Measuring willingness to pay for reliable electricity: evidence from Senegal

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Abstract

Power outages, brownouts, and voltage cuts constitute a major obstacle in achieving sustainable development. Governments and funding agencies have recently focused on designing incentives to improve the quality and reliability of electricity supply. Designing these incentives relies on an accurate understanding of willingness to pay (WTP) by households and firms. In this paper, we provide new evidence on the WTP for improved electricity from a nationally-representative survey in Senegal. We find that households and firms are willing to pay a statistically and economically significant premium over current tariffs for high quality electricity service. We show that WTP is higher among urban households and formal firms. Importantly, we demonstrate how these WTP results are sensitive to design choices in the elicitation method, and provide guidance to practitioners implementing these methods and analyzing their results.

Keywords: willingness to pay, contingent valuation, DCm, unique valuation assumption

JEL codes: L94, D46, L11, O13, Q41

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1 Introduction

Improving access to electricity is an important component of long-term development in low-income countries. Electrification can raise female employment (Dinkelman, 2011; Grogan & Sadanand, 2013), increase industrialization (Rud, 2012), improve development and labor productivity (Lipscomb et al., 2013), increase agricultural income (Chakravorty et al., 2016), and reduce indoor air pollution (Barron & Torero, 2017), although economic and employment impacts have varied across contexts (Burlig & Preonas, 2016; Chakravorty et al., 2016). However, improving access to and the quality of electricity remains a key policy challenge. Quantifying the benefits of electricity access and service quality could help direct governments and funders to invest efficiently and help households and firms.

Grid connections are one key component of improved electricity access. Experimental evidence from Kenya shows that real demand for grid connections is significantly lower than the construction costs required to connect these households (Lee et al., 2019). Peer effects may play a role in increasing household demand for grid connections (Bernard & Torero, 2015). Even if households do achieve grid access, impacts may be muted or accrue slowly if use of electricity and uptake of appliances is low (Lenz et al., 2017) or require significant household investment (Richmond & Urpelainen, 2019).

Beyond the ability to connect to the grid, service quality may play a large role in determining whether households and firms can enjoy the benefits of electricity access. Improved quality has a large impact on household incomes (Rao, 2013), perhaps larger than the impact of a low-quality grid connection (Chakravorty et al., 2014). Electricity shortages and high prices have negative impacts on firm productivity (Abeberese, 2016; Allcott et al., 2016; Hardy & McCasland, 2019) and reduce the share of small firms working in electricity-intensive sectors (Alby et al., 2013). Government policies to maintain service for nonpaying households may create disincentives for firms to increase the quality of electricity service (McRae, 2015).

With the exception of Lee et al. (2019), researchers wishing to study the willingness to pay (WTP) for electricity access and service quality must typically lean on hypothetical elicitations and choice experiments. This paper is no exception: we use a nationally-representative survey of households and firms conducted in Senegal in 2018 which elicited WTP using an iterative bid contingent valuation (CV) method approach. CV methods are common in the literature studying access to electricity, with a variety of sub-national (Abdullah & Mariel, 2010; Taale & Kyeremeh, 2016) and national (Carlsson & Martinsson, 2007; Osiolo, 2017) surveys using CVM show positive and economically meaningful WTP for improved energy quality.\(^1\) This iterative method involves offering respondents a sequence

\(^{1}\)Contingent valuation is also common for eliciting WTP for other types of infrastructure, like domestic water (Whittington et al., 1991; Altaf et al., 1993; Kaliba et al., 2003; Dutta & Tiwari, 2005; Ademike & Titus, 2009), sanitation and waste management (Whittington et al., 1993; Anjum Altaf & Hughes, 1994; Rahji & Oloruntoba, 2009; Ezebilo, 2013), water quality (Choe et al., 1996), and even for targeting conditional cash transfers (Alix-Garcia et al., 2019).
of prices, which ascend or descend depending on the first response.

CV methods can provide useful insights into the policy implications of household and firm WTP for electricity quality. Households with a high WTP for reliable electricity may engage in costly mitigation behaviors like investing in self-generation (Oseni, 2017). In some contexts, household WTP alone is high enough to justify investment in improved service quality (Gunatilake et al., 2012). Households and firms are willing to pay more to avoid unplanned outages than planned outages of the same duration (Carlsson & Martinsson, 2007; Morrison & Nalder, 2009). Households may be willing to pay more for reliable grid electricity than renewable energy (Abdullah & Jeanty, 2011). Research using other types of choice experiments across a range of sub-national contexts in middle and high income countries also shows a positive willingness to pay to reduce the frequency and duration of power outages (Pepermans, 2011; Hensher et al., 2014; Ozbaflı & Jenkins, 2015; Abrate et al., 2016), particularly during the winter (Ozbafi & Jenkins, 2016; Morrissey et al., 2018).

In Senegal, both access to electricity and service quality remain primary challenges. According to the World Bank, in 2016 65 percent of the population had access to electricity, a sharp increase from 25 percent in 1990. In this paper, we provide estimates of household willingness to pay for grid connections among the sub-sample of households and firms who have not yet achieved a grid connection. We show that many unconnected households are in areas with existing connectivity - households in these areas may be cheaper to connect, but may enjoy fewer benefits if they can already access electricity via neighbors. We find, similarly to Lee et al. (2019), that unconnected households are willing to pay significantly less than the average connection fee reported by connected households. Especially in rural areas, lack of quality electricity supply might result in foregone opportunities. Chuhan-Pole et al. (2018) found that in Senegal in rural areas, farmers recognize the value of grid connection and perceive the lack of access to the grid as a major obstacle in production.

Electricity services in Senegal are also beset by unreliability: households and firms report a mean 1.4 outages per week (median 1), lasting an average of 53 minutes (median 30) and 31 minutes (median 20), respectively. More than 75% of households and firms report at least one electricity cut per week. 70% of firms report that power cuts cause revenue losses. Understanding the magnitude of household and firm WTP for improved quality relative to increased investment requirements (as in Gunatilake et al. 2012) is one key step towards designing better public policy for the sector.

In this paper, we first provide a careful characterization of household and firm WTP for electricity access and quality using a nationally-representative survey in Senegal. We show how WTP relates to observable characteristics, and in particular how these relate to existing tariffs. This heterogeneity may prove important in designing reforms to the electricity sector and make electricity distribution more efficient and sustainable. We document within-

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2Somewhat in contrast to Hardy & McCasland (2019), formal firms are slightly more likely to report revenue losses due to outages than informal firms, and similarly large formal firms more likely than small formal firms.
household variation in WTP between male and female respondents. Second, we demonstrate some potential pitfalls in estimating WTP using an iterative bid design. In particular, we show that a failure to check the assumption of single valuation may result in an economically important downward bias.

The remainder of the paper is organized as follows. We first describe the dataset and present summary statistics in section 2. Then, we describe the analytical framework used for analyzing household and firm data in section 3. Section 4 presents the results of our analysis, and finally section 5 concludes.

2 Data and summary statistics

For this study, we use a nationally-representative survey of households and firms collected between March and June 2018 (see Almanzar & Ulimwengu (2019) for details on the survey implementation). The dataset includes detailed information on 2775 households and 1072 enterprises (206 formal and 866 informal) in all 14 regions of Senegal. Eighty three percent of the households are connected to the electrical network, provided by either Senelec (92 percent) or a private dealer (8 percent). Only 474 surveyed households are not connected to the grid.

2.1 Household sample

We first introduce the household sample. Of the 2775 households surveyed, 1827 males and 1793 females responded to the WTP modules, with 863 households having two respondents. Male respondents are older, more educated, more likely to be married, and more likely to report being the household head. See Table A.3 for more details on respondent-level demographics.

The sample also differs significantly along urban-rural lines. We find that urban households are significantly more likely to have a bank account, smaller, less likely to own their home, and more likely to be connected to the grid. See Table A.4 for more details on the urban-rural differences in the sample.

If we instead split the sample and compare connected and unconnected households, we find that unconnected households are significantly less likely to have a bank account, smaller, and no less likely to own their own home. See Table A.5 for more details on this comparison.

Unconnected households are most likely to report relying on flashlights, candles, firewood, and charcoal as energy sources. The median unconnected household spends $6 per month on energy (mean $10). Ninety-four percent of unconnected households in the sample report that electricity is available in their area, and the median household reports being just 15 meters from the nearest electric pole (mean 188 meters). As Lee et al. (2019) find in Kenya, one reason that these households remain unconnected may be a low willingness to
pay for connection costs: the median household reports a willingness to pay for a grid connection of $17 (mean $29), whereas connected households reportedly paid a median of $31 (mean $37) to Senelec for a connection, and 27% of households report additional connection expenses (mean $19).

Turning to connected households, we find that 21% of households rely exclusively on the electric grid for energy. The median connected household spends $10 per month (mean $12) on energy sources other than electricity from the grid, suggesting households stand to save money if they could rely more or exclusively on the grid. 35% of households report being “unsatisfied” or “very unsatisfied” by the electricity services they currently receive.

2.2 Enterprise sample

Next, we turn to the firm sample, which includes a sample of both formal and informal firms. The firm survey used a stratified sampling approach using the Senegal General Business Census of 2016 (see Almanzar & Ulimwengu (2019) for details on the sampling strategy). In total, the dataset includes 538 informal firms and 188 formal firms. The vast majority of the surveyed firms are located in Dakar, which reflects the highly concentrated nature of the economy in Senegal.

Table A.6 shows how firms differ by formal status. Informal firms are younger, more likely to be rural, report fewer employees, more likely to be a home-based business, and less likely to report an income loss from power cuts. The primary respondent for informal firms was younger and less educated than for formal firms, but no more likely to be female. Finally, informal firms report paying a smaller tariff per kWh than formal firms.

2.3 Willingness to pay elicitation method

Willingness to pay was elicited using an interative bid approach. For connected households and firms, the elicited WTP was for improved electricity service without power cuts or voltage swings. For unconnected households and firms, the elicited WTP was for a new high-quality connection, again without power cuts or voltage swings. See Appendix C for more details about the exact wording of the questions.

Respondents were first asked whether they would accept to pay one of five randomly-drawn starting values. If the respondent answered “yes” (“no”) to the first question, subsequent questions would increase (decrease) from the starting value. For all questions following the first, the amount offered was 115% (85%) of the previous value. The questions continued until the respondent changed their response (from “yes” to “no” or vice versa), to a maximum of 12 possible values offered. If the respondent maintained the same response for all 12 questions, he/she would be asked an open-ended question about their WTP.

The median household respondent answered only four rounds of the WTP survey before changing their response, and 82% responded to less than six rounds. Figure 2 shows the distribution of the number of rounds completed, and how this differs by whether respondents
took the ascending or descending path. The number of rounds completed is significantly larger for respondents on the descending path.

3 Methods

3.1 Individual WTP

The WTP elicitation method in the Senegal WTP for Electricity Survey follows a multiple-bound dichotomous choice design (DCm). The data generating process resembles the one of
an ordered probit model where the thresholds are known. Therefore, we employ maximum likelihood estimation and modify the likelihood function of the ordered probit model to account for the fact that the threshold values are known. This approach extends the double bounded (or interval) model formalized by Lopez-Feldman (2012) and applied in Oseni (2017) to estimate the WTP for reliable electricity in Nigeria.

More specifically, let \( t_i = t^1_i, \ldots, t^J_i \) denote the predetermined randomized values that differ across individuals, \( i \), and \( y_i = y^1_i, \ldots, y^J_i \) denote the dichotomous answer regarding the willingness to pay for that specified amount. Then \( y^j_i = 1 \) if individual \( i \) is willing to pay amount \( y^j_i \) and 0 otherwise. Furthermore, let \( z_i \) denote the vector of explanatory variables and \( \beta \) a corresponding vector of coefficients. Define an individual’s unique willingness to pay (WTP) as:

\[
WTP_i = z_i' \beta + u_i
\]  

(1)

where \( u_i \) denotes the error term.

A respondent will answer yes (\( y^j_i = 1 \)) when his/her WTP exceeds the suggested amount \( t^j_i \), such that \( WTP_i > t^j_i \) and no otherwise. The first answer determines whether the bids are ascending (if \( y^1_i = 1 \)) or descending (if \( y^1_i = 0 \)). Given that each respondent can be presented with \( j = 1, \ldots, J \) suggested amounts, the likelihood function comprises \( 2 \times J \) terms. In case of ascending bids the potential responses are as follows: \( \{yes, no\}, \{yes, yes, no\}, \{yes, yes, yes, no\}, \ldots, \{yes, yes, yes, \ldots, yes\} \). In the case of descending bids the answers take follow reverse pattern: \( \{no, yes\}, \{no, no, yes\}, \{no, no, no, yes\}, \ldots, \{no, no, no, \ldots, no\} \). Therefore, assuming that the error term is normally distributed, \( u_i \sim N(0, \sigma^2) \), the probability that the individual’s WTP will fall between two subsequent values \( t^{j-1}_i \) and \( t^j_i \) for \( j = \{2, \ldots, J\} \) when the respondent is on the ascending path (i.e. \( y^1_i = 1 \)) can be expressed as:

\[
\Pr(y^{j-1}_i = 1, y^j_i = 0|z_i) = \Pr(t^{j-1}_i \leq WTP < t^j_i|z_i)
\]

\[
= \Pr(t^{j-1}_i \leq z_i' \beta + u_i < t^j_i|z_i)
\]

\[
= \Pr \left( \frac{t^{j-1}_i - z_i' \beta}{\sigma} \leq \frac{v_i}{\sigma} < \frac{t^j_i - z_i' \beta}{\sigma} \right)
\]

\[
= \Phi \left( \frac{t^j_i - z_i' \beta}{\sigma} \right) - \Phi \left( \frac{t^{j-1}_i - z_i' \beta}{\sigma} \right)
\]

where \( v_i \sim N(0,1) \) and \( \Phi \) denotes the cdf of the standard normal distribution. When the respondent is instead on the descending path (i.e. \( y^1_i = 0 \)) the probability that his/her WTP falls between two subsequent values \( t^j_i \) and \( t^{j-1}_i \) for \( j = \{2, \ldots, J\} \) can be expressed

\[^3\text{This is equivalent to interval regression.}\]
as:
\[
\Pr(y_{i}^{j-1} = 0, y_{i}^{j} = 1|z_{i}) = \Pr(t_{i}^{j} \leq \text{WTP} < t_{i}^{j-1}|z_{i})
\]
\[
= \Pr(t_{i}^{j} \leq z_{i}'\beta + u_{i} < t_{i}^{j-1}|z_{i})
\]
\[
= \Pr\left(\frac{t_{i}^{j} - z_{i}'\beta}{\sigma} \leq \frac{v_{i}}{\sigma} < \frac{t_{i}^{j-1} - z_{i}'\beta}{\sigma}\right)
\]
\[
= \Phi\left(\frac{t_{i}^{j-1} - z_{i}'\beta}{\sigma}\right) - \Phi\left(\frac{t_{i}^{j} - z_{i}'\beta}{\sigma}\right)
\]

The probability that the respondent’s WTP exceeds all suggested bids (i.e. respondent \( i \) answered “yes” to all suggested values) is equal to:

\[
\Pr(y_{i}^{1} = 1, \ldots, y_{i}^{J} = 1|z_{i}) = \Pr(\text{WTP} > t_{i}^{J}|z_{i})
\]
\[
= \Pr(z_{i}'\beta + u_{i} > t_{i}^{J}|z_{i})
\]
\[
= \Pr\left(\frac{v_{i}}{\sigma} > \frac{t_{i}^{J} - z_{i}'\beta}{\sigma}\right)
\]
\[
= 1 - \Phi\left(\frac{t_{i}^{J} - z_{i}'\beta}{\sigma}\right)
\]

And similarly, the probability that the respondent’s WTP is lower than the lowest value of the suggested bids (i.e. respondent \( i \) answered “no” to all suggested values) is equal to:

\[
\Pr(y_{i}^{1} = 0, \ldots, y_{i}^{J} = 0|z_{i}) = \Pr(\text{WTP} < t_{i}^{J}|z_{i})
\]
\[
= \Pr(z_{i}'\beta + u_{i} < t_{i}^{J}|z_{i})
\]
\[
= \Pr\left(\frac{v_{i}}{\sigma} < \frac{t_{i}^{J} - z_{i}'\beta}{\sigma}\right)
\]
\[
= \Phi\left(\frac{t_{i}^{J} - z_{i}'\beta}{\sigma}\right)
\]

Note that, while in general with an ordered probit model one would need to assume that \( \sigma^2 = 1 \), we do not need to make that normalization when the cut-off points are known. As in case of an ordered probit, we estimate the parameter vector of interest, \( \beta \), using maximum likelihood. Given the above equations for possible probabilities, the likelihood
function becomes:

\[
\mathcal{L} = \sum_{i=1}^{N} \left\{ d_{y_i}^{y_i-1} = 1, y_i = 0 \ln(\Phi(\frac{t_{ij}^{y_i} - z_{ij}^{y_i} \beta}{\sigma}) - \Phi(\frac{t_{ij}^{y_i-1} - z_{ij}^{y_i} \beta}{\sigma})) + d_{y_i}^{y_i-1} = 1, \ldots, y_i = 1 \ln(\frac{t_{ij}^{y_i} - z_{ij}^{y_i} \beta}{\sigma} - \Phi(t_{ij}^{y_i-1} - z_{ij}^{y_i} \beta)) + d_{y_i}^{y_i-1} = 0, y_i = 1 \ln(\Phi(\frac{t_{ij}^{y_i} - z_{ij}^{y_i} \beta}{\sigma}) - \Phi(\frac{t_{ij}^{y_i-1} - z_{ij}^{y_i} \beta}{\sigma})) + d_{y_i}^{y_i-1} = 0, \ldots, y_i = 0 \ln(\Phi(\frac{t_{ij}^{y_i} - z_{ij}^{y_i} \beta}{\sigma} - \Phi(t_{ij}^{y_i-1} - z_{ij}^{y_i} \beta)) \right\}
\]

(6)

where \( d_{y_i}^{y_i-1} = 1, y_i = 0, d_{y_i}^{y_i-1} = 1, \ldots, y_i = 1, d_{y_i}^{y_i-1} = 0, y_i = 1, \ldots, y_i = 0 \) are indicator variables denoting which case an individual falls into.

In the results presented below, we take the logarithm of the interval boundaries \( t_{ij} \). For the covariate matrix \( z_i \), we follow previous empirical work and include a number of individual and household characteristics. More specifically, we include respondent age, gender and education level, measured as a dummy variable indicating whether the individual attained at least a high school level of schooling. At a household level we control for the household’s main source of income (agriculture, services, commerce or other), expenditure level (Q1-Q5 measured as dummy variables indicating whether the household’s expenditures falls in a given quintile of the distribution of expenditures), household size (measured as number of residents). We also control for whether a household has savings in the form of a bank account and for the ownership status of the dwelling. We also include region and interviewer fixed effects. Finally, we control for the level of the initial bid as previous work suggests it can be a source of a bias (Boyle et al., 1997).

One potential source of heterogeneity of particular interest is whether WTP is related to household quality of electricity supply. Households experiencing frequent or lengthy power cuts may have a higher WTP than households already receiving relatively high-quality service. To test for this heterogeneity, we include a dummy for households who report experiencing power cuts.

A primary critique of this type of WTP model is that it relies on the assumption that there is a single underlying latent WTP process. Several studies have raised concerns that dichotomous-choice designs can lead to answers that are internally inconsistent. The starting point may be a source of bias (Herriges & Shogren, 1996; Boyle et al., 1997), as well as Boyle et al. (1997) identify starting-point effects in single-bounded DC designs. Bateman et al. (2001) extend this result to double- and triple-bounded designs, identifying both starting-point and path effects. In our results below, we extend these results and test for the presence of starting-point and path effects.\(^4\)

\(^4\)One avenue for extending this approach further might be to adapt the methods in Cameron & Quiggin (1994).
3.2 Panel-like structure for subset of households

For some of the households, the dataset contains responses from two household members. In this case, for each household \( h \), we observe the WTP for a male and a female respondent. This gives us a unique opportunity to exploit the panel-like structure of the data and account for unobserved household level characteristics. We can decompose the error term in the WTP equations for male (\( m \)) and female (\( f \)) members of households to a household specific component, \( \nu_h \), and the idiosyncratic part, \( \varepsilon_m \) and \( \varepsilon_f \), respectively. Then assuming that \( \nu_h \sim N(0, \sigma_{\nu_h}^2) \) and that the household specific effects are not correlated with the other regressors in the willingness to pay equation (so assuming random effects structure), we can construct a likelihood function. However, given that the household specific effects are likely to be correlated with other regressors in the model, we apply Mundlak (1978) correction and model the household level individual effects as a function of household level averages of some of the regressors, i.e. we include averages of those regressors at a household level as additional variables. The obtained estimates of \( \beta \) are equivalent to estimates of a fixed effects model. This approach is particularly attractive for assessing the differences between genders in terms of WTP. Assuming a normal distribution, \( N \sim (0, \sigma_{\nu_h}^2) \) for the random effects \( \nu_h \) each individual contribution to the likelihood function is:

\[
l_h = \int_{-\infty}^{\infty} e^{-v^2/2\sigma^2} \prod_{t=1}^{2} F(t_{1ht}, t_{2ht}, z_{ht}\beta + v_h) \, dv_h
\]

where \( F(\cdot) \) is defined analogous to the probabilities above and the log likelihood \( L \) is the sum of the logs of the individual level likelihoods \( l_h \).

4 Results: WTP for improved electricity

4.1 Cross-sectional analysis (households)

In this section, we present results from the cross-sectional analysis of individual WTP for improved electricity services among already-connected households. We first test and reject an important assumption for interpreting the results of the method. We then present results from single-bound, double-bound, and multiple-bound models. Finally, we discuss interpretation of the results and potential policy implications.

A key underlying assumption of WTP estimation using a multiple-bound DCm design is that the latent distribution of resource values is consistent across rounds. If the underlying WTP distribution is significantly different in follow-up rounds relative to the distribution implied by the first-round responses, this could suggest the results using the follow-up bids are biased. In order to test it in our data, we estimate a model including interaction terms between all regressors and dummy variables indicating the number of completed rounds in the bidding game. If the coefficients on the interaction terms are jointly not statistically
significant from zero, we can conclude that this assumption holds. If, however we find that the coefficients are jointly statistically significantly different from zero, than we can no longer rely on our estimates and we should consider reverting to estimates based only on the initial bid. Since this substantially increases the number of coefficients to be estimated and since in Table B.7 it appears that the coefficients are very similar between 6 and 12 rounds, we perform this exercise for up to 6 rounds the bidding game. For 2, 3, and 6 rounds we reject the hypothesis that the $\beta$ coefficients do not differ between the rounds and therefore,\(^5\) we conclude the main underlying assumption in the above mentioned likelihood estimation does not hold in the data.

Although we are unable to support the assumption of a consistent underlying value distribution, in practice the bias may be small. If the resulting distributions are not very different, we could conclude it has a limited effect on the primary estimate of interest, i.e., the WTP for reliable electricity. Thus, we proceed with estimating the WTP using a probit model (Cameron & James, 1987; Lopez-Feldman, 2012) given different assumptions about the number of rounds in the game. We first estimate the implied WTP resulting from a single-bound model (Bishop & Heberlein, 1979), in which we consider only the initial bid. Coefficients in the latent WTP equation ($\beta$) are obtained via a transformation proposed by Cameron & James (1987): $\beta = \gamma_1/\gamma_0$ where $\gamma_1$ denotes the probit estimates and $\gamma_0$ the estimate on the initial bid. Then, we estimate a double-bound model where we consider the initial bid and a single follow-up (Hanemann et al., 1991). Next, we estimate multiple-bound models using 2, 3, and all 11 follow-up bids. Lastly, we compare the results of this probit estimation to results obtained by assigning individuals to the midpoint of the appropriate valuation interval and estimating the parameters using OLS.

The results of this exercise are summarized in Figure 3 (see Appendix B for a full corresponding table of coefficients). We find that the distributions are visibly similar, and all suggest a large majority of households willing to pay a price per kWh which is meaningfully higher than the average estimated rate households are currently paying in the data ($0.17 per kWh). Table 1 shows that across the models, we find a similar result that households are willing to pay 24-35 percent more than the current average price per kWh for reliable electricity. As in Bateman et al. (2001), we do find that increasing the number of follow-up questions results in lower average WTP among households. The difference is of economic importance, since as Figure 3 shows, the single-bound model shows a flatter distribution but one centered at a higher average WTP. Therefore, any policy recommendations based on DCm designs under the assumption of a unique latent valuation process should first check that assumption and consider the implications of its violation.

\(^5\)Detailed results can be obtained from the authors on demand. All p-values were 0.000.
Figure 3: WTP per kWh, households (cross-sectional)

Table 1: Household WTP compared to mean reported price per kWh

|                         | 1  | 2  | 3  | 6  | 12 | OLS |
|-------------------------|----|----|----|----|----|-----|
| Percentage with WTP > mean price | 0.84 | 0.80 | 0.79 | 0.83 | 0.85 | 0.74 |
| Mean difference (WTP - mean price) | 0.06 | 0.05 | 0.04 | 0.05 | 0.06 | 0.03 |
| Median difference (WTP - mean price) | 0.07 | 0.05 | 0.04 | 0.05 | 0.06 | 0.03 |
4.2 Panel-like analysis (households)

We next present the results of the random effects model for the households for which two respondents, male and female, answered the questionnaire. By doing so we can improve the efficiency of the estimates by comparing individuals within a household and thus assume away the confounding effect of unobserved household level characteristics. As above, given the concerns about bias in the multiple-bound models, we estimate several models with different restrictions on the number of rounds considered.

We first present a figure (analogous to Figure 3 above) which shows the overall distribution of willingness to pay by respondents. Figure 4 shows that, in general, we again find willingness to pay that is substantially higher than the mean price currently paid by households (see Appendix B for a full corresponding table of coefficients).

![Figure 4: WTP per kWh, households (panel-like)](image)

The models do not give consistent results about relative WTP by males and females. In most models, we find that females are willing to pay significantly less than males for reliable electricity. However, the full 12-round model finds the opposite result, that females are willing to pay significantly more than males. Further work may be needed to better understand the within-household differences in WTP, and whether these differences are meaningful for policy.

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注6 Results show that indeed panel level effects are present (LR test, p-value=0.000).
4.3 Cross-sectional analysis (formal and informal firms)

We next turn to the estimation of WTP among enterprises. As with the household sample, we report results from a number of models, and compare with results from OLS with the interval midpoint as the outcome. More precisely, we estimate a single-bound probit model, interval regressions with results from 2, 3, 6, and all 12 rounds of the elicitation, and compare with results estimated via OLS on the midpoint of the intervals.

We find that firms report positive and economically significant WTP for improved electricity. Figure 5 shows the distribution of WTP estimated from different models. Unlike the household sample, here we find substantial deviation between models. Interestingly, the results which incorporate more rounds of bidding approach the single-bound results more closely. This may be an avenue for future research.

Importantly, note that the firms in this sample report paying almost 50% more per kWh than households. The median formal firm reports paying $0.28/kWh, whereas the median informal firm reports paying $0.23/kWh. We do find that a meaningful proportion of firms are willing to pay more than the current average price, but the proportion varies widely across models. Table 2 summarizes these results for both formal and informal firms. This suggests caution for policymakers in deciding how to set tariffs for improved service for firms.

![Figure 5: WTP per kWh, firms](image-url)
Table 2: Firm WTP compared to mean reported price per kWh

|                    | 1   | 2   | 3   | 6   | 12  | OLS |
|--------------------|-----|-----|-----|-----|-----|-----|
| **Formal**         |     |     |     |     |     |     |
| Percentage with WTP > mean price | 0.88 | 0.73 | 0.78 | 0.77 | 0.74 | 0.72 |
| Mean difference (WTP - mean price) | 0.11 | 0.05 | 0.07 | 0.05 | 0.05 | 0.05 |
| Median difference (WTP - mean price) | 0.12 | 0.05 | 0.06 | 0.07 | 0.06 | 0.06 |
| **Informal**       |     |     |     |     |     |     |
| Percentage with WTP > mean price | 0.76 | 0.48 | 0.50 | 0.56 | 0.58 | 0.59 |
| Mean difference (WTP - mean price) | 0.05 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 |
| Median difference (WTP - mean price) | 0.05 | -0.00 | 0.00 | 0.01 | 0.01 | 0.01 |

5 Conclusions

Using new data and a variety of modeling approaches, we estimate the willingness to pay for improved electricity services among households and enterprises in Senegal. We find evidence of heterogeneity with respect to location and gender among households and legal status among enterprises. Urban household, men and formal enterprises exhibit on average higher willingness to pay for reliable electricity services. We find that willingness to pay for improved electricity is meaningfully greater than average tariffs for current service levels, suggesting a way forward for policymakers to raise the needed revenue to cover service improvements. Future work could extend this to conduct a more thorough cost-benefit analysis.

Moreover, we find that in any DCm design, it is of crucial importance to check the data against the single valuation assumption. Failure to do so may result in significant downward bias of the WTP estimates. Given that studies aiming at estimating WTP often take this assumption for granted, our results should serve as a cautionary tale for future practitioners.
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Appendix

A Additional Summary Statistics

Table A.3: Respondent characteristics

|                       | Male   | Female  |
|-----------------------|--------|---------|
| Respondent age        | 47.31  | 41.48   |
|                       | (14.81)| (13.18) |
| Any education         | 0.530  | 0.383   |
|                       | (0.499)| (0.486) |
| Household head        | 0.773  | 0.342   |
|                       | (0.419)| (0.474) |
| Married               | 0.859  | 0.797   |
|                       | (0.348)| (0.402) |

mean coefficients; sd in parentheses

B More on WTP estimates

C WTP scenarios

The scenario presented to connected respondents was as follows:

Taking into account your current expenses and that your household currently pays [amount previous bill] FCFA for [consumption in the previous bill]kwh. The average price is [average price paid in previous bill] CFA/Kwh and you experience [number of outages per week] outages per week.

If you were to receive "satisfactory electricity services" that give you electricity 24H/7J without outages or low voltages, would you be willing/ready to pay: [random initial price] CFA/Kwh or a bimonthly bill of [consumption in the previous bill]x[random initial price] for your current consumption?

The electricity will be metered, and you will be billed every 2 months and you would probably use more electricity than you use at the moment.
Table A.4: Characteristics of urban and rural households

| Variable                          | (1) | N  | Urban Mean/SE | (2) | N  | Rural Mean/SE | T-test Difference (1)-(2) |
|-----------------------------------|-----|----|---------------|-----|----|---------------|------------------------|
| Bank account                      |     | 1485 | 0.190 (0.010) | 1290 | 0.104 (0.008) | 0.086***                |
| Household size                    |     | 1485 | 8.627 (0.161) | 1290 | 11.369 (0.252) | -2.742***               |
| Owns home                         |     | 1485 | 0.556 (0.013) | 1290 | 0.854 (0.010) | -0.298***               |
| Connected to grid                 |     | 1485 | 0.876 (0.009) | 1290 | 0.775 (0.012) | 0.101***                |
| Non electricity energy expenses per month (USD) | 1539 | 13.368 (0.411) | 1307 | 9.815 (0.339) | 3.553***                |
| Estimated cost per kWh (USD)      |     | 1299 | 0.173 (0.000) | 1000 | 0.173 (0.000) | 0.000**                 |

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A.5: Characteristics of connected and unconnected households

| Variable                          | (1) | N  | Not connected Mean/SE | (2) | N  | Connected to grid Mean/SE | T-test Difference (1)-(2) |
|-----------------------------------|-----|----|-----------------------|-----|----|-------------------------|------------------------|
| Bank account                      |     | 474 | 0.021 (0.007)         | 2301 | 0.176 (0.008) | -0.155***               |
| Household size                    |     | 474 | 8.219 (0.281)         | 2301 | 10.248 (0.167) | -2.029***               |
| Owns home                         |     | 474 | 0.679 (0.021)         | 2301 | 0.698 (0.010) | -0.019                  |
| Non electricity energy expenses per month (USD) | 474 | 10.192 (0.567) | 2301 | 12.417 (0.314) | -2.226***               |

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.
### Table A.6: Characteristics of formal and informal firms

| Variable                  | Informal N | Mean/SE  | Formal N | Mean/SE  | T-test Difference |
|---------------------------|------------|----------|----------|----------|------------------|
| Firm age                  | 538        | 10.742 (0.428) | 188      | 14.309 (0.861) | -3.567***        |
| Rural                     | 538        | 0.283 (0.019)  | 188      | 0.059 (0.017)  | 0.224***         |
| Number of employees       | 538        | 3.368 (0.432)  | 188      | 11.511 (1.834) | -8.143***        |
| Home business             | 538        | 0.182 (0.017)  | 188      | 0.069 (0.019)  | 0.113***         |
| Experiences power cuts    | 538        | 0.771 (0.018)  | 188      | 0.777 (0.030)  | -0.005           |
| Income loss from cuts     | 538        | 0.680 (0.020)  | 188      | 0.766 (0.031)  | -0.086**         |
| Resp. age                 | 538        | 41.662 (0.495) | 188      | 48.372 (0.849) | -6.711***        |
| Resp. female              | 538        | 0.136 (0.015)  | 188      | 0.122 (0.024)  | 0.013            |
| Resp. attended primary school | 538   | 0.210 (0.018)  | 188      | 0.064 (0.018)  | 0.146***         |
| Resp. attended highschool  | 538        | 0.087 (0.012)  | 188      | 0.138 (0.025)  | -0.051**         |
| Resp. attended college    | 538        | 0.221 (0.018)  | 188      | 0.713 (0.033)  | -0.492***        |
| Estimated cost per kWh (USD) | 501      | 0.260 (0.006)  | 182      | 0.285 (0.009)  | -0.025**         |

*Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.*
Table B.7: Household WTP for improved electricity service

|                       | (1)     | (2)     | (3)     | (4)     | (5)     | (6)     |
|-----------------------|---------|---------|---------|---------|---------|---------|
| **main**              |         |         |         |         |         |         |
| Starting value        | -10.87*** | 0.71*** | 1.16*** | 1.60*** | 2.16*** | 0.97*** |
|                       | (0.59)  | (0.23)  | (0.18)  | (0.18)  | (0.19)  | (0.20)  |
| Female                | -0.20*** | -0.04** | -0.01   | 0.07*** | 0.18*** | -0.09***|
|                       | (0.06)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |
| Experiences power cuts| -0.07   | -0.03   | -0.02   | -0.01   | -0.05*  | -0.03   |
|                       | (0.08)  | (0.03)  | (0.02)  | (0.02)  | (0.03)  | (0.03)  |
| Age                   | -0.00** | -0.00***| -0.00***| -0.00***| -0.00***| -0.00***|
|                       | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  |
| Formal ed (0/1)       | 0.10*   | 0.03    | 0.03    | 0.03    | 0.02    | 0.02    |
|                       | (0.06)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |
| HH head               | 0.01    | 0.04*   | 0.04*** | 0.05**  | 0.08*** | 0.04*   |
|                       | (0.07)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |
| Married               | -0.05   | -0.02   | -0.02   | -0.02   | -0.00   | -0.01   |
|                       | (0.07)  | (0.02)  | (0.02)  | (0.02)  | (0.03)  | (0.03)  |
| HH size               | -0.01   | -0.00   | -0.00*  | -0.00*  | -0.00*  | -0.00** |
|                       | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  |
| Tot. exp. quintile 2  | -0.10   | -0.03   | -0.03   | -0.03   | -0.02   | -0.05   |
|                       | (0.10)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  |
| Tot. exp. quintile 3  | -0.11   | -0.06*  | -0.03   | -0.03   | -0.01   | -0.04   |
|                       | (0.10)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  |
| Tot. exp. quintile 4  | -0.16   | -0.06*  | -0.02   | -0.02   | -0.02   | -0.03   |
|                       | (0.10)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  |
| Tot. exp. quintile 5  | -0.06   | -0.01   | 0.01    | 0.01    | 0.03    | 0.01    |
|                       | (0.11)  | (0.03)  | (0.03)  | (0.03)  | (0.04)  | (0.04)  |
| Rural                 | 0.01    | 0.01    | 0.00    | -0.01   | -0.03   | -0.01   |
|                       | (0.07)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.03)  |
| Income source:        |         |         |         |         |         |         |
| agriculture           | 0.08    | 0.03    | 0.01    | -0.00   | -0.00   | -0.01   |
|                       | (0.09)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  |
| Income source:        |         |         |         |         |         |         |
| commerce              | -0.08   | -0.03   | -0.03   | -0.03   | -0.03   | -0.05** |
|                       | (0.07)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.03)  |
| Income source:        |         |         |         |         |         |         |
| services              | -0.12   | -0.03   | -0.03   | -0.02   | -0.02   | -0.04   |
|                       | (0.08)  | (0.03)  | (0.02)  | (0.02)  | (0.03)  | (0.03)  |
| Owns home             | -0.10   | -0.04*  | -0.04*  | -0.04*  | -0.02   | -0.03   |
|                       | (0.07)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |

Observations 3008 3008 3008 3008 3008 3008

\( R^2 \) 0.261

All regressions include region and enumerator fixed effects.
Table B.8: Household panel-like WTP for improved electricity service

|                           | (1)     | (2)     | (3)     | (4)     | (5)     | (6)     | OLS     |
|---------------------------|---------|---------|---------|---------|---------|---------|---------|
| main                      |         |         |         |         |         |         |         |
| Starting value            | -19.44*** | 1.03*** | 1.17*** | 1.46*** | 1.79*** | 0.99*** |         |
|                           | (1.93)  | (0.28)  | (0.22)  | (0.19)  | (0.20)  | (0.21)  |         |
| Female                    | -0.45*** | -0.06*** | -0.06*** | -0.01 | 0.04** | -0.08*** |         |
|                           | (0.13)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |         |
| Experiences power         | -0.15 | -0.05 | -0.03 | -0.02 | -0.07 | -0.04 |         |
| cuts                      | (0.25)  | (0.05)  | (0.04)  | (0.05)  | (0.05)  | (0.05)  |         |
| Age                       | -0.00 | -0.00 | -0.00 | -0.00* | -0.00* | -0.00* |         |
|                           | (0.01)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  |         |
| Formal ed (0/1)           | 0.06 | 0.01 | 0.01 | 0.03 | 0.02 | 0.00 |         |
|                           | (0.15)  | (0.03)  | (0.02)  | (0.02)  | (0.02)  | (0.03)  |         |
| HH head                   | -0.03 | 0.01 | 0.03 | 0.05** | 0.04** | 0.06*** |         |
|                           | (0.15)  | (0.03)  | (0.02)  | (0.02)  | (0.02)  | (0.02)  |         |
| Married                   | 0.11 | -0.00 | 0.01 | 0.01 | 0.01 | 0.02 |         |
|                           | (0.19)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  | (0.03)  |         |
| HH size                   | -0.01 | 0.00 | -0.00 | -0.00 | -0.00 | -0.00 |         |
|                           | (0.01)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  | (0.00)  |         |
| Tot. exp. quintile 2      | -0.08 | -0.03 | -0.00 | -0.04 | -0.06 | -0.08 |         |
|                           | (0.32)  | (0.06)  | (0.06)  | (0.06)  | (0.07)  | (0.07)  |         |
| Tot. exp. quintile 3      | -0.13 | -0.08 | -0.04 | -0.07 | -0.06 | -0.08 |         |
|                           | (0.31)  | (0.06)  | (0.05)  | (0.06)  | (0.06)  | (0.07)  |         |
| Tot. exp. quintile 4      | -0.30 | -0.07 | -0.02 | -0.00 | 0.00 | -0.00 |         |
|                           | (0.31)  | (0.06)  | (0.05)  | (0.06)  | (0.07)  | (0.07)  |         |
| Tot. exp. quintile 5      | -0.04 | -0.04 | 0.02 | 0.01 | 0.03 | 0.03 |         |
|                           | (0.33)  | (0.06)  | (0.06)  | (0.06)  | (0.07)  | (0.08)  |         |
| Rural                     | -0.23 | -0.07* | -0.06 | -0.08* | -0.11** | -0.11** |         |
|                           | (0.21)  | (0.04)  | (0.04)  | (0.04)  | (0.05)  | (0.05)  |         |
| Income source: agriculture| 0.20 | 0.08 | 0.05 | 0.01 | 0.00 | -0.01 |         |
|                           | (0.26)  | (0.05)  | (0.05)  | (0.05)  | (0.06)  | (0.06)  |         |
| Income source: commerce   | -0.22 | -0.04 | -0.04 | -0.07* | -0.09** | -0.09* |         |
|                           | (0.21)  | (0.04)  | (0.04)  | (0.04)  | (0.05)  | (0.05)  |         |
| Income source: services   | -0.53** | -0.04 | -0.04 | -0.05 | -0.07 | -0.07 |         |
|                           | (0.23)  | (0.04)  | (0.04)  | (0.04)  | (0.05)  | (0.05)  |         |
| Owns home                 | -0.10 | -0.04 | -0.05 | -0.06 | -0.05 | -0.04 |         |
|                           | (0.21)  | (0.04)  | (0.04)  | (0.04)  | (0.04)  | (0.05)  |         |
| Observations              | 1392    | 1392    | 1392    | 1392    | 1392    | 1392    |         |

All regressions include region and enumerator fixed effects, and household random effects.
|                              | (1)   | (2)   | (3)   | (4)   | (5)   | (6)   |
|------------------------------|-------|-------|-------|-------|-------|-------|
| Starting value               | -8.64*** | 2.14*** | 1.90*** | 1.71*** | 1.63*** | 1.58*** |
|                             | (1.49) | (0.42) | (0.40) | (0.39) | (0.43) | (0.48) |
| Formal                      | 0.38*  | 0.10*  | 0.13** | 0.12** | 0.10  | 0.10  |
|                             | (0.22) | (0.06) | (0.06) | (0.06) | (0.06) | (0.07) |
| Firm located in Dakar       | 0.09   | 0.02   | 0.03   | 0.03   | 0.04  | 0.03  |
|                             | (0.19) | (0.05) | (0.05) | (0.05) | (0.06) | (0.07) |
| Firm age                    | 0.00   | 0.00   | 0.00   | 0.00   | 0.00  | 0.00  |
|                             | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Rural                       | 0.11   | 0.03   | -0.00  | 0.03   | 0.05  | 0.04  |
|                             | (0.21) | (0.06) | (0.06) | (0.06) | (0.07) | (0.07) |
| Number of employees         | 0.01   | 0.00   | 0.01   | 0.00   | 0.00  | 0.00  |
|                             | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Home business               | 0.07   | -0.01  | -0.02  | -0.01  | -0.04 | -0.06 |
|                             | (0.20) | (0.05) | (0.05) | (0.05) | (0.06) | (0.07) |
| Log avg monthly revenue     | -0.01  | -0.00  | -0.00  | 0.00   | 0.00  | 0.00  |
|                             | (0.03) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| Turned a profit in 2017     | 0.05   | 0.04   | 0.05   | 0.04   | 0.06  | 0.07  |
|                             | (0.19) | (0.05) | (0.05) | (0.05) | (0.06) | (0.06) |
| Experiences power cuts      | 0.04   | 0.05   | 0.06   | 0.05   | 0.04  | 0.05  |
|                             | (0.20) | (0.05) | (0.05) | (0.05) | (0.06) | (0.07) |
| Income loss from cuts       | -0.08  | 0.01   | 0.01   | 0.01   | 0.01  | -0.01 |
|                             | (0.16) | (0.04) | (0.04) | (0.04) | (0.04) | (0.05) |
| Resp. female                | 0.03   | -0.01  | -0.06  | -0.05  | -0.04 | -0.03 |
|                             | (0.22) | (0.06) | (0.06) | (0.06) | (0.06) | (0.07) |
| Resp. attended primary school | 0.10  | 0.02   | 0.01   | -0.01  | -0.00 | -0.01 |
|                             | (0.21) | (0.05) | (0.06) | (0.06) | (0.06) | (0.07) |
| Resp. attended highschool   | 0.11   | 0.10   | 0.04   | 0.02   | 0.02  | -0.00 |
|                             | (0.27) | (0.07) | (0.07) | (0.07) | (0.08) | (0.09) |
| Resp. attended college      | 0.05   | 0.06   | 0.03   | 0.04   | 0.01  | -0.00 |
|                             | (0.20) | (0.05) | (0.05) | (0.05) | (0.06) | (0.07) |
| Resp. age                   | -0.01  | -0.00**| -0.00**| -0.00***| -0.01***| -0.01**|
|                             | (0.01) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| Observations                | 597    | 597    | 597    | 597    | 597    | 597    |
| $R^2$                       |        |        |        |        |        | 0.220  |

*All regressions include region and enumerator fixed effects.*