0.0317)	(0.0318)	(0.0317)	(0.0307)	(0.0318)
Log(No. of Members in HH)	0.0438	0.0339	0.0446*	0.0383	0.0372	0.0240	0.0372
	(0.0276)	(0.0266)	(0.0269)	(0.0271)	(0.0286)	(0.0259)	(0.0271)
Have Own Pipe	-0.171***	-0.158***	-0.167***	-0.162***	-0.164***	-0.125***	-0.149***
	(0.0331)	(0.0322)	(0.0323)	(0.0324)	(0.0322)	(0.0311)	(0.0331)
Avg Time to Collect Water	0.000650*	0.000700*	0.000721*	0.000771**	0.000736**	0.000873**	0.000784**
	(0.000386)	(0.000373)	(0.000372)	(0.000373)	(0.000372)	(0.000356)	(0.000373)
Log(Total HH Spending)	0.00874						
	(0.0220)						
Log(Food Spending)		0.0348**	0.0429**	0.0409**	0.0409**	0.0587***	0.0427**
		(0.0164)	(0.0167)	(0.0168)	(0.0167)	(0.0161)	(0.0168)
Log(Cloth Spending)			-0.0249**	-0.0276***	-0.0305***	-0.0294***	-0.0271***
			(0.0102)	(0.0103)	(0.0105)	(0.00981)	(0.0103)
Log(Intox Spending)				0.0113*	0.0127**	0.00916	0.0105*
				(0.00607)	(0.00607)	(0.00580)	(0.00608)
Log(Educ Spending)					-0.00181		
					(0.00395)		
Log(No. of sellers in Village)						0.253***	
						(0.0243)	
Log(No. of sellers the buyer knows)							0.0570*
							(0.0301)
Constant	0.705***	0.547***	0.624***	0.607***	0.632***	0.255**	0.530***
	(0.187)	(0.112)	(0.116)	(0.116)	(0.116)	(0.116)	(0.123)
Observations	1,030	1,114	1,114	1,112	1,109	1,112	1,112
R-squared	0.045	0.055	0.060	0.063	0.065	0.147	0.066

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 11: Results from Structural Demand Estimation

Prob(HH Buys q_j)	(I)	(II)	(III)	(IV) [Instrumental Var]
Price	-39.46***	-45.6411***	-46.9014***	-54.783***
	(2.44)	(2.63)	(2.64)	(3.55)
Price × Income	1.997***	1.768***	2.11***	4.21***
	(0.29)	(0.29)	(0.30)	(0.38)
Price × Women time share	0.04***	0.02***	0.01***	0.06***
	(0.01)	(0.007)	(0.007)	(0.01)
Price × log(Number of Members)			-1.720***	
			(0.428)	
Price × log(Women Time)		2.20***	2.57***	2.99***
		(0.33)	(0.34)	(0.48)
Sigma	1.30***	1.27***	1.26***	1.55***
	(0.0328)	(0.032)	(0.032)	(0.04)
Log(Time to Collect Water By women)		-0.27***	-0.27***	-0.28***
		(0.04)	(0.04)	(0.05)
Have Own Pipe	0.53***	0.47***	0.48***	0.56***
	(0.09)	(0.09)	(0.09)	(0.1)
Have Own Car	-0.0114	-0.006	-0.005	0.02*
	(0.0586)	(0.058)	(0.06)	(0.01)
Avg Time to Collect Water	0.004***	0.004***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Log(Cloth Spending)	0.0895***	0.094***	0.091***	0.11***
	(0.0262)	(0.0257)	(0.0255)	(0.028)
Log(Educ Spending)	-0.0322***	-0.0279***	-0.023***	0.014
	(0.0100)	(0.0098)	(0.009)	(0.01)
Log(Food Spending)	-0.0491	-0.0295	-0.025	-0.03
	(0.0438)	(0.0433)	(0.042)	(0.042)
Log(Intox Spending)	-0.0512	-0.0593***	-0.056***	-0.058***
	(0.0169)	(0.016)	(0.02)	(0.02)
Dummy for Month 5	-0.0779	-0.0812	-0.0767***	0.0721
	(0.078)	(0.0765)	(0.077)	(0.077)
Dummy for Month 6	-0.5507***	-0.5487***	-0.5406***	-0.5607***
	(0.0771)	(0.0757)	(0.0752)	(0.078)
Dummy for Month 7	-0.2735	-0.2777***	-0.2755***	-0.276***
	(0.0705)	(0.0692)	(0.0687)	(0.0702)
Constant	10.3783***	11.3529***	11.3728***	11.4203***
	(0.3655)	(0.3921)	(0.3890)	(0.3901)
Observations	12,104	12,104	12,104	12,104
Price Instrumented	No	No	No	Yes

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 12: Estimation of Market power

Measure of Coordination among sellers ($\hat{\kappa_0}$)	0.394*** (0.04)

Table 13: Instrumental Variable Estimates

	First Stage	Instrumental Variable Estimate
Dependent Variable:	Log Village Average Price	Log Quantity Purchased
No Salt	-0.65***	
	(0.14)	
Low Salt	0.09	
	(0.05)	
Medium Level of Salt	0.05	
	(0.06)	
Village Average Price		-2.45***
		(0.78)
Observations	848	848

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Appendix Figure 1: Water Tankers used by Vendors

(a)

(b)

Appendix Figure 2: Household Storage Unit

Appendix Figure 3: Examples of Alternate Sources of Water

(c)