POLICY RESEARCH WORKING PAPER   8407

Why Are Connection Charges So High?

An Analysis of the Electricity Sector in Sub-Saharan Africa

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Abstract

This study develops and structurally estimates a model of household and electric utility behavior to describe how the low access rates and high connection charges that are common in the Sub-Saharan Africa region arise from regulated electricity tariffs being set too low. As a result, the utilities lose money on each connected customer and low electricity consumption by households makes it difficult to recover the cost of providing a connection. For each possible choice of the regulated tariff, the optimal upfront connection charge is computed that will maximize profits for the utility in its service territory. Higher tariffs are associated with lower optimal connection charges and higher electrification rates. Nonetheless, due to households' low willingness to pay for electricity services, the equilibrium electrification rates in the model are much lower than 100 percent. Future advances in electrification will require higher incomes, increased coverage of the distribution network, and lower connection costs.

Why Are Connection Charges So High? An Analysis of the Electricity Sector in Sub-Saharan Africa[*]

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The World Bank   ITAM   The World Bank

1　Introduction

Electrification rates in Sub-Saharan Africa are the lowest of any region in the world. In 2012, 35.3 percent of the population had access to electricity, compared to 22.8 percent in 1990.[1] Lack of electricity can stunt economic development through various channels including education, labor supply, and productivity (Dinkelman, 2011; Fisher-Vanden et al., 2015; Allcott et al., 2016; Chakravorty et al., 2016).

Many factors contribute to this highly complex problem of limited access to electricity. This paper is concerned about one of these factors, namely electricity connection charges.[2] These are the fixed upfront amount that new customers pay to connect to an existing distribution network. In many African countries, electricity connection charges are very high, both relative to local incomes and relative to connection charges in other parts of the world. Golumbeanu and Barnes (2013) argue that high electricity connection charges may be the most significant obstacle to improving electricity access in the Sub-Saharan Africa region.

In this paper, we develop a model of household and distribution utility behavior to describe how high connection charges and low access rates can arise from regulated electricity tariffs that are set too low.[3] Wholesale costs of generating and supplying electricity in many parts of Africa are high. However, in many countries, regulated tariffs are set below a level that would allow utility firms to recover these costs (Trimble et al., 2016). The potential losses from connecting additional customers make it optimal for distribution utilities to set high connection charges. These high charges both reduce the demand for connections and recover future losses from those customers who do connect.

Our analysis requires the estimation of a household-level model of the joint demand for electricity and electricity connections. Households are assumed to choose between several alternatives for their primary fuel source, including kerosene, grid electricity, and modern off-grid electricity sources such as solar.[4] This choice will depend on, among other factors, the

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[1]World Bank Global Electrification Database, `http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS`.

[2]Other important factors include low households' willingness to pay for electricity service at market prices, high costs of electrification, and inefficient and dysfunctional utilities (Kojima et al., 2016; Trimble et al., 2016).

[3]Other potential explanations for these high charges include geographical challenges for network construction, inefficient procurement practices, and excessive stringency of technical standards (Golumbeanu and Barnes, 2013). As we demonstrate below, these explanations are not inconsistent with our framework. Rather they tend to exacerbate the problem we discuss.

[4]In practice, many households use multiple energy sources for different purposes, such as charcoal for cooking and kerosene for lighting. Because households rarely cook or heat with electricity in our setting, we focus on the choice of energy source for lighting.

capital cost of the fuel source, the characteristics of the household, and the future benefit from utilization of that fuel source. Conditional on choosing a particular fuel source, we estimate the monthly demand for that type of energy and use these estimates as an input in the discrete choice model.

We estimate our model using data from Uganda. The electricity industry in Uganda was restructured starting in 1999, and the reform process has been one of the most advanced in Africa. It included the vertical separation and partial privatization of the incumbent utility (Mawejje et al., 2013). The system operator, Uganda Electricity Transmission Company Limited (UETCL), is responsible for electricity purchases from independent generators. Electricity distributors, including the primary distribution utility Umeme, pay a regulated price to buy electricity from UETCL. This feature of the restructured industry is useful for our analysis. The regulated wholesale price makes the cost for a distribution utility of adding a customer more transparent than it would be in the case of a vertically-integrated firm.

The Electricity Regulatory Authority in Uganda sets tariffs using a rate-of-return methodology (Electricity Regulatory Authority, 2006).[5] The revenue requirement for each firm is the sum of operating and maintenance costs, lease costs, and costs related to capital investment, including an allowed rate of return on invested capital. The revenue requirement is split by customer category and divided by electricity volumes to calculate the unit price (Pöyry Management Consulting, 2012). Under rate-of-return regulation, firms have an incentive to keep the connection and fixed charges low to encourage new connections and increase their rate base (Averch and Johnson, 1962; Davis and Muehlegger, 2010). However, this result may not hold if regulators cannot credibly commit to setting future tariffs that allow for recovery of past capital investment (Laffont and Tirole, 1986). For example, in Uganda the President has directly intervened in favor of particular energy projects, overriding existing contracts. This type of interference has undermined investor confidence (Whitley and Tumushabe, 2014, p.25). Another issue is that bureaucratic red tape may increase the cost of projects but not be recoverable through additions to the rate base.

Despite our choice of setting, we should emphasize that the regulatory distortion created by low retail prices is not an issue in Uganda. Instead, we will show that the regulated price in Uganda is sufficient to recover the costs of supplying electricity, and given this regulated price, the connection charge set by Umeme is close to optimal. Along with the Seychelles, Uganda is one of only two countries in Sub-Saharan Africa that Trimble et al. (2016) describe as having

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[5]The regulator reviews the rate-of-return tariffs annually for each firm. There is a quarterly adjustment to allow for pass-through of changes in fuel prices, inflation, and exchange rates.

a financially viable electricity sector. Nonetheless, with our joint model of households and the distribution utility, we can undertake counterfactual analyses using different prices, to explore the relationship between regulated tariffs, connection charges, and access rates. Furthermore, despite the reforms, electricity access rates in Uganda are low, although increasing. We can use our model to explore the other demand-side and supply-side factors that have constrained connection rates.

The primary data source for our analysis is the Uganda National Panel Survey, a household panel that began in 2009–10. We use data from the first three waves of this survey: 2009–10, 2010–11, and 2011–12. The survey has a complete section on household energy use. We use the geographical coordinates of the enumeration area to match households to several additional datasets, including the locations of the distribution and transmission lines and a map of solar radiation. Monthly price data for energy commodities is from the Uganda Bureau of Statistics and (for electricity) the Electricity Regulatory Authority. Distribution utility financial data are from Umeme.

Kerosene is the dominant energy source used for lighting in Uganda. Our demand analysis includes both the demand for kerosene and the demand for electricity, as well as the choice of the type of fuel. Higher incomes increase the demand for both kerosene and electricity, conditional on using that fuel. However, higher income households are more likely to choose either electricity or solar, and less likely to choose kerosene. Increasing reliability or decreasing the distance to the grid both increase the probability of obtaining an electricity connection. Higher kerosene prices also shift households towards electricity.

Our primary motivation for estimating the demand model is to analyze the incentives faced by the distribution utility. For a utility charging a high regulated price, sufficient to cover variable costs, each additional connected household will make a positive contribution to profits. These profits create an incentive for the utility to reduce its connection charge so that more households wish to connect. The utility trades off the lost revenue from a lower upfront connection charge, against the higher future profits from having more customers. This description matches the current setting in Uganda.

An alternative scenario is that the utility charges a low regulated price that is insufficient to cover variable costs. This lower price means that each connected customer has a higher electricity consumption. However, the utility loses money on each customer that connects, creating an incentive to set a high upfront connection charge to discourage new connections. This analysis describes the electricity sector for several countries in Sub-Saharan Africa and explains the observation of low connection rates combined with high connection charges.

The analysis in this paper is closely related to the theoretical literature on optimal two-part tariffs for regulated monopolies. Feldstein (1972) studies the trade-off between a fixed charge and a marginal price per unit for a regulated monopoly, assuming all households pay the same prices, in a setting in which households have different marginal utilities of income. However, he assumes that all households are connected and must pay the fixed charge. Sherman and Visscher (1982) study the more general problem in which households can choose whether or not to connect. The monopolist can choose to reduce the connection charge (and add more customers) or reduce the marginal price (and increase the consumption per household).[6] In that case, the optimal two-part tariff depends on the relative demand elasticities. Violette (2017) develops a model in which households can choose between a shared or an individual water connection. In his setting, with increasing block prices that include a zero marginal price for low consumption, the utility implicitly sets high connection costs for households. This leads to many households choosing a shared connection. He shows that higher connection charges and a flatter price schedule would increase welfare, because more households would choose to share a connection and costs for the utility would be lower. This result depends on the relative magnitude of sharing costs for households and connection costs for utilities, which may be very different for electricity compared to water.

There is a growing literature that studies the causes and effects of the lack of electricity provision in many parts of the developing world. Lee et al. (2016a) induce experimental variation in connection charges in Kenya to estimate the demand for an electricity connection. They find that the consumer surplus from a connection is less than their estimate of the cost of a new connection. This result suggests that programs to increase electrification may be welfare-reducing.

Our study differs in many respects from the analysis in Lee et al. (2016a). In our model, the value of electrification is the future stream of energy services that the household receives from the connection. Changing the retail price of electricity will change the benefit that the household derives from these future services. However, changing the retail price will also change the profitability for the distribution utility of providing a connection. Unlike in Lee et al. (2016a), we explicitly account for the role of these future costs and future benefits, for both the utility and the household, in the decision to provide (or obtain) an electricity connection. Our approach also makes explicit the role of an industry regulator in setting retail prices and changing the incentives for both the utility and the household.

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[6]In our analysis, we consider a simpler case, where an external regulator fixes the marginal price, and the only choice for the regulated utility is the level of the connection charge.

There are numerous socioeconomic, engineering, and political challenges that contribute to the low rate of electrification in Sub-Saharan Africa. As with any modeling exercise, our analysis omits many of these factors. Instead, we focus on a previously little-remarked problem: the role of regulated tariffs set below cost-recovery levels and the disincentive these create for distribution utilities to connect new customers.[7] We believe that a narrow focus on "high connection charges" may lead to a misdiagnosis of the problem. If connection charges are high because distribution utilities wish to discourage unprofitable connections, then providing connection subsidies may result in the utilities using non-price barriers to connection instead. These might include, for example, reducing the reliability of electricity supply, or increasing the wait-time for a connection.

For the remainder of the paper, Section 2 provides descriptive evidence on the relationship between connection charges and electricity prices in Sub-Saharan Africa. Section 3 sets out our model of households and firms. Section 4 describes the data used for the analysis, and Section 5 presents our empirical findings. Section 6 discusses the implications of our results.

2   Descriptive evidence

For many electricity distributors in Sub-Saharan Africa, adding a residential customer is unprofitable. The wholesale cost of electricity is high, the regulated retail tariffs are low, and the typical consumption of residential users is low. High access charges may be an optimal way for distribution utilities to make up the losses from connecting new customers.

The wholesale cost of generating electricity in Sub-Saharan Africa is high compared to many other countries. Fossil fuels, especially coal, are the predominant form of generation: in 2015 they comprised 74 percent of total generation in the region, with most of the remainder (21 percent) provided by hydroelectricity.[8] Insufficient capacity means that expensive diesel generation is often relied upon to satisfy demand. Inadequate transmission capacity limits the market size and restricts the potential for economies of scale in generation.

Most electricity in the region is generated and sold by vertically-integrated firms, with little transparency on wholesale costs. One exception is the Southern Africa Power Pool (SAPP), which coordinates electricity trade between 12 countries in southern Africa. The

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[7]This analysis has parallels with the setting described by McRae (2015). In Colombia, the regulator sets high subsidy reimbursement rates for informal settlements, creating a disincentive for distribution utilities to upgrade the quality of the infrastructure serving these areas. This result holds even if the upgrade could convert non-paying households to paying customers.

[8]Data from the BP Statistical Review of World Energy June 2016. Statistics are for all of Africa excluding the Arab Republic of Egypt and Algeria.

wholesale price in this market averaged $76/MWh between 2014 and 2016, compared to an average wholesale price of $35/MWh in the United States in 2015 (Figure 1). However, electricity traded through SAPP represented only 0.14 percent of total generation in member countries in 2015. [9] This means that the wholesale prices may understate the marginal cost of generation, especially in areas with binding transmission constraints.

In most SSA countries, electricity consumption for households with grid connections is very low (Figure 2). In Uganda in 2011, median household electricity consumption, for grid-connected households, was 40 kWh per month. Such low consumption makes it difficult to recover the fixed costs of providing a grid connection using volumetric charges alone.

Regulated retail electricity tariffs in many countries have a nonlinear structure, based on either increasing block tariffs or volume-differentiated tariffs. In either case, households with low usage pay a low marginal price for an additional unit consumed (Figure 3). For eight countries in SSA, the average price for consumption of 50 kWh per month is below the SAPP wholesale price. Electricity retailers in these countries would lose money from supplying these customers, even before considering the cost of providing the connection. Conversely, a small number of countries have very high retail electricity prices (in one case over 50 cents per kWh), likely reflecting the high cost of small-scale diesel generation.

A simple calculation demonstrates that, given the low consumption, high wholesale prices, and low retail tariffs, adding a residential customer would be unprofitable for most electricity distributors in Sub-Saharan Africa. Based on the above averages, suppose the median new user has electricity consumption of 40 kWh per month, and the wholesale cost of electricity is US$76 per MWh. Assume that transmission and distribution losses are 15 percent. Apart from the wholesale cost of electricity, there is assumed to be a fixed annual cost of US$41 per user for administration, billing, and network maintenance. The before-tax retail price in each country is the average shown in Figure 3. Distribution utilities are assumed to have an annual discount rate of 5 percent.

With these assumptions, the distribution utilities in 15 countries would lose money from adding one more user, before considering any connection costs or charges (Figure 4). Assuming an upfront cost of US$200 to provide a connection, adding consumers would be unprofitable in all but ten countries. Distribution utilities in all of the remaining countries would need to set a high access charge for it to be profitable to add a user.

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[9]Calculation based on data from the SAPP 2015 Annual Report. Total generation in member countries in 2015 was 363 TWh (page 38). Trading volume in the market was 0.5 TWh (page 24).

3   Empirical model

3.1   Household model

We separately model two components of the household energy consumption decision: the choice of which fuel to use for lighting and, conditional on that choice, the quantity of energy consumed.

The household consumption of kerosene or electricity is given by the estimation equation (1):

$$\log(q_{it}) = \alpha + \beta \log(p_{it}) + \gamma_1 y_{it} + \gamma_2 y_{it}^2 + \mathbf{z}_{it}' \boldsymbol{\delta} + \varepsilon_{it} \tag{1}$$

The dependent variable q_{it} is household i's consumption of the fuel (either kerosene or electricity) during month t, measured in kWh. Other household characteristics are captured by the vector $\mathbf{z}_{it}$. These include the number of adults and the number of children in the household, the size of the dwelling, the type and ownership status of the dwelling, the nature of any improvements to the dwelling, and an urban/rural indicator.

The variable p_{it} is the price per kWh of the fuel in the region of household i during month t. For electricity, one challenge is that the regulated tariff for Umeme is a two-part, increasing block tariff. Households pay a low subsidized price for the first 15 kWh of consumption each month, then a higher price for each additional unit of consumption. The quantity on the first price tier is much smaller than the consumption of most households in the sample. For simplicity, we do not explicitly model the nonlinearity in the tariff. Instead, we assume that p_{it} is the regulated price per kWh on the highest consumption tier.

The variable y_{it} is the annual expenditure of household i, as measured at the survey date t.[10] The choice to use expenditure from the household survey, rather than income, reflects the considerable difficulty of measuring self-reported income on a household survey. This challenge is especially relevant for a rural setting in a developing country where few people have a stable salary. We make an implicit assumption that income and expenditure are fixed and do not depend on the choice of fuel source. If access to modern energy services increases household productivity, it is possible that expenditure might change based on the fuel choice. We assume that energy services provide consumption utility and do not enter as inputs into household production, so there is no feedback from fuel choice to household income or expenditure.

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[10]In both the consumption and discrete choice models, we deduct the annualized capital cost of the fuel choice from household expenditure y_{it}, using an annual discount rate of 15 percent.

One potential concern is unobserved heterogeneity across households in preferences for energy consumption (Miller and Alberini, 2016). Our main specification uses a pooled estimator, treating repeated data for energy usage within the same household as independent observations. However, we also estimate a model with household fixed effects, which absorb all unobserved, time-invariant household characteristics.[11] In this model, the estimates for β, γ_1, and γ_2 are identified only from within-household variation over time.

Another potential issue for the use of panel data in this context is the potential secular trend in energy consumption. This trend might occur within households: for example, households with an electricity connection may acquire new appliances and so increase their consumption of household energy services. In the pooled data, the composition of households using kerosene or electricity may change over time. For example, more affluent households may give up the use of kerosene lamps first. If their consumption of kerosene had been higher than average, then this would reduce the average kerosene consumption. We study these issues by estimating versions of equation (1) including time trends, for both the pooled and fixed effects models.

The second component of the household model is the choice of energy source for lighting. Households are assumed to choose between four categories of fuel source for lighting: (i) no lighting source or primitive fuels such as firewood or dung, (ii) kerosene, (iii) grid-connected electricity, and (iv) solar. We partition these categories into two nests: unimproved sources (i) and (ii) in B_1, and improved sources (iii) and (iv) in B_2.

Let V_{ij} be the indirect utility of household i from fuel choice j in nest B_k:

$$V_{ij} = \tilde{V}_{ij} + \varepsilon_{ij} \tag{2}$$

where ε_{ij} is distributed as a generalized extreme value distribution with the following cumulative distribution (Train, 2009):

$$\exp\left(-\sum_{k=1}^{2}\left(\sum_{j \in B_k} e^{-\varepsilon_{ij}/\lambda_k}\right)^{\lambda_k}\right)$$

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[11]In the fixed effects model, we drop the household characteristic terms from the vector $\boldsymbol{z_{it}}$. In theory, these could be identified based on within-household variation in demographics and dwelling characteristics. However, the estimates for these coefficients are noisy, and in any case, these control variables are not the primary focus of our study.

and $\tilde{V}_{ij}$ is given by:

$$\tilde{V}_{ij} = \alpha \hat{q}_{ij} + \beta_1 K_j + \beta_2 K_j^2 + \boldsymbol{z'_{it} \delta_j}$$

The first term in the expression for $\tilde{V}_{ij}$ is the predicted energy consumption of the household, in kWh, conditional on choosing fuel j. For the kerosene and electricity choices, these predicted values are based on the estimates of equation (1), using the characteristics of household i. For the solar choice, the predicted energy consumption is calculated from the mean solar radiation at household i's location, assuming a solar panel size of 30 watts and an efficiency of 75 percent. Energy consumption for the primitive or no-lighting choice is assumed to be zero. In this model, the price per kWh of the fuel enters the discrete choice of fuel only through the predicted consumption term $\hat{q}_{ij}$.

The expression for $\tilde{V}_{ij}$ also includes a quadratic in the initial capital cost of the energy source j, K_j. For an electricity connection, this capital cost is the upfront connection charge set by the distribution utility.

Finally, household characteristics $\boldsymbol{z_{it}}$ may differentially affect the indirect utility from fuel choice j, captured by the fuel-specific parameter vector δ_j. Household characteristics included in the model are the distance to the electricity distribution network, household expenditure, the number of adults and children, and the size of the dwelling.

Households are assumed to choose the fuel source alternative that maximizes their utility. With this assumption, and given the assumptions on the model structure and error term above, the probability that household i chooses fuel type j is:

$$\Pr_i(j) = \frac{e^{\tilde{V}_{ij}/\lambda_k} (\sum_{l \in B_k} e^{\tilde{V}_{il}/\lambda_k})^{\lambda_k - 1}}{\sum_{m=1}^2 (\sum_{l \in B_m} e^{\tilde{V}_{il}/\lambda_m})^{\lambda_m}} \tag{3}$$

3.2 Electricity distributor model

Electricity distributors are assumed to be profit-maximizing monopolists within their service territory. The government regulator sets their tariffs, including fixed and per unit charges. The only price variable that the distributors choose is the initial connection charge.

Let p_k be the regulated electricity price received by distributor k. This price may differ from the retail price paid by the consumer in countries with sales taxes or other fees. Let F_k be the annual fixed charge received by distributor k for one household connection. Let c_k be the per unit cost of procuring electricity for distributor k.

The distributor will choose the connection charge K to maximize profits:

$$\max_{K} \pi = (p_k - c_k) \sum_{i} \Pr(connect_i | K) q_i + \sum_{i} \Pr(connect_i | K)(\delta(K - C) + (F_k - C_F)) \quad (4)$$

Here δ is the distributor's discount rate, C is the capital cost of providing a connection, and C_F is the annual fixed cost associated with an additional connection. The sum is over all households i in the distributor's service territory.[12]

The first part of this expression is the distributor's profit or loss from the sale of electricity.[13] The quantity of electricity sold will depend on the connection charge K. A lower connection charge will increase the number of connected households. The electricity quantity q_i consumed by household i, conditional on having a connection, is given by equation (1).[14] We calculate total electricity sales by summing over all households the electricity quantity they would consume if they had a connection, multiplied by the connection probability. The electricity fuel choice in equation (3) provides the probability of having a connection.

The second part of the equation is the distributor's profit or loss on the fixed and capital costs and charges—everything that does not depend on the quantity of electricity sold. All of the costs and charges are "per household". We multiply these costs by the expected number of connections, which again depends on the connection charge K through equation (3). K and C are the one-time initial revenues and costs associated with providing a connection. These are annualized using the distributor's discount rate δ. F_k and C_F are annual revenues and costs associated with a connection.

This model is sufficiently general to capture a lot of interesting interactions between the regulator, distribution firms, and consumers, while still being empirically tractable. If the regulator uses a nonlinear structure for p_{k1}, so that consumers with low consumption pay less than the cost c_k, then the distributor would want to set K high enough to screen these customers out of the market.

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[12]This model assumes that the capital cost of a connection is the same for all households in the service territory. In practice, there may be a high fixed cost of connecting the first household in a village or neighborhood, which requires the provision of electricity lines and a distribution transformer. Adding subsequent households in the village will have a lower cost. The current model ignores this potential interaction between the decisions of different households.

[13]The model assumes that all customers pay their electricity bill. Customer nonpayment is a troubling issue for utilities in many Sub-Saharan African countries, although the rollout of prepaid metering has the potential to ameliorate this problem (Jack and Smith, 2016).

[14]This will also depend directly on K by the income effect from the annualized connection cost.

4   Data

The data sets compiled for this analysis include household characteristics and energy consumption from three waves of a panel survey, geographical data on the electricity transmission and distribution network, monthly energy prices by region, and financial data for the electricity distribution utility. The combined data sets provide a comprehensive perspective on the energy sector in Uganda.

4.1   Household survey data

The Uganda National Panel Survey (UNPS) is a household panel that began in 2009–10. There were three waves in the original panel: 2009–10, 2010–11, and 2011–12. The sample frame for this survey was the national household survey in 2005–06.[15]

The survey recorded both the total amount paid and the quantity of energy consumed for each energy commodity. For kerosene, firewood, gasoline and charcoal, the quantity and the amount paid were asked in two separate sections of the survey: the energy module and the consumption module. This repetition provides a consistency check on the responses.

During the period covered by the panel, there was a gradual increase in the number of households with electricity connections, a substantial increase in the number of households using solar installations for lighting, and a small decrease in the number of households using kerosene for lighting.

In 2011, the dominant fuel used for lighting was kerosene (Table 1). Even a significant number of households with an electricity connection still reported using kerosene for lighting, either in combination with electricity or on its own. Generator ownership is uncommon, and even the households with a generator appear to use it more as a backup rather than as a primary source of energy. By 2011, solar was a more popular form of off-grid generation than diesel or gasoline generators.

4.2   Electricity coverage

The decision by a household to obtain an electricity connection depends on the availability of the electricity grid in the household's community. Extending the grid to a new area would be prohibitively expensive for a single household. We develop several complementary measures of grid availability for each household in the survey data.

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[15]The energy section of the UNPS is the most complete of all African Living Standards Measurement Surveys. It has 33 out of 41 possible energy-related questions, the highest of 17 countries considered.

We have GIS data on the entire transmission and distribution network in Uganda as of 2016.[16] With few exceptions, respondents who report having a connection live close to the distribution network (Figure 5). Households located far from the network do not have electricity connections. However, there are still many households close to the network without a connection (Figure 6).[17]

For each enumeration area in the survey, we calculate the straight-line distance to the nearest distribution line and the nearest transmission line. Households in enumeration areas located within 500 meters of the distribution network are much more likely to have a connection (Figure 7). For households in the highest expenditure quartile living within 500 meters of the network, the proportion with a connection exceeds 50 percent. The probability of a connection declines rapidly at greater distances from the grid, with almost no households more than five kilometers from the grid observed to have a connection. At all distances, households in the highest expenditure quartile are much more likely to have a connection.

4.3   Energy prices

Umeme is the major electricity distributor in Uganda, with more than 90 percent of the total number of electricity customers. There are nine small distribution companies (or co-operatives in rural areas) covering 13 service territories. Some are operated by private operators and others by the Uganda Electricity Distribution Company Ltd. (UEDCL). Quarterly data on residential electricity prices for each distribution company are from the Electricity Regulatory Authority.[18]

Umeme has a two-tier, increasing block tariff for electricity. The consumption quantity for the first tier is 15 kWh per month. Of the households for which we observe monthly consumption, 86 percent have consumption higher than 15 kWh. Given the low proportion of households on the first tier, we do not explicitly model the nonlinear price structure. Instead, we assume that all Umeme households face the second tier price.

The regulator does not report information on connection charges. We collected connection charge information from the websites of the distribution companies, with historical

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[16]The Ugandan Energy Sector GIS Working Group makes these data publicly available: `http://data.energy-gis.opendata.arcgis.com/`.

[17]The finding that many households close to the grid are unconnected matches the findings of Lee et al. (2016b). They undertake a census of all structures within a 600-meter radius of 150 electricity transformers in rural Kenya. Despite the availability of the distribution network in their communities, only 5 percent of households and 22 percent of businesses have an electricity connection.

[18]`http://era.or.ug/index.php/statistics-tariffs/tariffs/distribution-tariffs/2014-10-14-10-24-55`.

connection charge data obtained from websites archived by the Wayback Machine. Including an inspection fee, in 2016 Umeme charges 139,300 Ugandan shillings (US$40) for a connection that does not require a pole, and 367,300 Ugandan shillings (US$100) for connection with a pole.[19] Before 2011 the Umeme connection charge without a pole was much higher—about 237,000 Ugandan shillings.

Connection charges for other firms are higher than those for Umeme. Ferdsult charges about 342,200 Ugandan shillings for connections without a pole.[20]. Wenreco is reported to charge at least 1.5 million Ugandan shillings for a connection with a pole.[21] For the distribution firms for which no information is available, we assume the connection costs are equal to those of Ferdsult.

Monthly price data for other energy commodities in Uganda are published by the Uganda Bureau of Statistics in their Consumer Price Index reports. These include price data in seven cities for propane, gasoline, diesel, firewood, charcoal, and kerosene. There is some geographical dispersion in energy prices although the correlation of price changes is high.

4.4 Distribution utility financial data

Umeme buys all of the electricity it sells from the grid operator, UETCL. The Electricity Regulatory Authority sets the price that Umeme pays for electricity. At the end of 2012, this price was 262 Ugandan shillings per kWh (10.4 US cents per kWh). For each kWh that a household consumes, Umeme has to buy more than one kWh from the transmission grid, to cover technical losses in the distribution network. The proportion of electricity lost due to these technical losses is assumed to be 15 percent.

In its financial statements, Umeme books both revenue from connection fees and the costs of providing connections, with the costs assumed to be equal to revenue. Based on this accounting convention, the cost of providing a connection was US$130 in 2012. For our analysis, we assume a higher connection cost of US$200. For the counterfactual analysis with alternative connection fees, we convert the difference between the revenue from connection fees and the cost of providing a connection to monthly revenue (or loss) based on an annual discount rate of 5 percent.

A final requirement to calculate the profitability of connecting an additional customer is the variable component of administrative and network maintenance costs. By how much

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[19]http://www.umeme.co.ug/about-umeme/yaka/new-connection.html
[20]http://ferdsult.net/services.html
[21]http://www.newvision.co.ug/new_vision/news/1193739/electric-poles-cost-sh2m-west-nile

do these increase as the result of one extra connection? We compiled annual data on the number of connections and the administrative and network maintenance costs from Umeme's annual reports. We convert these costs to 2012 prices based on the Uganda Manufacturing PPI in July each year. Figure 8 shows the relationship between these annual costs and the number of customers. We use the slope of the regression line as our estimate of the variable component of costs. This slope is equal to 8,650 Ugandan shillings, or US$41 per connection per year.

5 Results

5.1 Fuel demand model

Fuel demand is estimated separately for kerosene and electricity (Table 2). Each observation is an individual household's consumption of the fuel in one month, for a household who has chosen that fuel for lighting.[22] For example, all households with an electricity connection are assumed to use electricity for lighting, so they will not be included in the kerosene estimation even if they report using kerosene. The primary specification pools repeated observations for individual households in the panel.

Fuel price has a negative effect on the consumption of kerosene and electricity (Columns 1 and 4) that is statistically significant for kerosene. The kerosene coefficient is smaller for the regression that includes a linear time trend (Columns 2). The coefficients on log price in Columns 2 and 5 imply price elasticities of -0.24 for kerosene and -0.14 for electricity. These are consistent with previous estimates in the literature. Similarly, household total expenditure has a significant positive effect on kerosene and electricity consumption, at least over the range of expenditures observed for most households in the data.

For kerosene, the coefficient on log price reduces in magnitude from -0.24 in the pooled model to -0.03 in the fixed effects model (Columns 3). This result is consistent with the results of Miller and Alberini (2016), who use data for the United States to show that consumers are found to be more price inelastic for models that include fixed effects. For electricity, the coefficients on log price are not significantly different from zero, and there is an imprecise positive coefficient in the fixed effects model (Column 6).

The signs of the other variables in the model are as expected. Kerosene and electricity

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[22]Where available, fuel consumption quantities are those reported by households. If quantity data are not available, we calculate the consumption quantity as the household's reported expenditure on the fuel in the previous month, divided by the regional price of the fuel in the month before the interview.

consumption are higher for larger households and (for kerosene) larger dwellings. Having a dwelling that is a house instead of a hut or apartment also increases both kerosene and electricity consumption. Fuel consumption is higher in urban areas. Also included in the estimation are dummy variables for the dwelling having improved walls, roof, and floors. Improved roof and floors have a significant positive effect on kerosene consumption (not shown in the table).

The electricity model includes a measure of the reliability of the electricity supply. Reliability is measured as the district-level mean reported hours of electricity per day, scaled by 24 so that the variable lies between 0 and 1. Higher reliability has a positive, although not statistically significant, effect on the consumption of electricity.

5.2 Fuel choice model

A core part of our analysis is a discrete choice model of the household's decision about their primary energy source for lighting. There are four choices considered: no or primitive fuels, kerosene, electricity, or solar. Any household with an electricity connection is assumed to use this as their primary energy source. Otherwise, the household's choice depends on the self-reported use of each fuel for lighting.

The model uses a mixed logit structure with a discrete choice between the four lighting alternatives. An important explanatory variable for the choice of energy source is the household's predicted consumption of energy, conditional on having chosen that energy source. This prediction is based on the fuel demand estimation results in Columns 2 and 5 of Table 2. Because we do not observe energy consumption for solar and so do not have a model of solar demand, we instead include an estimate of generation from a 30-watt solar panel, based on annual solar radiation at the household's location.

Apart from predicted consumption, other explanatory variables in the model include the capital cost of the energy source (included as both a linear and a squared term), the distance to the electricity distribution network, household income (linear and squared), household size and dwelling size. The price per kWh and the reliability of the fuel do not directly enter the choice model. Instead, these only affect the fuel choice through their effect on the household's predicted consumption of energy. For example, a higher electricity price would reduce the electricity consumption of households with an electricity connection, which reduces the probability that the household chooses that fuel.

There is no clear interpretation of the coefficients from the mixed logit estimation, and so these are not reported. Instead, we show elasticities of the fuel choice probabilities for

the explanatory variables of interest (Table 3). For example, the first line shows that an increase in the electricity price will reduce the probability of the household choosing to have an electricity connection, and increase the probability of choosing kerosene. A ten percent increase in the electricity price will reduce the probability of choosing to have an electricity connection by 3.8 percent (not percentage points). As noted above, this effect only occurs through a reduction in the predicted electricity consumption conditional on having a connection.

The signs of the effects on fuel choice probabilities are as expected. Higher capital costs for an electricity connection reduce the probability of choosing a connection. Household income affects both the predicted consumption conditional on choosing a fuel, as well entering the fuel choice decision directly. Higher income increases the probability of choosing electricity or solar and reduces the probability of choosing kerosene. A more reliable electricity supply in the district, or being located closer to the electricity distribution network, both increase the probability of choosing to have an electricity connection.

5.3 Distribution utility model

We use the estimated models of fuel demand and fuel choice to analyze the profitability of an electricity distribution utility, focusing on how profits depend on the electricity price and connection charge. We calculate revenues as the electricity price multiplied by the total quantity of electricity demanded, where the latter is the sum across all households of the quantity of electricity consumed conditional on having a connection, multiplied by the probability of having a connection. There are three types of cost that we consider: the wholesale cost of electricity (scaled up to reflect distribution losses), the ongoing variable costs of providing a connection, and the upfront capital costs of a connection. We convert the difference between the connection charge paid by consumers and the capital cost of the connection to a monthly cost based on an assumed discount rate. We do not consider fixed costs that are independent of the number of connections.

This stylized model captures the economic relationships between the household and the distribution utility behavior. Higher connection charges increase the profitability of a connected household for the utility but reduce the probability of a household connecting. Lower electricity prices increase the quantity of electricity demanded, but if they are too low, then the distribution utility will lose money on the connected households. The utility offsets this loss by setting higher connection charges, which increases profits by both reducing the number of connected households and increasing revenues for the households who do connect.

We first analyze the case of a distribution utility with a low price for supplying electricity (first panel of Table 4). At the price of 16 cents/kWh and a zero connection charge, the average consumption of electricity for connected households is 58 kWh per month. Each column in the table shows the effect of a different connection charge. If the connection charge is $0, then 16.8 percent of households will choose to connect. The proportion of households with an electricity connection decreases for higher connection charges, dropping to 2.0 percent of households for a connection charge of $600.

Because the electricity price in this example is low, the utility would make a loss for each connected household if it sets a low connection charge. With a connection charge of $0, the distribution utility loses $2.11 per month for each connected household. Raising the connection charge has two effects. The average consumption of the connected households increases, because the higher connection charge selects for those households with higher electricity consumption who value the connection more. Second, there is additional revenue provided by the higher connection charge. Overall, gross profit for the connected households increases from a loss of $2.11 to a profit of $1.60 per month with a connection charge of $600.

The relevant variable for the firm's choice of connection charge is not the gross profit on the connected households, but instead the overall gross profit across all households in the service territory. For the total population of connected and unconnected households, the average gross profit is -$0.35 per month with a connection charge of $0 and $0.03 per month with a connection charge of $600. For the values of the connection charge shown in the table, the utility maximizes its profit per actual and potential customer with a connection charge of $500 to $600.

The result is different for a distribution utility that charges a higher regulated price for electricity, with prices and costs similar to those prevailing in Uganda in 2012 (second panel of Table 4). With this higher electricity price, the average consumption for connected households at a connection charge of zero is slightly lower: about 56 kWh per month. The small change in electricity consumption between the two panels reflects the relatively inelastic price elasticity of demand for electricity from the estimation results in Column 5 of Table 2.

The higher electricity price in the second panel is sufficient to cover all costs associated with supplying electricity. Gross profit for connected households is positive, varying from $0.64 per month for a connection charge of $0 to $5.89 per month for a connection charge of $600. In each column, the proportion of connected households is slightly lower when the electricity price is higher, reflecting the effect of a higher price on the value of a connection.

For example, with zero connection charge, the proportion of connected households is 16.8% with a price of 16 cents per kWh and 15.3% with a price of 21 cents per kWh.

With a higher regulated electricity price, the optimal connection charge is lower. For the connection charges shown in the table, the maximum profit per actual and potential customer is attained with a connection charge of $200 to $300, giving an average gross profit of about $0.19 per household in the service territory. The profit-maximizing connection charge is higher than the observed connection charges set by Umeme (which vary based on whether or not new pole installation is required).

Optimal connection charges are lower for higher regulated electricity prices (Figure 9). For an electricity price of 27 cents/kWh, the optimal connection charge would be zero (left panel), and this connection charge would maximize the number of connected households (right panel). For electricity prices below 27 cents/kWh, the connection charge that would maximize utility profits increases, leading to a drop in the number of connected households. This decline is because the higher upfront connection cost outweighs the value of a lower electricity price for households in their connection decision. For electricity prices above 27 cents/kWh, the number of connected households declines slightly, given that the connection charge remains zero and the value of a connection is lower at higher electricity prices.

Our model of the distribution utility suggests the theoretical possibility of setting a negative connection charge for high regulated tariffs. For electricity prices above 27 cents per kWh, the utility would maximize profits by paying households to connect to the electricity grid (left panel of Figure 10). However, even though households are paid to connect, the high price they pay for their consumption still limits the value of the connection. The tariff caps the number of households who would connect (right panel of Figure 10).

5.4   Sensitivity analysis

In this section we study the sensitivity of the main results in Figure 9 to changes in the model parameters.

Lower costs of providing households with a connection to the distribution network reduce the optimal connection charge and increase the number of connected households (Figure 11). However, there is not a one-to-one relationship between connection costs and connection charges. From the distribution utility's perspective, the profitability of connecting an additional customer depends on the future stream of profits or losses, not just the initial connection cost. In particular, much of the benefit of reduced connection costs (through external subsidies or technological improvements) will be passed through to higher distribution

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utility profits, not to lower charges for consumers.

In the model, the distance from the household to the distribution network does not affect the value for the household of an electricity connection, because the cost of providing a connection is assumed to be constant. This assumption implies that changing the distance from households to the network (through an expansion of the distribution network) has little effect on the optimal connection charges (Figure 12). Only in the case when the regulated tariff is low, and the optimal connection charge is zero, does the network expansion have a large effect on the number of connected households. If the connection cost also varies (as in Figure 11) then the expanded network will have a large effect on electricity connections for low regulated tariffs.

Distortions in fuel prices, such as subsidies for kerosene, may affect the demand for electrification. However, increasing the price of kerosene has little effect on the optimal connection charge (Figure 13). Connection rates are higher for higher kerosene prices only when optimal connection charges are zero.

Household income affects both the demand for energy, conditional on the fuel choice, as well as the fuel choice decision directly. Higher household incomes have little effect on the optimal connection charge (Figure 14). However, higher incomes will lead to much higher electricity connection rates, for all but the very lowest regulated tariffs.

Changes in the parameter assumptions for the financial model of the utility firm will affect the optimal connection charge. For electricity tariffs above the break-even price (about 18 cents per kWh), higher discount rates will increase the optimal connection charge and reduce the number of connections (Figure 15). The opposite occurs for tariffs below the break-even price.

A final robustness check compares the results from the alternative demand specifications in Table 2 (Figure 16). The base case results use the demand model that includes a time trend (Columns 2 and 5 of Table 2). The alternative demand results exclude the time trend, leading to estimates of demand for electricity (kerosene) that are more price inelastic (elastic) (Columns 1 and 4 of Table 2). With electricity demand that is more price inelastic, the proportion of connected households rises, reflecting the higher value that households place on having an electricity connection.[23]

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[23]It is not possible to show the scenario analysis for the demand estimates that include household fixed effects (Columns 3 and 6 of Table 2). With household fixed effects, it is not possible to predict consumption for those households who do not currently use electricity or kerosene.

6 Discussion

High electricity connection charges are a primary barrier to electricity access and a major contributor to low electrification rates in Sub-Saharan Africa. It is a trivial observation that lowering the connection price will increase the number of connections demanded. A more fundamental question is the reason for the distribution utilities to set high connection charges in the first place. Without understanding the economic determinants of connection charges, any attempts to increase electrification by directly subsidizing these charges may be costly and ineffective.

The household and utility firm model demonstrates how low regulated tariffs might lead to high connection charges and low electrification rates. Why would utility regulators set low electricity tariffs given the potentially detrimental effects on the financial and economic performance of the sector? Note that low tariffs are most visible and most beneficial to those households who already have an electricity connection. These are likely to be high-income, urban, educated households—a natural political constituency for the regulator.

The households who suffer most from the low regulated tariffs are those who would choose to have an electricity connection if offered higher prices and lower connection charges than the status quo. The harm caused to these households is much less visible. If anything, households will blame the distribution utility for setting high connection charges, rather than blame the regulator for setting low tariffs. The regulator is much less likely to consider this group in its tariff-setting process.

These considerations highlight the importance of ensuring the regulatory agency is independent and free from political influence. Ideally, the regulator should maximize the welfare of all households, not just the ones with existing connections. Based on the analysis in this paper, this may involve setting higher, not lower, tariffs.

The analysis has several limitations. First, the household and utility firm models are static. The regulator sets the tariff, the utility firm sets the optimal connection charge, and the household then reoptimizes its choice of fuel source. For the case of electricity, this would imply that a household can costlessly move to a dwelling without a connection if having electricity is no longer optimal at the new prices. Real estate prices would adjust to reflect changes in connection charges.

In reality, we might expect that the household and utility firm decisions are dynamic. For example, it may be optimal for a utility firm to act as a durable good monopolist and start by setting a very high connection charge. Only households with very high willingness-to-pay for a connection will connect at this price. Over time, the utility firm could set the

connection charge lower and lower, capturing a larger and larger share of households. This type of forward-looking behavior is not allowed for in the model.

An additional assumption in the analysis is that the household makes a utility-maximizing decision in its choice of fuel source. Potential market failures make this unlikely. For example, the household might have imperfect information about the health effects of fuel sources such as kerosene that create indoor air pollution. Although consumption utility from the polluting fuel source includes the pollution damage, uninformed households would ignore this effect in making their choice. Imperfect information increases the probability of choosing a polluting fuel such as firewood or kerosene.

The analysis suggests that policies designed to address energy market failures in developing countries should target the source of the market failure. For example, imperfect information about indoor air pollution justifies the provision of better information, not subsidies for cleaner fuels. Targeted policies are especially relevant for countries with private investment in restructured electricity markets. Profit-maximizing firms may absorb much of the benefit of connection cost subsidies, and these subsidies may have little effect on electrification rates. Instead, by setting cost-recovery tariffs, the regulator can ensure that distribution utilities have an incentive to increase the number of connections.

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Figure 1: Monthly average wholesale prices for the Southern African Power Pool (SAPP)
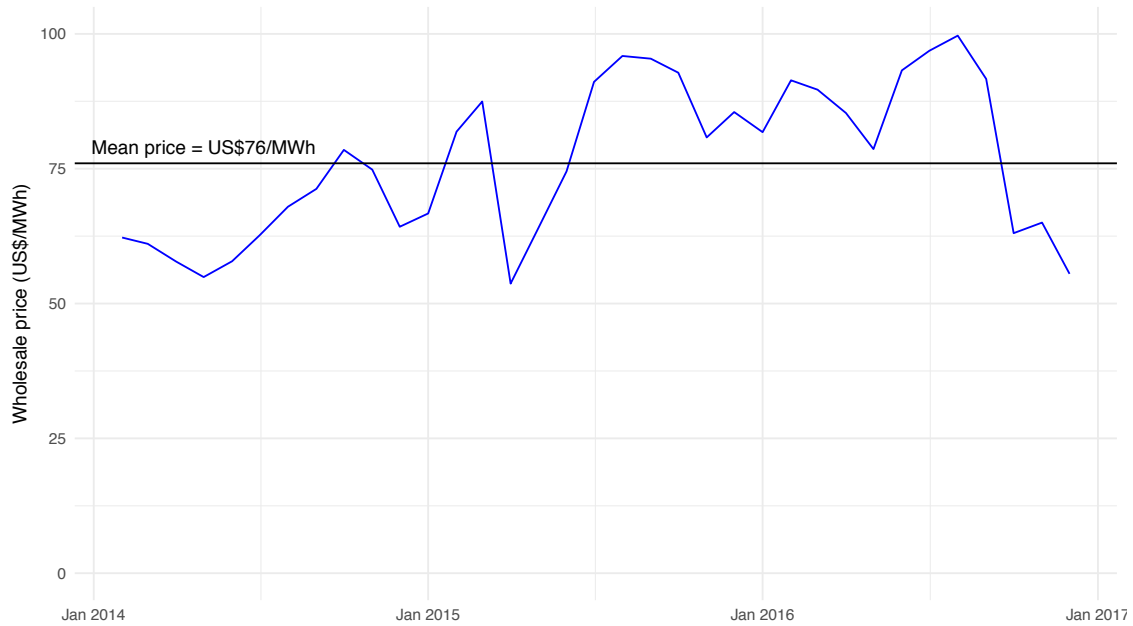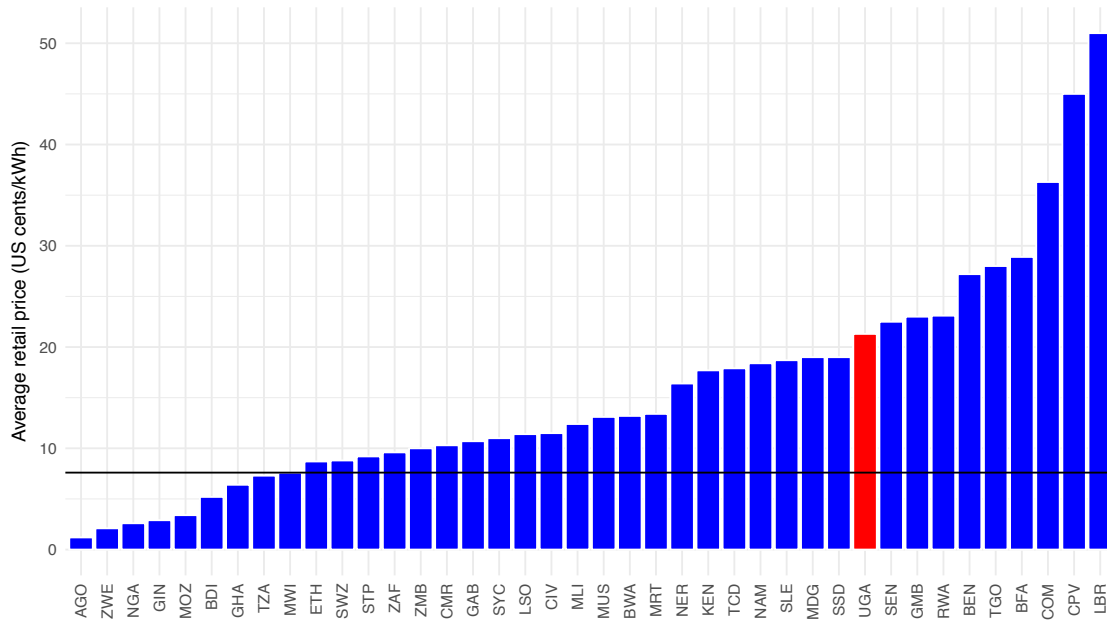

Source: Southern African Power Pool

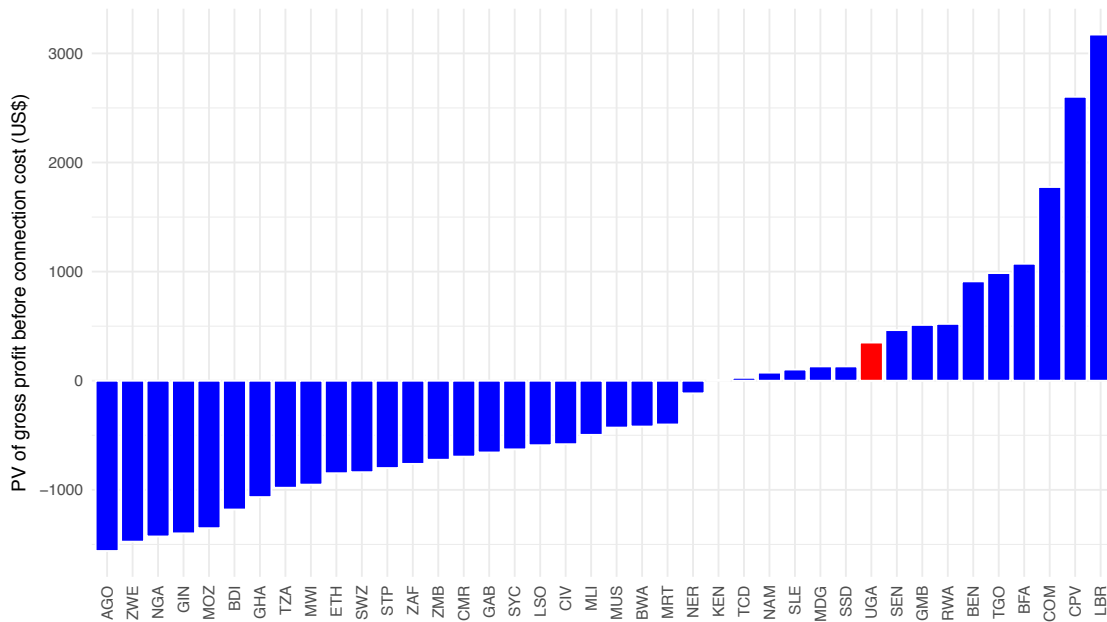**Figure 2:** Distribution of monthly residential electricity consumption in Uganda, 2011–12
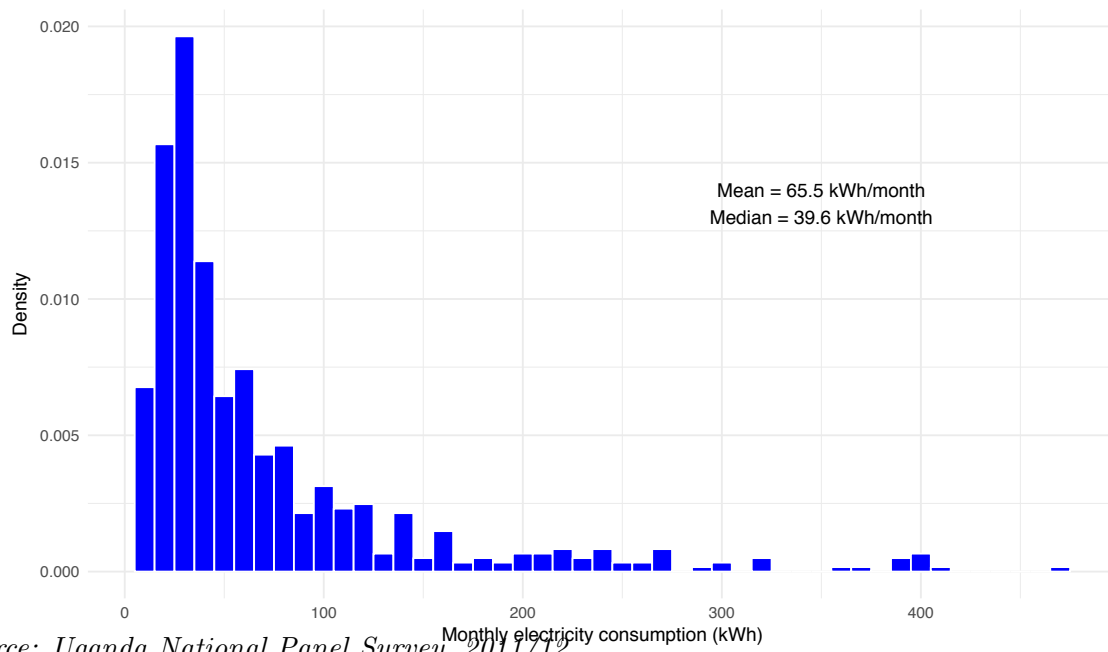
Source: Uganda National Panel Survey, 2011/12

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**Figure 3:** Average retail price based on monthly consumption of 50 kWh

Source: World Bank SSA electricity tariff database

Figure 4: Present value of gross profit from an additional user, before connection costs


Source: Calculations based on tariff database. See text for other assumptions.

Figure 5: Electricity distribution and transmission network, and location of households with electricity connections
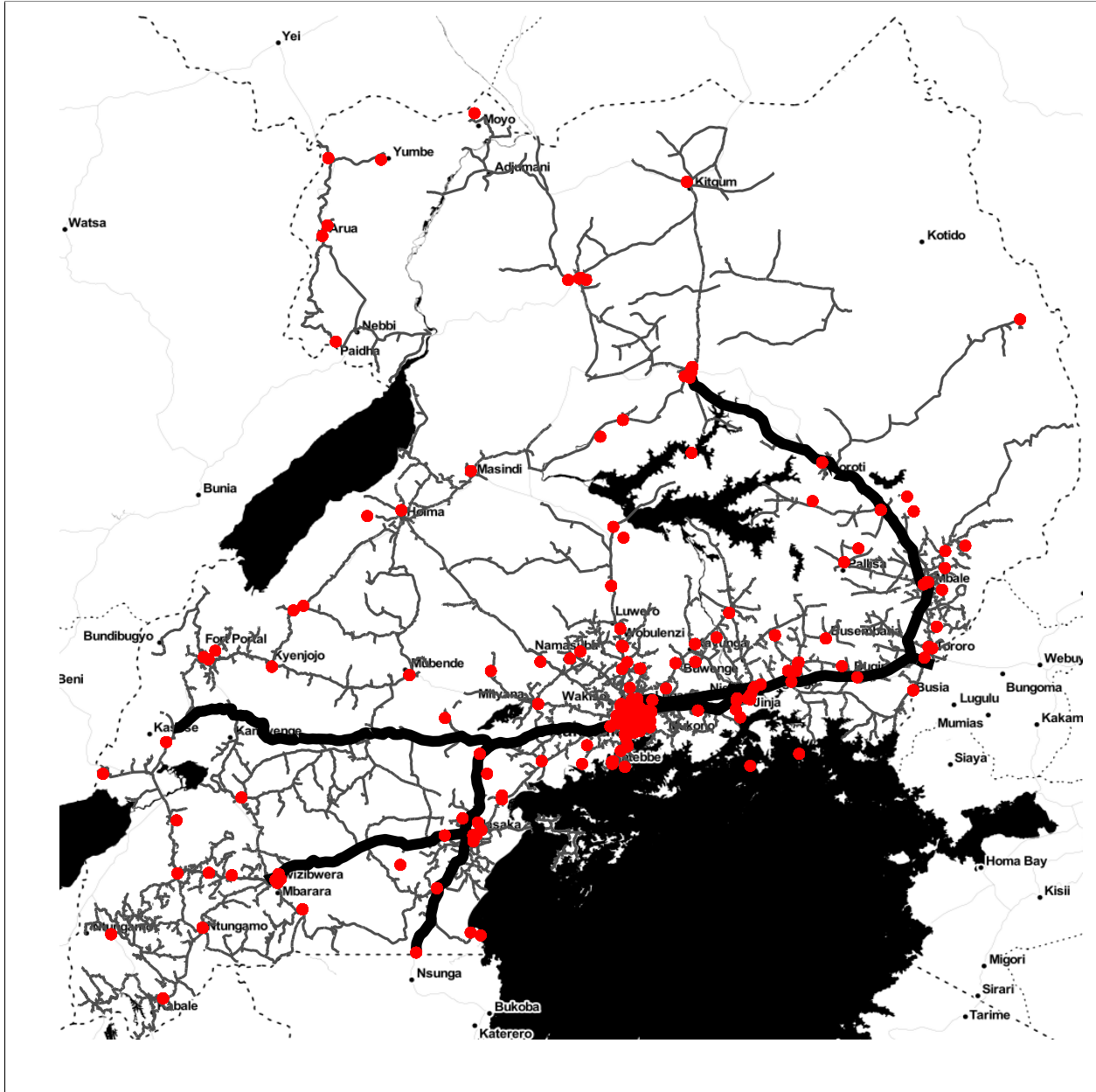
Source: Electricity transmission and distribution network data from the Ugandan Energy Sector GIS Working Group. Electricity connection information as of 2012 from the Uganda National Panel Survey.

Figure 6: Electricity distribution and transmission network, and location of households without electricity connections
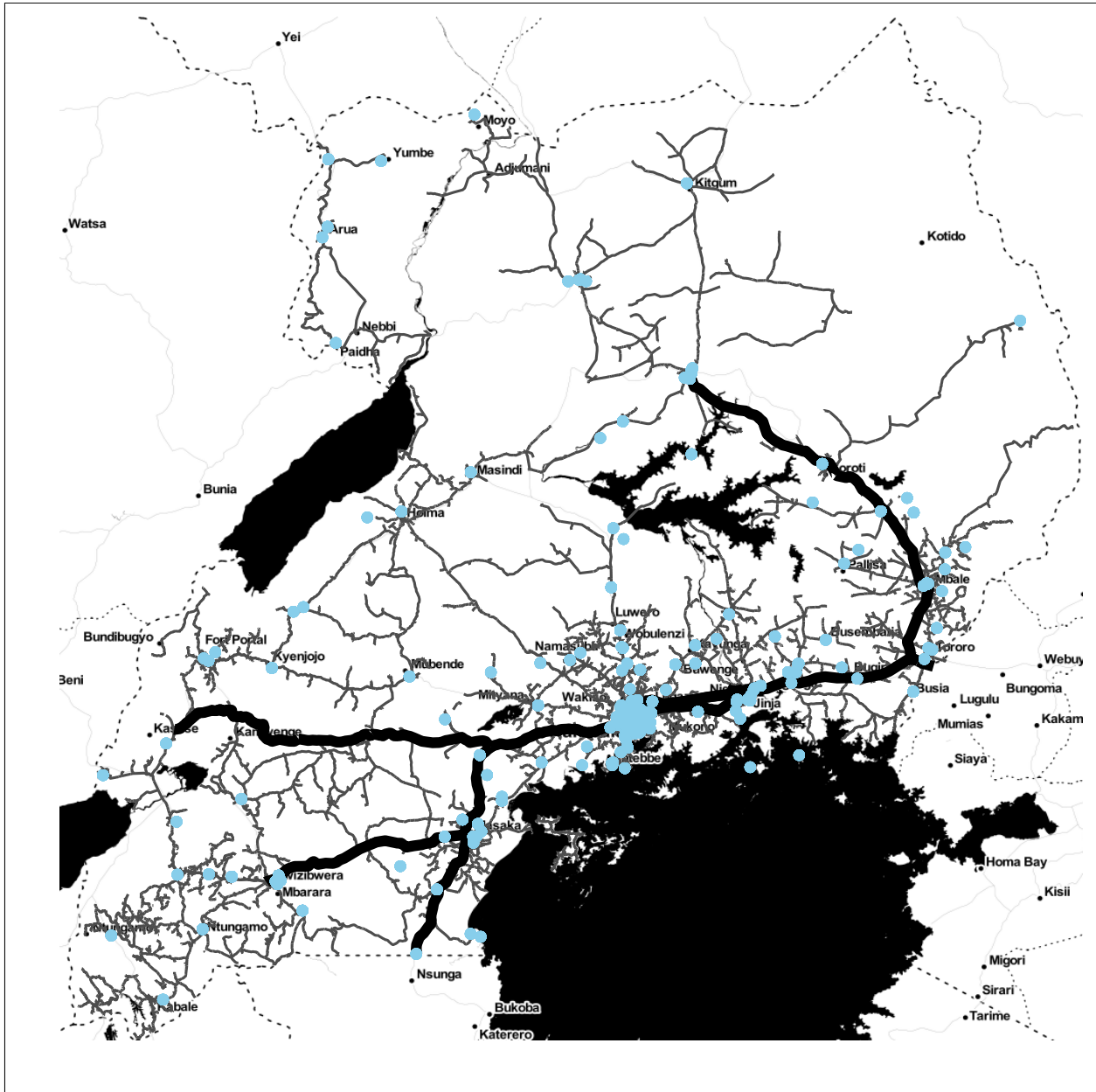
Source: See Figure 5.

Figure 7: Electricity connections, household income, and distance to distribution network
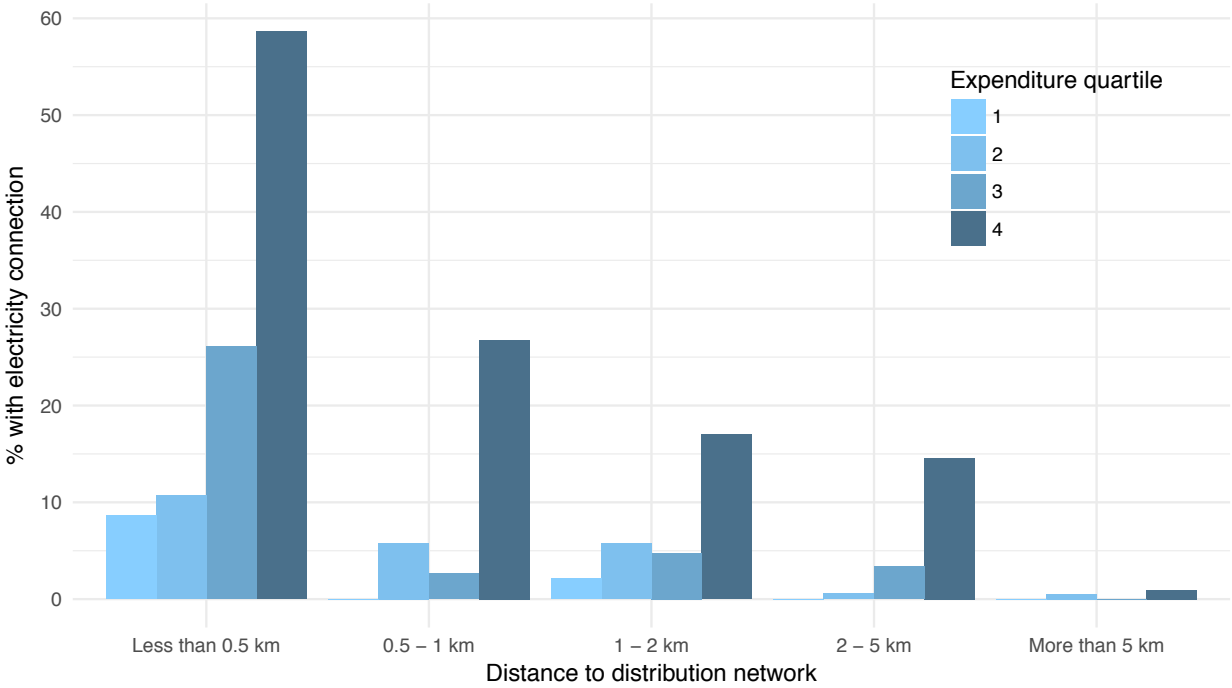
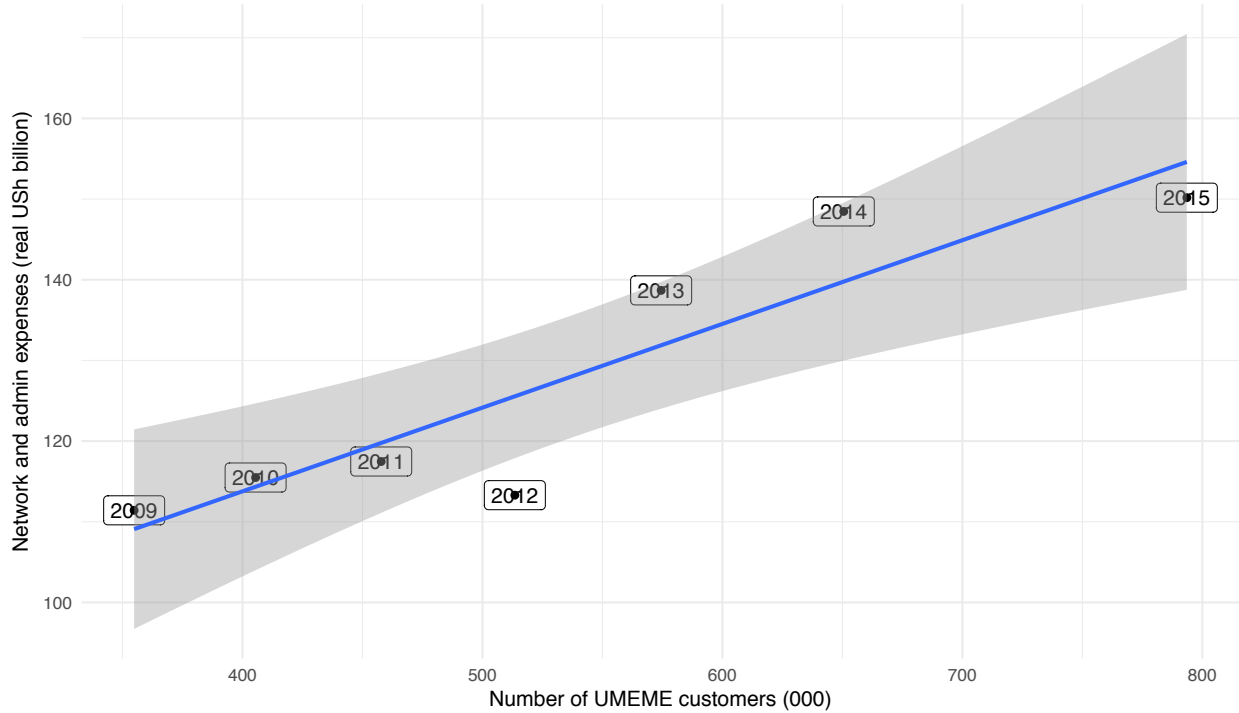**Figure 8:** Estimation of the variable costs associated with providing an electricity connection
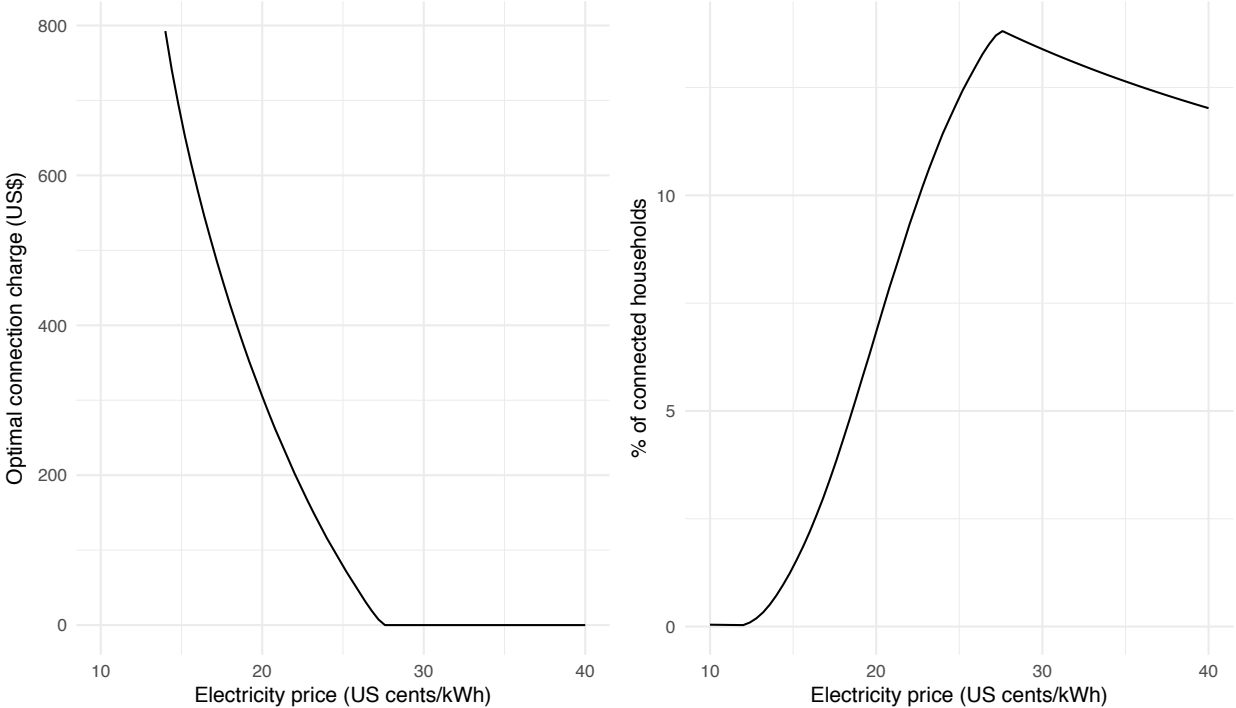
Figure 9: Optimal connection charges and share of connected households, as a function of regulated electricity price

Note: Calculation based on a wholesale electricity price of 10.4 cents/kWh, distribution losses of 15%, a marginal connection cost of $200 per connection, annual costs of $41 per connection, and a discount rate for the distribution utility of 5%.

Figure 10: Optimal connection charges and share of connected households, allowing for negative connection charges (connection subsidies)
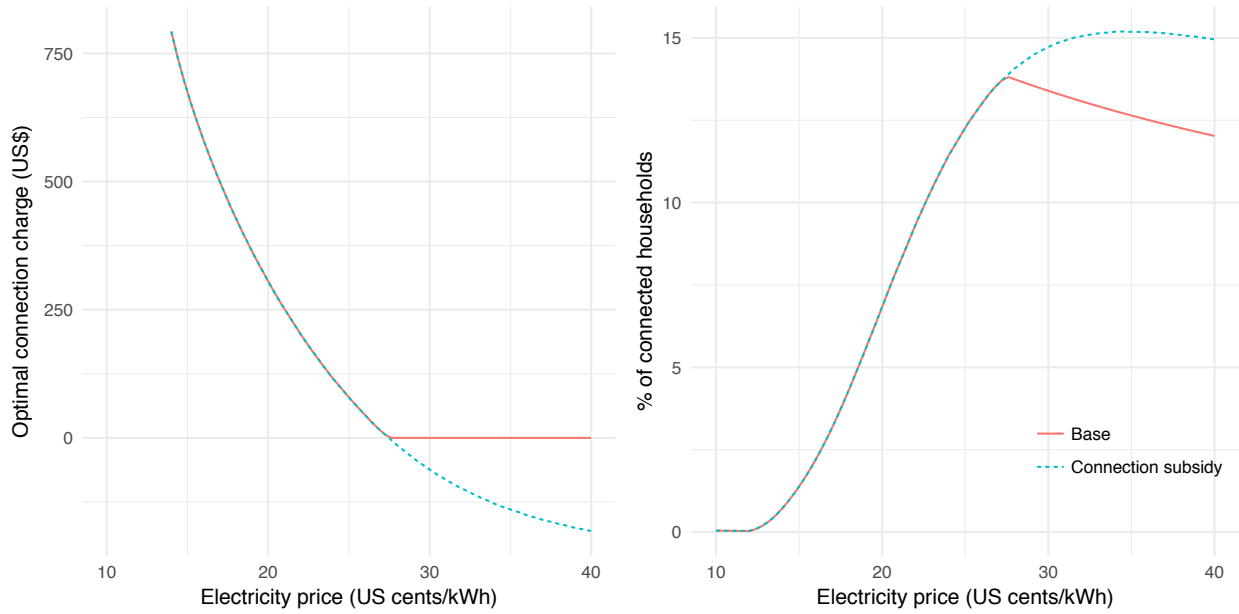

Figure 11: Sensitivity of optimal connection charges and share of connected households: connection costs
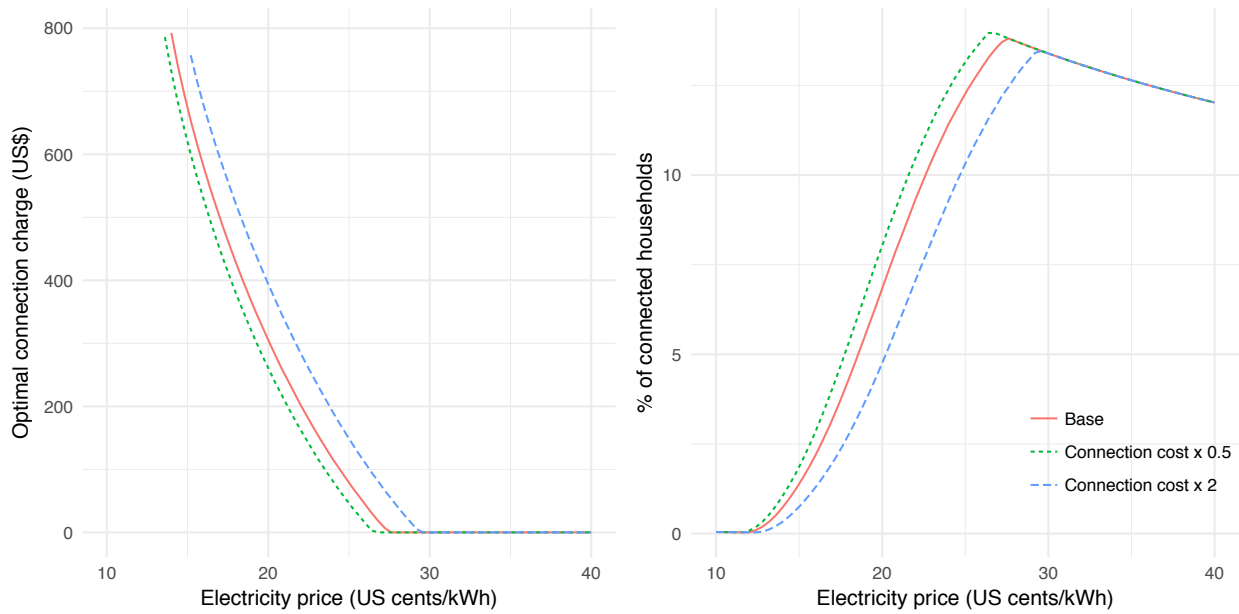
Figure 12: Sensitivity of optimal connection charges and share of connected households: distance to distribution network

Figure 13: Sensitivity of optimal connection charges and share of connected households: kerosene price
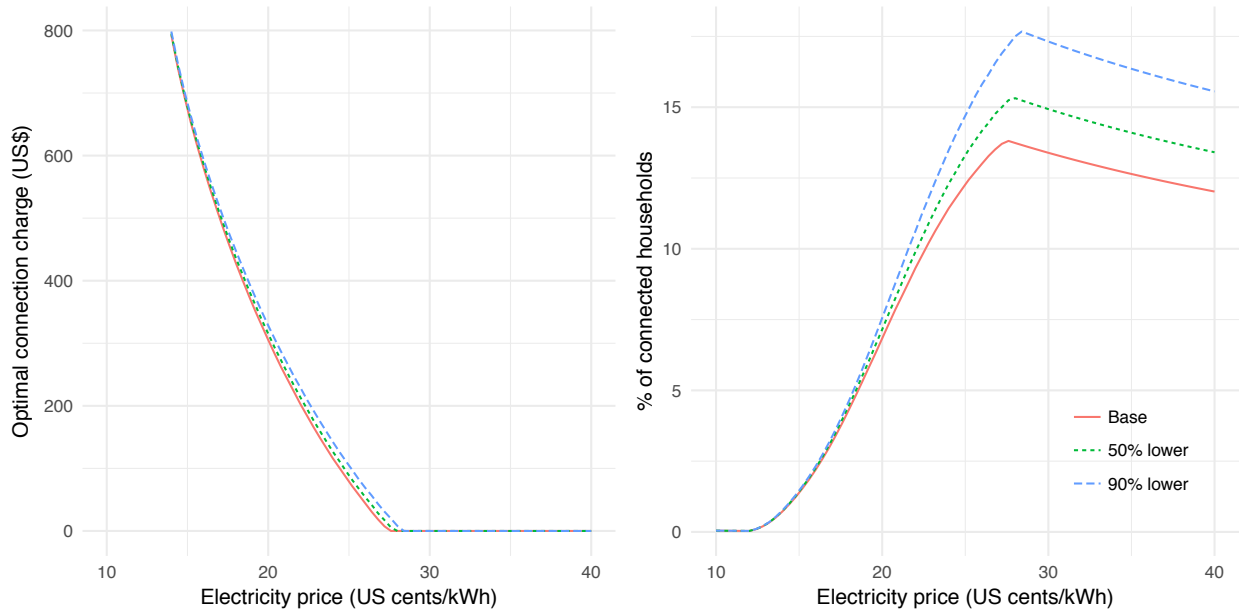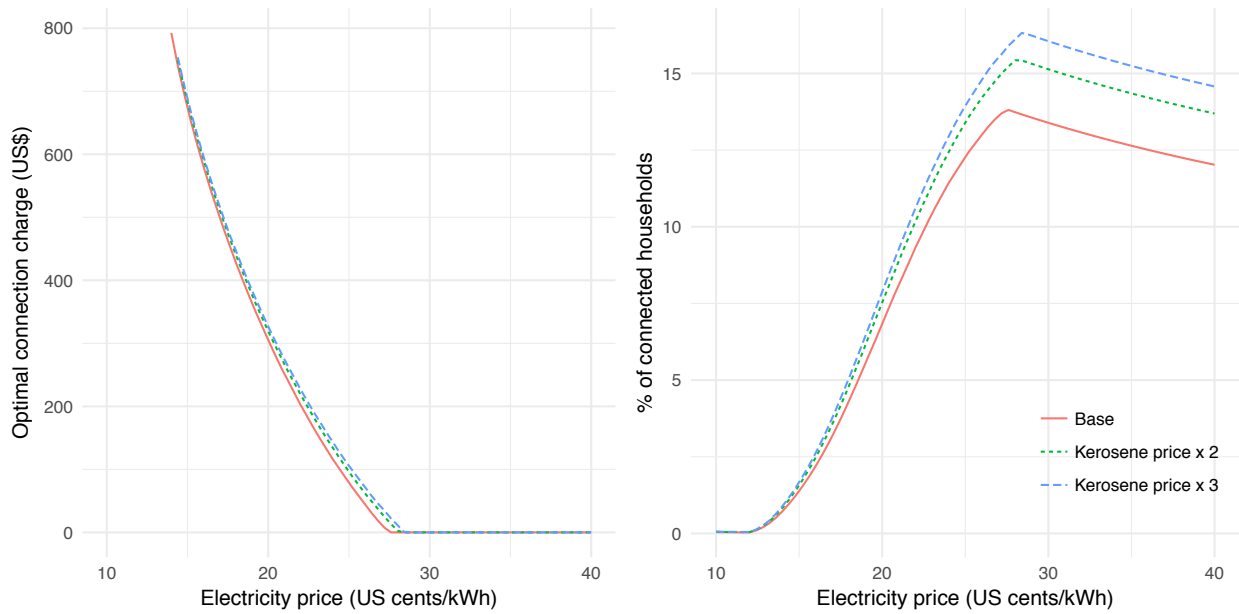
Figure 14: Sensitivity of optimal connection charges and share of connected households: household income
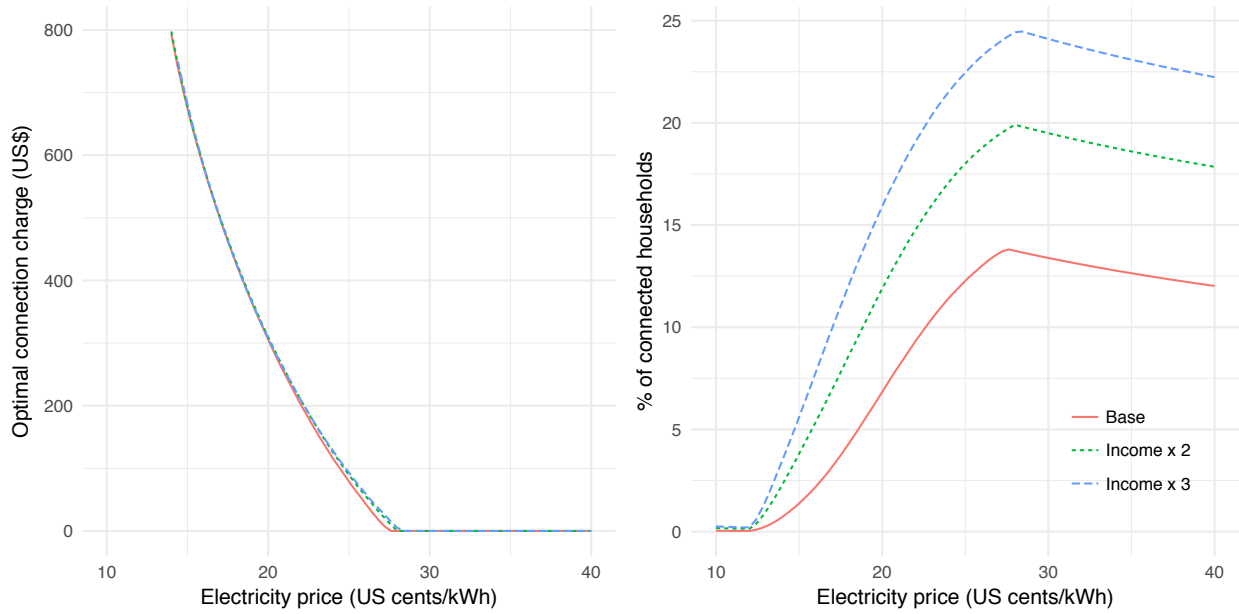

Figure 15: Sensitivity of optimal connection charges and share of connected households: firm discount rates
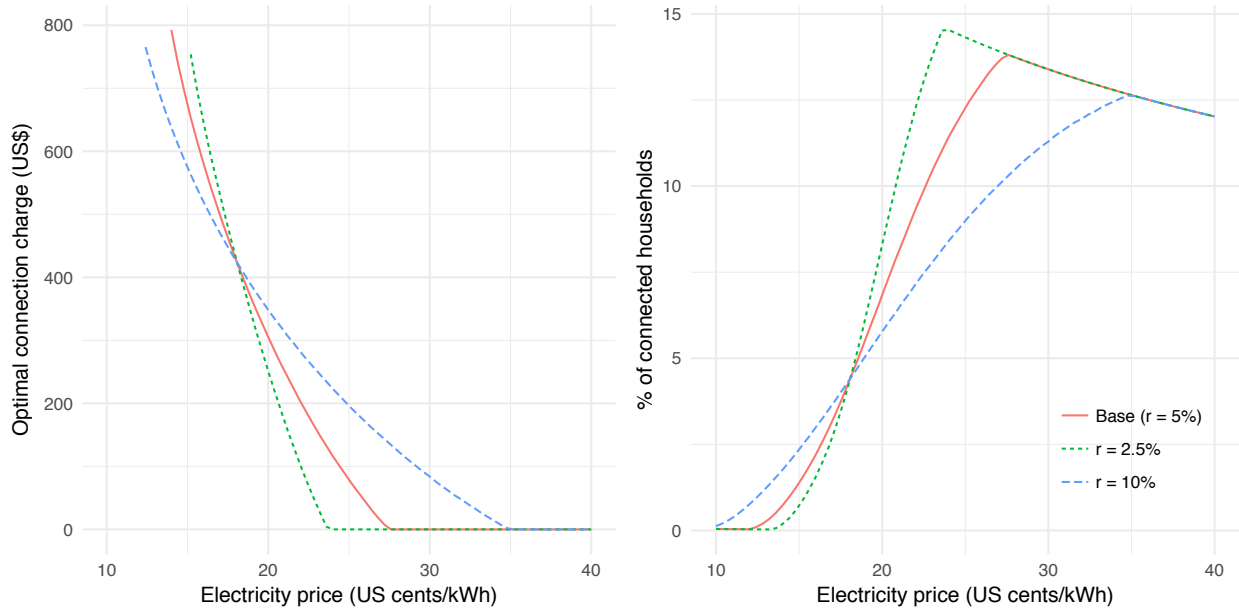
Figure 16: Sensitivity of optimal connection charges and share of connected households: alternative demand estimates
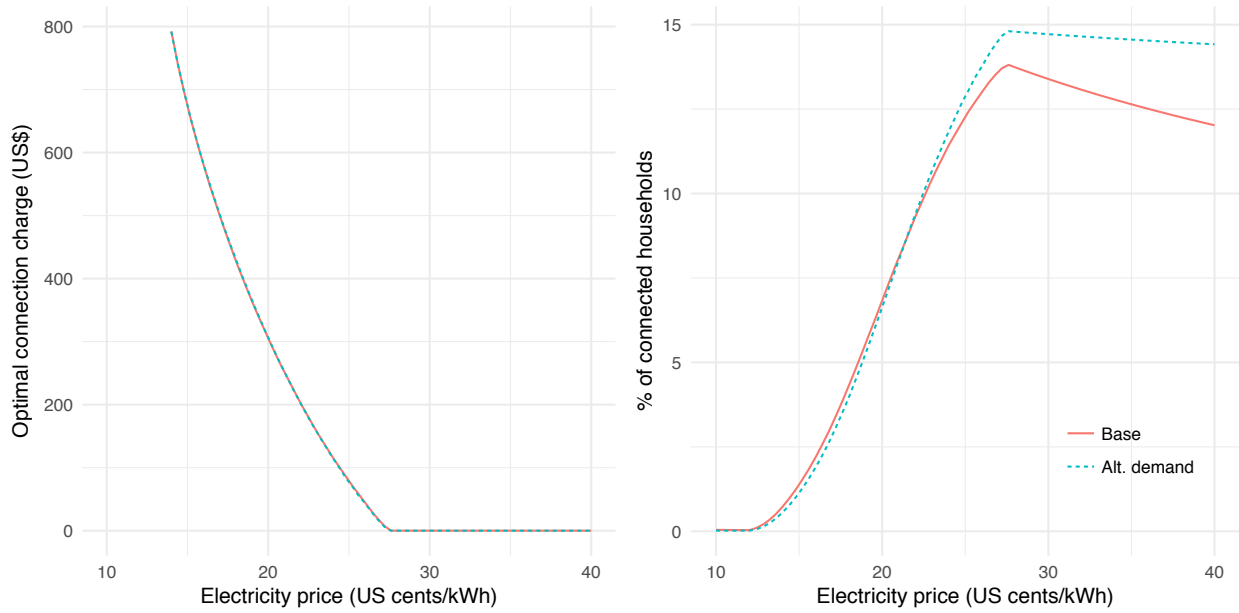
Table 1: Population share of households by lighting source in 2011, by electricity connection and generator ownership

Percentage of households	No electricity connection		Electricity connection	
	No generator	Generator	No generator	Generator
None	13.2	0.0	1.6	0.0
Firewood/dung/residue	3.0		0.2	
Kerosene only	67.8	0.1	1.7	
Kerosene + firewood/dung/residue	1.7		0.1	
Electricity only	0.0		3.7	0.1
Electricity + kerosene	0.2		4.5	0.0
Solar only	0.4	0.0		
Solar + kerosene	0.7	0.1		
Other combination	0.1	0.0	0.5	0.0
Total	87.1	0.3	12.4	0.2

Table 2: Estimation results for household fuel demand equations (log-log model)

	Log kerosene usage			Log electricity usage		
	(1)	(2)	(3)	(4)	(5)	(6)
Log price	-0.58***	-0.24*	-0.03	-0.03	-0.14	0.01
	(0.11)	(0.12)	(0.17)	(0.38)	(0.39)	(0.81)
Expenditure (US 000)	0.30***	0.29***	0.08	0.22***	0.22***	0.05
	(0.03)	(0.03)	(0.05)	(0.04)	(0.04)	(0.10)
Expenditure sq.	-0.03***	-0.03***	-0.01	-0.01***	-0.01***	-0.005
	(0.005)	(0.005)	(0.01)	(0.003)	(0.003)	(0.01)
No. adults	0.05***	0.05***		0.02	0.01	
	(0.01)	(0.01)		(0.02)	(0.02)	
No. children	0.03***	0.03***		0.01	0.01	
	(0.004)	(0.004)		(0.02)	(0.02)	
No. rooms	0.04***	0.04***		-0.005	-0.002	
	(0.01)	(0.01)		(0.02)	(0.02)	
Dwelling owned (0/1)	-0.18***	-0.18***		-0.07	-0.07	
	(0.04)	(0.04)		(0.10)	(0.10)	
Dwelling = house (0/1)	0.14***	0.14***		0.10	0.11	
	(0.03)	(0.03)		(0.10)	(0.10)	
Urban (0/1)	0.16***	0.15***		0.21***	0.20***	
	(0.03)	(0.03)		(0.08)	(0.08)	
Time trend		-0.09***	-0.08***		-0.05	-0.02
		(0.01)	(0.02)		(0.04)	(0.07)
Reliability				0.36	0.24	0.08
				(0.22)	(0.24)	(0.57)
Household fixed effects	.	.	Y	.	.	Y
Dwelling characteristics	Y	Y	.	Y	Y	.
Observations	4,582	4,582	4,582	567	567	567
Adjusted R^2	0.19	0.20	0.45	0.14	0.14	0.31

Notes: Each observation is the logged monthly fuel consumption of a household, for kerosene (1–3) and electricity (4–6). The second column for each fuel adds a linear time trend. The third column for each fuel further adds household fixed effect. Dwelling characteristics in the first two columns for each fuel are indicator variables for improved walls, floor and roof.
*p<0.1; **p<0.05; ***p<0.01

Table 3: Elasticities of fuel choice probability with respect to selected regressors

Variable	None	Kerosene	Electricity	Solar
Electricity price	0.040	0.056	-0.378	-0.003
Kerosene price	0.124	-0.058	0.198	0.296
Household expenditure	0.114	-0.125	0.586	0.546
Electricity connection charge	0.034	0.046	-0.300	-0.077
Solar capital cost	0.021	0.027	-0.019	-1.525
Electricity reliability	-0.048	-0.068	0.458	-0.004
Distance to grid	0.267	-0.020	-0.136	-0.005
Number of adults	-0.165	0.042	-0.077	-0.177
Number of children	-0.185	0.058	-0.189	0.160
Dwelling rooms	-0.401	0.082	-0.271	1.566

Notes: Each row shows the effect of a small increase in that variable on the probability of the household choosing the fuel type in that column. These are reported as elasticities, that is, the percentage change in the probability of choosing that fuel divided by the percentage change in the variable.

Table 4: Effect of connection charges on distribution utility profitability

	Connection charge (US$)						
	0	100	200	300	400	500	600
Electricity price (US cents/kWh)	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Connected %	16.80	13.90	10.75	7.74	5.20	3.29	1.98
Connected households							
Av. consumption (kWh/month)	57.61	59.90	63.19	67.69	73.62	81.05	89.69
Gross profit (US$/month)	-2.11	-1.60	-1.06	-0.48	0.16	0.86	1.60
All households							
Av. consumption (kWh/month)	9.68	8.33	6.79	5.24	3.83	2.67	1.78
Gross profit (US$/month)	-0.35	-0.22	-0.11	-0.04	0.01	0.03	0.03
Electricity price (US cents/kWh)	21.00	21.00	21.00	21.00	21.00	21.00	21.00
Connected %	15.25	12.52	9.58	6.82	4.52	2.83	1.68
Connected households							
Av. consumption (kWh/month)	56.12	58.40	61.66	66.12	71.97	79.21	87.50
Gross profit (US$/month)	0.64	1.26	1.96	2.77	3.70	4.75	5.89
All households							
Av. consumption (kWh/month)	8.56	7.31	5.91	4.51	3.25	2.24	1.47
Gross profit (US$/month)	0.10	0.16	0.19	0.19	0.17	0.13	0.10