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Price elasticities of residential electricity demand: Estimates from household panel data in Bangladesh

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ABSTRACT

We collect a household level panel dataset to estimate the price elasticities of electricity demand for different types of urban households in Bangladesh. We use an instrumental variable estimation strategy which exploits exogenous variation in average electricity prices induced by a value-added-tax shock. The results indicate significant heterogeneity in price elasticities by electricity consumption levels. We conduct a number of simulations under alternative policy scenarios to illustrate how incorporating the heterogeneous nature of price elasticities into pricing policy can help decrease electricity demand-supply mismatch and inequality in electricity consumption. The results have important policy implications for developing countries aiming to address major energy issues by implementing tariff reforms.

1. Introduction

Energy use in non-OECD countries exceeded that in OECD countries in 2007 and it has been projected to reach nearly two-thirds of the global energy consumption by 2040 (IEO 2018). Electricity – the most widely used form of energy in developing countries – is probably the most significant strategic input for long-term economic and social development as it has direct relationship with economic growth and environmental sustainability. The governments in many developing countries, however, face significant challenges to address the problems they face with electricity demand-supply mismatch and inequality in electricity access (Kaygusuz, 2012).

The main objective of this paper is to estimate short-term price elasticities of urban residential electricity demand in a developing country and to examine how differential pricing of electricity can be used to reduce electricity demand-supply mismatch and inequality in electricity access. A key novelty of this paper is to exploit exogenous price variation induced by a Value-Added-Tax (VAT) shock that took place between different rounds of household surveys we collected from Bangladesh. Our estimation strategy takes advantage of a sudden change in VAT and the unique electricity pricing structure that differentially affects households with different consumption levels. The features of the household panel data and VAT shock allow us to implement a fixed-effect instrumental variable (FE-IV) estimation method to examine whether the price elasticities of residential energy demand vary across households with different consumption levels.

Our results show that the short-term average price elasticity is −0.577, which means that residential electricity demand is on average price inelastic in urban Bangladesh. We also find evidence of considerable heterogeneity in price elasticities across different electricity consumption groups. The results show that the lowest and the highest consumption groups are price elastic whereas households with moderate consumption levels are relatively price inelastic. Using these estimates, we perform simulations under different policy scenarios to demonstrate how policymakers in Bangladesh can improve the

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differential pricing to narrow the demand-supply gap and reduce inequality in electricity consumption. Particularly, we use the actual national price hike in December 2017, which occurred several months after the last round of survey data used in this paper, as a benchmark, and solve the optimization problem of policymakers with respect to alternative price changes up to 7.2% or up to 10% in each marginal price step. We demonstrate that information about heterogeneous price elasticities can be better incorporated into pricing policy to reduce inequality in electricity consumption while maintaining the revenue of electricity suppliers.

This paper is closely related to three strands of economic literature on energy demand. First, this paper contributes to the literature on estimating price elasticities of residential electricity demand in developing countries, particularly in Bangladesh. Although some existing studies of electricity demand focus exclusively urban households, such as Filippini and Pachauri (2004), there are also a number of studies that estimate price elasticities for various income groups and regions. For example, Tiwari (2000) finds that price elasticities of residential electricity demand were around −0.8 for upper income and lower income groups, but much lower around 0.65 for middle and upper middle-income groups in India based on household survey data in 1987–1988. Chindarkar and Goyal (2019) report price elasticities of residential electricity demand across urban and rural areas for various Indian states, with a mean around −0.5 and range between −1.17 and −0.13 for rural areas and a mean around −0.25 and range between −1.51 and 0.46 for urban areas. Recently, using time-series data from 1980 to 2015, Amin and Khan (2020) find that the long-run price elasticity of energy demand is −0.75 in Bangladesh. The magnitudes of these estimates are similar to the range between −1.6 and −0.2 that Athukorala and Wilson (2010) report. To the best of our knowledge, there are few studies for developing countries and particularly for Bangladesh that highlight the heterogeneity in price elasticities by consumption group. By focusing on Bangladesh, a lower middle-income country that faces major challenges in electricity demand-supply mismatch and inequality of electricity access, this paper also aims to shed light on how tariff reforms and pricing strategies that account for heterogeneous price elasticities of residential electricity demand can play a role in addressing the energy challenges that developing countries face.

Improving pricing strategies is particularly policy relevant for developing countries as Burgess et al. (2019) argue that developing countries should implement tariff reform by reducing electricity subsidies that disproportionately benefit the rich who have high electricity consumption levels. If electricity demand is highly price elastic for households with high consumption levels and less price elastic for households with moderate consumption levels, increasing the marginal prices of electricity (tariffs) at the top half of the consumption distribution can help reduce the overall demand and government subsidies, decrease demand-supply mismatch, and potentially improve inequality in electricity consumption. In fact, Burke and Kurniawati (2018) find that when subsidies were reduced in Indonesia, the demand for electricity decreases significantly, which enabled the government to address some supply side infrastructure issues. In this regard, our estimates and policy simulations show that for economies that adopt a (consumption-based) tariff system and with similar magnitudes of heterogeneous price elasticities, incorporating heterogeneous price elasticities into pricing decisions can potentially reduce demand-supply gap and inequality in electricity consumption.

Second, this paper contributes to the literature on the estimation methods for identifying price elasticities of electricity demand. Most of the existing econometric literature on residential energy demand uses cross-sectional data (e.g., Deaton and Muellbauer, 1980; Filippini, 1995; Filippini and Pachauri, 2004; Kamerschen and Porter, 2004; Labandeira et al., 2006; Yoo et al., 2007; Barnes et al., 2010; Ngui et al., 2011). The majority of them would apply an Ordinary Least Squares (OLS) regression framework to derive their findings. Some papers use time series or annual aggregate data for all sectors to estimate short-run and long-run price elasticities on the basis of cointegration, structural time series, or error-correction models (e.g., Holtedahl and Joutz, 2004; Hondroyiannis, 2004; Narayan and Smyth, 2005; Sa'ad, 2009; Amin and Khan, 2020). There are also past studies on electricity demand in Bangladesh that use repeated cross-sectional data, such as Mozumder and Marathe (2007), Munim et al. (2010), and Mottaleb et al. (2017).

The concerns with the estimation methods used in these aforementioned studies are the extent to which potential endogeneity bias, selection bias, and omitted variable bias are minimized. For example, Filippini and Pachauri (2004) attempt to address omitted variable bias by adding more explanatory variables, such as income and prices of other energy types, in their demand equation specification. Other research, such as Blázquez et al. (2013), uses panel data sets with fixed effects (FE) estimation to deal with unobserved heterogeneity and selection bias. Although having additional explanatory variables and using fixed effects estimation can help reduce omitted variable bias and selection bias, Hung and Huang (2015) argue that the endogeneity of the price variable is an important issue to address, particularly when studying demand for electricity with decreasing or increasing block pricing. To address the endogeneity problem caused by average prices, they propose an instrumental variable, constructed from predetermined electricity rates, to estimate price and income elasticities of electricity demand within a fixed effects (FE) framework using city and county level monthly panel data. In line with the empirical strategy of Hung and Huang (2015), we attempt to improve upon previous studies by utilizing an instrumental variable strategy that exploits an exogenous increase in prices due to the VAT change within a household fixed-effects framework to address the endogeneity problem in average price.

Our demand estimation framework that exploits exogeneous variation in average prices to identify price elasticities of electricity demand is closely related to the growing literature that relies on natural and field experimental designs to examine causal effects of treatments on energy consumption. For example, Deryugina et al. (2020) exploit a natural experiment in the United States that provides exogenous price shocks to some but not all households to estimate both short-run and long-run price elasticities of residential electricity demand. Similarly, Feehan (2018) utilizes a natural experiment in Canada that brought about an abrupt, substantial, and permanent price change to one of two otherwise similar adjacent regions to estimate the long-run price elasticity of residential electricity demand using a difference-in-differences estimator. There are also numerous field experiments that randomly assigned treatments to households to examine the effects of these treatments on their energy consumption. Examples of these field experiments include Allcott (2011), Ferraro et al. (2011), Allcott and Rogers (2014), and Brent et al. (2015) that investigate the effects of social norms or peer comparisons on energy consumption. A key feature of these natural and field experimental studies is that by ensuring the variation in electricity prices or information treatments is exogeneous, the researchers can credibly estimate price elasticities or other treatment effects without including prices of other energy types, incomes, and other household characteristics as additional explanatory variables. Our research design is consistent with this strand of literature.

The paper is structured in seven sections, including this introduction. Section 2 provides background information on the energy sectors in developing countries and Bangladesh. Section 3 describes the data and methodology used. Section 4 reports and discusses the empirical findings. Section 5 tests the robustness of our main empirical results. Section 6 presents some policy simulations. The final section concludes the paper with some discussions about the limitations and practical applicability of the findings.

2. Background

Many developing countries have poor access to reliable and sustainable energy despite the importance of energy as a strategic input for development. In 2015, about 2.8 billion people had no access to modern energy services and over 1.1 billion did not have electricity (World Bank, 2016a). Around 3.8 million people are facing premature death every year due to indoor pollution and poor health resulting from cooking and heating using unsustainable fuels (WHO, 2016).[1] As a result, the United Nation's (UN) Sustainable Development Goal (SDG) 7 for the World is to ensure access to affordable, reliable, sustainable and modern energy for all (United Nations, 2017). The lack of reliable energy services has serious implication on the welfare of the population in developing countries.

The World Bank, 2020 report (World Bank, 2020) describes that South Asia has the second-largest population (after Sub-Saharan Africa) living off the grid—255 million people in 2016, more than a quarter of all the people in the world living without access to electricity. According to the World Bank (2018), 81% of the rural population and 99% of the urban population in Bangladesh had access to electricity in 2017. The 2018 Global Competitiveness Report, which ranks 137 economies on the reliability of electricity supply, places Bangladesh at 101th (Schwab, 2018). Bangladesh has recently made remarkable progress in reducing extreme poverty and advanced to a lower middle-income country. Sustainable economic growth, strong domestic demand, and urbanization have rapidly increased the demand for energy in Bangladesh.

The two major challenges that Bangladesh faces are demand-supply mismatch and inequality in electricity access. The maximum power demand in Bangladesh has been growing at an increasing rate in recent years (Bangladesh Power Development Board, 2017). On the supply side, the electricity generation capacity has increased from 5272 Megawatt (MW) in 2009 to 16,892 MW in 2018 (Amin and Rahman, 2019). Despite such a significant increase in generation, the energy sector struggles to meet actual demand for electricity due to the transmission and distribution bottlenecks, deficit in gas supply to power plants, high system losses, electricity theft and more.[2] The rising demand predominantly came from residential customers in urban areas, given that the residential sector has become the most important end-user of electricity in recent years (Islam and Khan, 2017). Hasan and Mozumder (2017) find that urban residents in Bangladesh have significantly larger electricity consumption than rural households while the mean of electricity expenditure share of total expenditure is only 2.4%. Rural households are significantly more likely to be energy poor than income poor. 58% of rural households in Bangladesh is energy poor compared to income poverty of 45% (Barnes et al., 2010).

The Bangladeshi government has implemented a number of energy policy reforms to address its energy challenges. In response to acute power shortages, the Bangladeshi government launched a major power sector power reform in 1994 (Zhang, 2018). The reform substantially reduced distribution and transmission losses from 26% in fiscal 2000 to 10% in fiscal 2017 (Bangladesh Power Development Board, 2018; Asian Development Bank, 2009). Supply inefficiency has also decreased over the years which is evident from the decline in power shortages (Zhang, 2018). In order to combat power theft issues, the government aims to install prepaid electric metering nationwide by 2021 (Bangladesh Power Development Board, 2018). In 2007, as a part of its tariff reform, the government also introduced a new price slab system that charges progressive marginal prices on electricity consumption (Asian Development Bank, 2012).

Major issues that Bangladesh faces in its electricity sector are common issues other low-income and low middle-income countries face, and thus, it provides a suitable setting to study residential energy demand in developing countries. Burgess et al. (2019) argue that developing countries should implement tariff reforms and reduce energy subsidies that disproportionately benefit the rich. The simultaneous presence of demand-supply mismatch and inequality in electricity access highlights a potential flaw in the pricing of electricity as the prices faced by high-end users may be too low while the prices faced by low-end users may be too high. Understanding the determinants of residential electricity demand and especially the price elasticity of demand by different consumption level in a low middle-income country is imperative to inform policies that aim to improve pricing in the residential sector. Since other low-income or low middle-income countries such as India, Cambodia, Myanmar, Indonesia, and Timor-Leste similarly face these issues in their energy sector (World Bank, 2016b), the findings drawn from Bangladeshi experience may provide valuable lessons for other developing countries too.

3. Data and methodology

3.1. Survey data

We collected the dataset used in this study through three rounds of household-level surveys from three major cities in Bangladesh: Dhaka, Jessore, and Khulna. These three cities are located in two different divisions that are close in proximity and have similar climate conditions.[3] The surveys took the form of in-home interviews covering approximately 2250 households selected from 10 suburbs in these cities. These households typically own or rent apartments in these suburbs, and intended to stay for more than 12 months at the time of the first-round (baseline) survey in May 2017. The baseline survey gathered detailed information about household demographics, dwelling characteristics, electricity usage and bills for the month of April 2017, and more. In July 2017, we conducted the second-round survey focusing on collecting detailed information regarding electricity usage and bills for the month of June 2017. We conducted the third-round survey in September 2017 to collect detailed information regarding electricity usage and bills for the month of August 2017.

The surveys were conducted as parts of a large scale randomized controlled trial in these cities, and we were not anticipating any changes in government policies at the time of the first and second rounds of the surveys. The government increased the Value-Added-Tax (VAT) applied to electricity consumption between round-2 survey and round-3 survey and the VAT change took effect from July 2017 onwards. To study how this VAT shock affected residential electricity consumption, we focus on round-2 and round-3 survey data in our empirical analysis. Thus, we use a balanced household panel sample of 2246 households and two rounds of data to perform estimation. Noe that we also use round-1 survey data to categorize households into different baseline consumption levels. The available data is a relatively short panel data, and therefore, the emphasis of this paper is to exploit the VAT price shock to estimate the short-term price elasticities of residential electricity demand.

Table 1 presents summary statistics of the key variables. In the top panel of Table 1, we find that the average electricity consumption in rounds 1, 2, and 3 are 322.08 kwh, 340.61 kWh, and 331.91 kWh, respectively. The minimum level of electricity consumption over all households in three rounds is 110 kWh, while the maximum is 1045 kWh. The average electricity bill in each round is in the range between 1715 Tk and 1807 Tk, and the average price is in the range

[1] Due to lack of access to affordable and reliable electricity services, households rely heavily on traditional biomass fuels such as fuelwood, charcoal, agricultural waste and animal dung.

[2] See Finance Division (2017) and Islam et al. (2014) for more information on challenges faced by the power sector in Bangladesh to meet actual demand for electricity.

[3] The administration of Bangladesh is divided into eight main regions called divisions. Each division is further split into several districts. The Dhaka district is from the Dhaka Division. Jessore and Khulna districts are from the Khulna Division.

Table 1
Descriptive statistics.

	Mean	SD	Min	Max
A. Consumption and price variables				
Round 1				
Consumption (kWh)	322.08	117.19	130	987
Electricity bill (Tk)	1715.63	691.35	850	9722
Average price (Tk)	5.31	0.56	2.59	10
Round 2				
Consumption (kWh)	340.61	113.47	135	1045
Electricity bill (Tk)	1807.65	674.28	930	7861
Average price (Tk)	5.29	0.55	2.56	11.11
Round 3				
Consumption (kWh)	331.92	106.88	110	921
Electricity bill (Tk)	1785.95	681.58	164	8245
Average price (Tk)	5.36	0.60	0.78	10.65
B. Household demographics				
Proportion of households by district				
Dhaka	0.78	0.414	0	1
Jessore	0.093	0.29	0	1
Khulna	0.127	0.333	0	1
Employment status of the household head				
Unemployed	0.025	0.156	0	1
Employed	0.964	0.186	0	1
Not disclosed	0.011	0.105	0	1
Employment status of the household head's partner				
Unemployed	0.013	0.115	0	1
Employed	0.132	0.339	0	1
Homemaker	0.843	0.364	0	1
Not disclosed	0.011	0.105	0	1
Other household characteristics				
Household size	3.715	1.198	1	24
Single family	0.945	0.228	0	1
C. Climate conditions across different districts by survey round				
Round 1				
Dhaka (23.79°N, 90.30°E)				
Temperature (°C)	29		23.5	34.5
Rainfall (mm)	138			
Jessore (23.16°N, 89.22°E)				
Temperature (°C)	29.5		23.2	35.9
Rainfall (mm)	77			
Khulna (22.67°N, 89.40°E)				
Temperature (°C)	28.9		23.3	34.6
Rainfall (mm)	87			
Round 2				
Dhaka (23.79°N, 90.30°E)				
Temperature (°C)	28.8		25.9	31.8
Rainfall (mm)	367			
Jessore (23.16°N, 89.22°E)				
Temperature (°C)	29.2		25.8	32.6
Rainfall (mm)	314			
Khulna (22.67°N, 89.40°E)				
Temperature (°C)	29.1		25.8	32.4
Rainfall (mm)	333			
Round 3				
Dhaka (23.79°N, 90.30°E)				
Temperature (°C)	28.9		26.2	31.6
Rainfall (mm)	317			
Jessore (23.16°N, 89.22°E)				
Temperature (°C)	28.6		25.6	31.6
Rainfall (mm)	293			
Khulna (22.67°N, 89.40°E)				
Temperature (°C)	28.6		26	31.3
Rainfall (mm)	307			
$N = 2246$				

Notes: Table 1 gives the descriptive statistics for our household level panel data. Panel A provides the summary statistics for important household consumption and price variables for each survey round. Panel B summarizes some household characteristics, as well as, the proportion of households from each district in our study sample. Panel C provides climate information for Dhaka, Jessore and Khulna during the three survey rounds. Weather information is based on averages between 1982 and 2012 and is sourced from https://en.climate-data.org/.

between 5.29 Tk and 5.36 Tk. These average prices are slightly higher than the national average price of 5.09 Tk for residential customers in Bangladesh during this period.[4] As our sample contains urban households that tend to consume more electricity and face higher marginal prices, this slightly higher figure is expected.

The second panel of Table 1 shows household demographic characteristics of the sample. Among all households, 78% lives in Dhaka. 96% of household heads are employed at the time of round-1 survey, while the majority of their partners are housewives. The average size of households is between 3 and 4. 94% of the households are a single-family unit.

Finally, the bottom panel of Table 1 reports the climate conditions of the three sampled districts. The average temperatures of these districts are almost identical. The average rainfall in Dhaka is a bit higher in round 1, but it is similar to those in other districts in rounds 2 and 3, during which we focus on our analysis.

3.2. Price slab system in Bangladesh

Bangladesh uses a non-linear pricing system for residential electricity consumption since 2007. Table 2 illustrates the increasing price slab system for final residential tariffs that was in effect during the sample period.

There are seven different consumption steps in the price slab system. Let k denote the different electricity consumption steps, where $k = 0, 1, 2, 3, 4, 5, 6$. The lifeline step ($k = 0$), concerns households with the lowest electricity consumption. These units are priced at 3.33 Tk. per unit. When a household's electricity consumption exceeds 50 units, their electricity bill is calculated from the first consumption step ($k = 1$), where the first 75 units are priced at 3.80 Tk. per unit. Subsequent consumption steps are charged at higher marginal prices according to the pricing system. Once the electricity consumption of a household exceeds 300 kWh, the household faces multiple marginal price exposure. Table 1 also illustrates the non-linear increase in marginal price across different consumption steps in the rightmost column. The largest jump in marginal price is about 55% between consumption steps 4 and 5. The second largest jump in marginal price is 35% between consumption steps 1 and 2. However, policymakers have priced consumption steps 3 and 4 in a relatively flat manner. It is interesting to see how the structure of the price slab system allows the burden of a price shock to vary according to households' consumption level. Low consumption households experience a lower price hike compared to households that consume more. Thus, we expect the VAT shock to have similar properties in terms of price shock burden.

3.3. Electricity bill structure

This subsection discusses the electricity bill structure and the difference between marginal price and average price during the sample period. A typical electricity bill document for a residential customer contains the following information:

1. Customer information: name, address, account and meter numbers, etc.
2. Administrative information: billing month and period, bill number, and issue date.
3. Usage information: current and previous meter information
4. Charges: raw electricity charge, demand charge, VAT, and the total bill amount.
5. Due date and disconnection date if the amount owed is not paid.

[4] While we do not have the information about the nationwide average price in 2017, the average electricity price for all residential customers in Bangladesh in September 2019 is 5.34 Tk based on information at https://www.globalpetrolprices.com/Bangladesh/electricity_prices/. Between August 2017 (our last survey period) and September 2019, there was only one national price hike in December 2017, which was an average 5% increase in electricity tariffs. Based on this, we can infer that the average price in August 2017 is approximately 5.09 Tk.

Table 2
Price slab system for residential electricity consumption.

Tariff rates in sample period		Change in marginal price
Consumption steps	Tk. per unit	%
Lifeline: 00–50	3.33	–
1st step: 00–75	3.80	14.11%
2nd step: 76–200	5.14	35.26%
3rd step: 201–300	5.36	4.28%
4th step: 301–400	5.63	5.04%
5th step: 401–600	8.70	54.53%
6th step: 601+	9.98	14.71%

Notes: Table above illustrates the increasing price slab system used to price residential electricity consumption in Bangladesh. The electricity units are measured in kilowatt-hour (kWh). There are seven successive consumption steps. The lowest consumption step – *Lifeline* step – concerns households with consumption of 50 units or less. When electricity consumption exceeds 50 units, the electricity bill is calculated from the *1st step*, where the first 75 units are charged at 3.8 Tk per unit. Subsequent steps are priced at a higher marginal price. There is a non-linear increase in marginal price across the consumption steps as reported in the final column. The largest surge in marginal price takes place between consumption steps 4 and 5 (54.53%), followed by the upsurge between consumption steps 1 and 2 (35.26%). There is minimal variation in marginal price for consumption steps 3 and 4.

The final electricity bill, B_{it}, paid by household i in round t for their electricity consumption is given as:

$$B_{it} = Raw\ bill_{it} + VAT_{it} + Demand\ charge_t \tag{1}$$

$$Raw\ bill_{it} = \sum_k^K p_{t,k} q_{it,k} \tag{2}$$

The raw bill in (2) is calculated by multiplying the units consumed at a certain step k with the marginal price at step k and aggregating the product across relevant consumption steps.[5] Therefore, $p_{t,\ k}$ is the price charged in round t for consumption step k and represents the marginal price for units consumed at a certain consumption step k. The units consumed by household i at step k for round t is given by $q_{it,\ k}$. The second component of the final electricity bill is the VAT charges paid by household i in round t and is given by,

$$VAT_{it} = v_t * Raw\ bill_{it} \tag{3}$$

where v_t is the VAT rate in round t. Because the raw bill is multiplied by the VAT rate directly, the post-VAT tariffs are equal to the pre-VAT tariffs multiplied by $(1 + v_t)$. The third component of the final electricity bill is a fixed demand charge of 25 Tk paid by household i in round t.

$$Demandcharge_t = 25\ Tk.per\ household \tag{4}$$

The household electricity demand in round t, q_{it}, is the aggregate of the household's electricity consumption at various consumption steps $q_{it,\ k}$,

$$q_{it} = \sum_k^K q_{it,k} \tag{5}$$

The average price charged to household i in round t for current electricity usage is denoted as $\overline{p}_{it}$ and can be calculated as below,

$$\overline{p}_{it} = \frac{B_{it}}{q_{it}} = \frac{Rawbill_{it} + VAT_{it} + Demand\ charge_t}{q_{it}} = \frac{\left[\sum_k^K p_{t,k} q_{it,k} \cdot (1 + v_t)\right] + 25}{\sum_k^K q_{it,k}} \tag{6}$$

Due to the structure of the price slab system, $\overline{p}_{it}$ is unique to the level of units consumed by a household and is valuable to study how price-elasticities differ across households with different consumption levels.[6] It is important to note that the majority of households face more than one marginal price due to the non-linear pricing structure.

Table 3
Comparison of bill structure for two consumption levels.

	Household 1	Household 2
Consumption (kWh)	200	300
Related consumption steps (k)	1, 2	1, 2,3
Marginal prices	3.80 Tk/kWh 5.14 Tk/kWh	3.80 Tk/kWh 5.14 Tk/kWh 5.36 Tk/kWh
Raw electricity bill	927.50 Tk	1463.50 Tk
Demand charges	25.00 Tk	25.00 Tk
VAT charges	139.13 Tk	219.53 Tk
Final electricity bill	1091.63 Tk	1708.03 Tk
Average price	5.46 Tk/kWh	5.69 Tk/kWh

Notes: This table shows how electricity bill components and price variables vary across two households with different consumption levels. Household 1 has two marginal prices whereas Household 2 has three marginal prices. The VAT rate is assumed to be 15%. The demand charge is fixed at 25 Tk per month for both the households regardless of their consumption. An important observation here is that households with same level of consumption will have the same raw electricity bill, final electricity bill and average price. Consequently, average price is unique to household consumption level.

To illustrate how the electricity bill structure and price variables vary across households with different consumption levels using an example; let us consider a VAT rate of 15%, Household 1 that consumes 200 units, and Household 2 that consumes 300 units. Table 3 shows how marginal prices and average prices differ across different consumption levels.

Household 1 faces two marginal prices whereas Household 2 faces three marginal prices as seen in Table 3. Therefore, the number of marginal prices that concern household electricity consumption increases with the level of electricity consumption. As expected, the average price for Household 1 is lower than Household 2. Table 3 also demonstrates that average price is unique to the level of units consumed by a household.

3.4. Marginal versus average price

Given that the minimum monthly household electricity consumption is 110 units (kWh) in our sample, all households in the data are exposed to multiple marginal prices. To the best of our knowledge, however, there is no study that specifically tested residential customers in Bangladesh about their knowledge of the price slab system and marginal prices. The price slab system was first introduced in 2007 and subsequently refined in 2012 to have the current step structure. There was widespread news about how the marginal prices were raised in September 2015 (two years before our sample period), but it is unclear if consumers respond to marginal prices for electricity consumption.

In accordance with standard economic theory, well-informed households facing numerous prices respond to marginal prices instead of average prices when making consumption decisions (Shin, 1985). However, Shin (1985) and Ito (2014) show that consumers actually respond to average prices, rather than marginal prices. Hung and Huang (2015) argue that households do not pay attention to marginal prices in the price slab system even though it is common knowledge that the marginal price increases as they use more electricity. As a result, the literature commonly focuses on average prices when estimating price elasticities of electricity demand (Hung and Huang, 2015).

Following the findings from the energy literature, we estimate price elasticities using average prices. An important caveat that we emphasize is that regardless of whether the customers are aware of the exact marginal prices or not, we are still able to estimate the price elasticity of

[5] The raw bill is obtained after deducting the VAT and demand charges from the final bill that a household pays for the electricity units consumed.

[6] Two households with different consumption levels, have different average prices whereas households with the same level of consumption will have the same raw bill, final electricity bill and average price. Therefore, $\overline{p}_{it}$ is unique to the level of consumption.

demand by running a regression of electricity consumption quantity on the average price of electricity they face because average prices vary across households as a result of the price slab system.

3.5. Demand equation

We employ a household and time fixed-effects (FE) regression strategy to estimate average residential electricity demand to control for unobserved heterogeneity and omitted variable bias due to time invariant household specific influences. Eq. (7) below gives the fixed effects specification.

$$ln\, q_{it} = \alpha_i + \alpha_t + \beta ln\overline{p}_{it} + \epsilon_{it} \tag{7}$$

The outcome variable q_{it} is the total units of electricity (kWh) consumed by household i in survey round t. The main independent variable $\overline{p}_{it}$ is the average price charged to household i in round t for current electricity usage. Following the literature (e.g., Ito, 2014), we choose average price as the main explanatory variable because we expect households to make consumption decisions based on average price derived from the final electricity bill. We estimate the specification in log-log form, so the coefficient β provides the average price elasticity of residential electricity consumption. The term α_i captures unobserved, time-constant household specific factors that contribute to electricity consumption. These factors may include the efficiency of electricity usage, types of electrical appliances used, household size, and household income that typically do not vary within our short sample period (April 2017 to August 2017). The survey-round fixed effect denoted as α_t captures time-varying unobserved influences or patterns in electricity consumption that are specific to each round of survey. These time-varying unobserved influences common to all households in a specific round may include factors, such as prices of natural gas, prices of petroleum, and seasonal patterns which typically do not vary across households during our sample period. Because we focus on two rounds of survey data, we include a single dummy variable for round 2 to control for unobserved factors common to all households in round 2 (the omitted category controls for unobserved factors common to all households in round 3). The error term ϵ_{it} captures all other time-varying household specific unobserved factors.

There are two important remarks about the demand Eq. (7). First, past studies, such as Filippini and Pachauri (2004), Yoo et al. (2007), and Sa'ad (2009) explicitly include additional explanatory variables such as prices of other energy types, weather conditions, household size, and household income in their demand equation specification to address potential omitted variable bias that may arise due to the correlation between omitted variables and average price. Since these factors either do not vary over time within the same household during our sample period (e.g., household size and household income) or do not vary across households at the same time (e.g., prices of other energy types), the inclusion of household and time fixed effects in Eq. (7) remove the bias that may arise from the omission of any other these factors. Our fixed effects approach to address omitted variable bias is consistent with Blázquez et al. (2013) and Hung and Huang's (2015). Second, if the inclusion of the household and time fixed effects can ensure the identification condition $E(\epsilon_{it}|\overline{p}_{it}, \alpha_i, \alpha_t) = 0$ holds, then the demand Eq. (7) will yield an unbiased estimate of the own price elasticity of electricity demand β. The estimated own price elasticity of electricity demand indicates the extent to which households are willing to substitute away from electricity, holding all prices of substitutes and other influences constant. When households face higher average prices of electricity, they will reduce their demand for electricity by substituting towards alternative energy sources. The more willing and able is a household in switching to alternative energy sources, the more price elastic is the household's demand for electricity. For example, households with low consumption levels are likely to be households with low income levels. As the average prices of electricity increase for these households, they have to reduce their electricity consumption significantly in order to maintain their consumption of other necessities, such as food. Given their low incomes, these households may also be more willing to incur inconvenience by restricting their electricity use or switching to traditional biomass fuels that create more in-door air pollution. Therefore, we expect price elasticity to differ by consumption level.

3.6. Addressing endogeneity issue using instrumental variable

Although the inclusion of household and time fixed effects in Eq. (7) can address a range of problems due to omitted variables and selection bias, the average price $\overline{p}_{it}$ in Eq. (7) varies according to electricity consumption as shown in Eq. (6). As a result, the key explanatory variable $ln\,\overline{p}_{it}$ is endogenous and the price elasticity estimate obtained via a simple household fixed effect estimator will still suffer from endogeneity bias. In other words, the identification condition $E(\epsilon_{it}|\overline{p}_{it}, \alpha_i, \alpha_t) = 0$ does not. To address this concern of endogeneity, we exploit the national VAT shock that occurred during the sample period to construct an instrumental variable $ln\, z_{it}$, which influences $ln\,\overline{p}_{it}$ but is uncorrelated with the error term ϵ_{it}.[7]

The instrument for average price $\overline{p}_{it}$, which we term as simulated average price, z_{it}, is constructed as follows:

$$z_{it} \equiv \frac{\left[\sum_k^K p_{t,k} q_{it-1,k} * (1 + v_t)\right] + 25}{\sum_k^K q_{it-1,k}} \tag{8}$$

The simulation is made by replacing the units consumed by household i at step k in round t, $q_{it,\,k}$, with the units consumed by household i at step k in round $t-1$, $q_{it-1,\,k}$. The instrument z_{it} is constructed using the consumption level in the previous survey round and current prices.

For an instrument to be valid, it needs to fulfil the relevance condition, and satisfy the exclusion criteria. The instrument z_{it} is likely to meet the relevance condition because lagged consumption and current consumption tend to be correlated for the same household while marginal prices ($p_{t,\,k}$) do not vary across rounds. How z_{it} is related to the actual average price $\overline{p}_{it}$ is also an empirical question and we discuss this relationship further when we report the first-stage results. The instrument z_{it} is also likely to be satisfy the exclusion restriction for the following reasons. First, because the VAT rate, v_t, is exogenously set by the government and the VAT shock occurred within the sample period, the lagged electricity consumption is independent of the change in VAT. This is especially the case as the regression also includes the time fixed effect (α_t) which controls for prices of other energy sources in the same period and any seasonal effects. Secondly, because we use lagged values of household electricity consumption to simulate the new average price while including household fixed effects (α_i) in the regression, the IV provides the counterfactual average prices that households would have faced when the new VAT came into effect had they not changed their consumption. This strategy is similar to Hung and Huang's (2015) approach that exploits predetermined rate structures. Combining the exogenous nature of the change in VAT rate, household fixed effects, time fixed effects, and the counterfactual nature of the simulated average price, our IV is likely to be independent of the unobserved influences of current electricity consumption that the condition $E(\epsilon_{it}|z_{it}, \alpha_i, \alpha_t) = 0$ holds.

4. Results and discussion

4.1. First stage results

Table 4 reports the first stage results for the FE-IV regression. The relationship between $ln\,\overline{p}_{it}$ and $ln\, z_{it}$ is negative. A 10% increase in

[7] A proposed instrument is likely to be valid if it fulfils the relevance condition [$Cov(\overline{p}_{it}, z_{it}) \neq 0$] and exclusion criteria [$E(\epsilon_{it}|z_{it}, \alpha_i, \alpha_t) = 0$].

Table 4
First stage regression for FE-IV.

First stage regression	
	Log kWh
Log adjusted price	−0.342 (0.040)
Constant	2.274 (0.070)
F-stat	73.9 [0.000]
Round FE	Yes
Observations	4492

Notes: The dependent variable is the logarithm of average price charged to household *i* in round *t* for current electricity usage. The instrumental variable is the logarithm of average price charged to household *i* in round *t* based on consumption in the previous round (round $t-1$) and current prices (round *t*). F-stat and the corresponding *p*-value are reported for the F-test of excluded instrumental variable. *Round FE* represents the survey-round fixed effect that controls for a trend in log average price over two survey rounds, rounds 2 and 3. Robust standard errors clustered by households are reported in parentheses. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

Table 5
Estimated average price elasticity from POLS, FE and FE-IV.

	POLS	RE	FE	FE-IV
	(1) Log kWh	(2) Log kWh	(3) Log kWh	(4) Log kWh
Log average price	0.050 (0.069)	−0.340 (0.061)	−0.403 (0.066)	−0.574 (0.083)
Constant	5.679 (0.113)	6.330 (0.102)	–	–
F-stat	–	–	–	73.90 [0.000]
Round FE	Yes	Yes	Yes	Yes
Observations	4492	4492	4492	4492

Notes: The dependent variable is the logarithm of total units of electricity (kWh) consumed by household *i* in round *t*. The key explanatory variable is the logarithm of average price charged to household *i* in round *t* for current electricity usage. F-stat and the corresponding *p*-value are reported for the F-test of excluded instrumental variable. *Round FE* represents the survey-round fixed effect that captures a trend in electricity consumption over two survey rounds, rounds 2 and 3. Column (1) reports results from pooled ordinary least squares (POLS) regression. Column (2) reports results from random effect (RE) regression. Column (3) reports results from household fixed effects (FE) regression framework. Column (4) gives the estimates from fixed effects instrumental variable (FE-IV) regression. Robust standard errors clustered by households are reported in parentheses. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

simulated average price z_{it} corresponds to a decrease of 3.42% in average price $\overline{p}_{it}$. The partial F-statistic of this negative relationship is 73.82 and it is statistically significant at the 1% level. Since the test statistic is greater than 10, we can reject the null hypothesis of a weak instrument according to the weak instrument test (Staiger and Stock, 1997). The instrument is thus relevant and strong.

To understand this negative relationship, we first discuss how changes in consumption and VAT rate affect the simulated average price, z_{it}, within households. The independent variable $\overline{p}_{it}$ reflects the average price paid for consumption at time period *t* given marginal prices and VAT rate in round *t*. The instrument z_{it}, on the other hand, reflects the average price that a household pays for consumption in round $t-1$ given (current) marginal prices and VAT rate in round *t*. Since z_{it} is made up of the consumption level in the previous survey round and current prices, when VAT rate increases, the price component in z_{it} increases but the consumption stays constant. This causes a mechanical and exogenous increase in z_{it}, the simulated average price. As the rise in VAT between *t* and $t-1$ is as quite large with an increase in VAT rate from 5% to 15%, households were likely to considerably reduce their electricity consumption levels between *t* and $t-1$. The large reduction in consumption levels would then bring them from a higher consumption step in the price slab structure to a lower consumption step in the price slab structure. Based on Table 3, we can infer that when households reduce electricity usage and fall into a lower consumption step, the average price falls.[8] This is especially true for households that are currently in the top two ($k = 5, 6$) or bottom two ($k = 1$, 2) consumption steps. The VAT increase actually leads to a decrease in actual average price paid by the household by moving the household to a lower consumption step with an overall lower average price. Thus, the relationship between simulated average price z_{it} and average price $\overline{p}_{it}$ is negative.

4.2. Average price elasticity

Table 5 provides results from four different estimation methods: pooled ordinary least squares (POLS) regression, random effects (RE) regression, fixed effects (FE) regression, and fixed effects instrumental variable (FE-IV) regression.

Column (1) of Table 5 reports the average price elasticity estimate obtained using POLS regression. The POLS estimate is positive which indicates a positive relationship between price and electricity demand and contradicts the standard expectation. Moreover, the POLS estimate is small in magnitude and not statistically significant at the 5% level.

Column (2) of Table 5 provides the results from RE estimation, while Column (3) of Table 5 provides the results from FE estimation. The RE estimate of price elasticity is negative and therefore has the expected sign. Similarly, the FE estimate is negative and statistically significant at the 1% level. However, the RE estimate is lower in magnitude as compared to the estimates produced by the FE estimation. This disparity could be due to unobserved household characteristics being correlated with the average price of electricity in the RE estimation. Both RE and FE estimates, however, are likely to be inconsistent and biased because of the simultaneity between current consumption and average price.

Finally, column (4) gives the results from the FE-IV estimation. The average price elasticity estimate given by the FE-IV regression method is negative and statistically significant at the 0.1% level of significance. The FE-IV estimate shows that a 10% increase in average price results in a 5.77% decrease in residential electricity consumption on average. This estimate shows that residential electricity demand is on average inelastic to price changes.

4.3. Price elasticities across different baseline consumption levels

4.3.1. Examining heterogeneity of price elasticities

The standard FE-IV estimation summarizes average price elasticity of electricity for households in the dataset. However, this standard estimation only provides a partial view of the responsiveness of residential electricity consumption to prices. Studying the demand elasticities at different consumption levels is likely to give a clearer picture of this relationship. It also facilitates a richer understanding of the dataset since it allows the study of how households in different consumption categories react to price shocks. A better understanding of how households respond to price changes will provide valuable information to inform related policy decisions and welfare analysis.

To study the heterogeneity in price elasticities, we categorize households into different groups based on baseline consumption levels. We consider two scenarios to examine this heterogeneous consumption pattern.

[8] This is a reliable inference since the VAT shock resulted in a consistent increase in tariffs for all consumption steps.

For the first scenario, we compute the median electricity consumption from the baseline survey data, and classify households with electricity consumption below the median level as 'Low consumption households' and 'High consumption households' if otherwise. Median electricity consumption at the baseline level is 287 units (kWh).

For the second scenario, we categorize households into quartiles based on their baseline consumption. The first quartile represents the lowest consumption group. The second and third quartiles represent moderate consumers whereas the final quartile characterizes the high consumption households.

We then run FE-IV estimation on each category to inspect the heterogeneity in consumption and price elasticities of demand. Upon estimating average price elasticities for each of the categories, we conduct post-estimation analysis to check if the price elasticity estimates are significantly different across groups.

4.3.2. Scenario 1: two consumption groups

Table 6 reports the average price elasticities for two consumption groups categorized as per the procedure described in the above Section.

Both the FE-IV estimates are negative and statistically significant at the 1% level. Table 6 also reports the F-statistics for the weak instrument test. Both the F-statistics are greater than 10. We once again reject the null for weak instrument test and conclude that the instrument is strong in this context. As expected, households in the bottom 50% – low consumption category – are more price responsive as compared to the high consumption households. Column (1) in Table 6 indicates that on average, for a 10% increase in average price, residential electricity consumption decreases by 6.96% among low consumption households. On the other hand, high consumption households only experience an average drop of 5.64% in electricity consumption with a 10% surge in average price. However, the price elasticities of the two consumption categories only differ by 0.132. Fig. 1 shows that the 90% confidence intervals of these two estimates do not overlap. Therefore, we cannot reject the null hypothesis of coefficient equality at the 10% level of significance.

4.3.3. Scenario 2: four consumption groups (quartiles)

In the second scenario, we group households into consumption quartiles as outlined in Section 4. Table 7 reports the price elasticity estimates by quartile.

The estimated price elasticity for quartile 1 is negative and statistically significant at the 1% level. Similarly, estimates for quartile 2 to quartile 4 are negative and statistically significant at the 1% level. As anticipated, the lowest consumption quartile has the highest price elasticity estimate of −1.105. We expect households in the first quartile to decrease their electricity consumption by 11.05% for a 10% increase in average price. Quartiles 2 and 3 represent the moderate consumption households. Results show that households in quartile 3 are less price elastic compared to households in quartile 2. This pattern could be due to an increase in wealth across the quartiles. Consequently, we would expect households in quartile 4, the highest consumption group to be the least responsive to price changes. However, as reported in Table 7, households in quartile 4 are – surprisingly – the second most elastic group of households with price elasticity of −0.924.

The households in the first quartile respond more sensitively to the price change because households with low consumption levels are also likely to be households with low income levels. As the average prices of electricity increase for these households, they have to reduce their electricity consumption significantly in order to maintain their consumption of other necessities, such as food. Given their low incomes, these households may also be more willing to incur inconvenience by restricting their electricity use or switching to traditional biomass

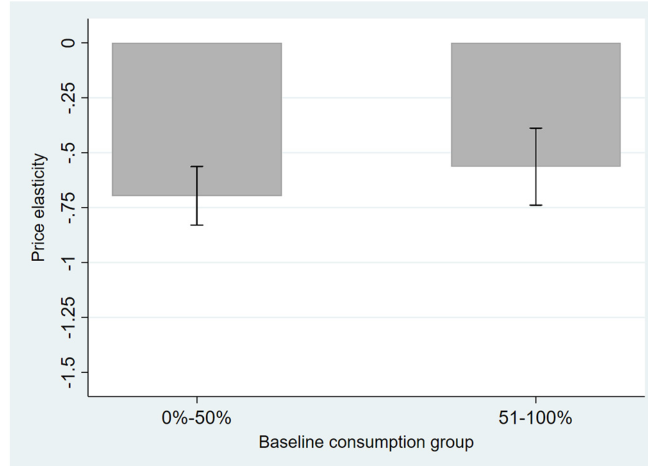

Fig. 1. Price elasticities of demand for two consumption categories. *Notes*: Figure shows price elasticity estimates plotted with 90% confidence intervals. There is an overlap between the error bands. Therefore, we do not reject the null hypothesis of coefficient equality at the 10% level of significance.

Table 6
Estimated price elasticities for two consumption groups from FE-IV.

FE - IV Scenario 1	Bottom 50% Log kWh	Top 50% Log kWh
Log average price	−0.695 (0.104)	−0.562 (0.136)
F-stat	37.79 [0.000]	36.94 [0.000]
Round FE	Yes	Yes
Observations	2274	2218

Notes: The dependent variable is the logarithm of total units of electricity (kWh) consumed by household *i* in round *t*. The key explanatory variable is the logarithm of average price charged to household *i* in round *t* for current electricity usage. F-stat and the corresponding *p*-value are reported for the F-test of excluded instrumental variable. *Round FE* represents the survey-round fixed effect that captures a trend in electricity consumption over two survey rounds, rounds 2 and 3. Based on baseline consumption, households are divided into two consumption groups: the *bottom 50%* consumption group consists of households with electricity consumption below the median level of 287 units (kWh), the *top 50%* consumption group includes households that consume more than 287 units (kWh) per month. Robust standard errors clustered by households are reported in parentheses. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

Table 7
Estimated price elasticities for four consumption groups (quartiles) from FE-IV.

FE - IV Scenario 2	Quartile 1 Log kWh	Quartile 2 Log kWh	Quartile 3 Log kWh	Quartile 4 Log kWh
Log average price	−1.102 (0.354)	−0.554 (0.080)	−0.391 (0.116)	−0.922 (0.235)
F-stat	10.46 [0.001]	38.03 [0.000]	25.40 [0.000]	12.77 [0.000]
Round FE	Yes	Yes	Yes	Yes
Observations	1126	1148	1100	1118

Notes: The dependent variable is the logarithm of total units of electricity (kWh) consumed by household *i* in round *t*. The key explanatory variable is the logarithm of average price charged to household *i* in round *t* for current electricity usage. F-stat and the corresponding *p*-value are reported for the F-test of excluded instrumental variable. *Round FE* represents the survey-round fixed effect that captures a trend in electricity consumption over two survey rounds, rounds 2 and 3. Based on baseline consumption, households are divided into quartiles: quartile 1 has consumption less than or equal to 233 kWh; quartile 2 has consumption more than 233 kWh and less than or equal to 287 kWh; quartile 3 has consumption more than 287 kWh and less than or equal to 381 kWh; quartile 4 has consumption greater than 381 kWh. Robust standard errors clustered by households are reported in parentheses. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

fuels that create more in-door air pollution, holding prices of substitutes constant.

The households in the fourth quartile are likely to be relatively rich. These households tend to use a larger range of electronic appliances and may have these appliances turned on even when they are not in use. When average prices of electricity increase for them, they have more room to decrease their usage of electricity (and waste). On the other hand, households in the second and third quartiles are relatively less price responsive because these households are likely to: (i) have less room to reduce wastage than households in the top quartile; and (ii) be less constrained in their incomes and less willing to switch to alternative dirty energy sources than households in the bottom quartile. The differential relative magnitudes of estimates are broadly consistent with other past studies for India, such as Tiwari (2000) and Chindarkar and Goyal (2019).

Fig. 2 illustrates the pattern of heterogeneity in price elasticities across different quartiles. The 90% confidence intervals of estimates show that the price elasticity estimates are different from one another. We report in the figure note the *p*-values obtained from the formal tests of differences using *Z*-test statistic (Clogg et al., 1995):

$$z = \frac{\widehat{\beta}_1 - \widehat{\beta}_2}{\sqrt{\left(se\left(\widehat{\beta}_1\right)^2 - se\left(\widehat{\beta}_2\right)^2 \right)}},$$

where β_1 and β_2 are two parameters from different regressions, which we want to test for $H_0 : \beta_1 = \beta_2$. We find that the difference in the estimates for the first and third quartiles is statistically significant (*p*-value of 0.056). The estimates for third and fourth quartiles are also significantly different from each other with *p*-value less than 0.05. The differences between first and second, and between the second and fourth quartile estimates are marginally significant with *p*-values around 0.13–0.14. These test results are in line with our graphical illustration. There is, however, a slight overlap between quartiles 2 and 3. This could potentially be due to the minimal change in marginal prices for moderate consumption steps ($k = 3,4$), as well as the lack of substantial variation in electricity consumption between the two quartiles. Nevertheless, we find the significant evidence of heterogeneity in price elasticities at the conventional levels of significance.

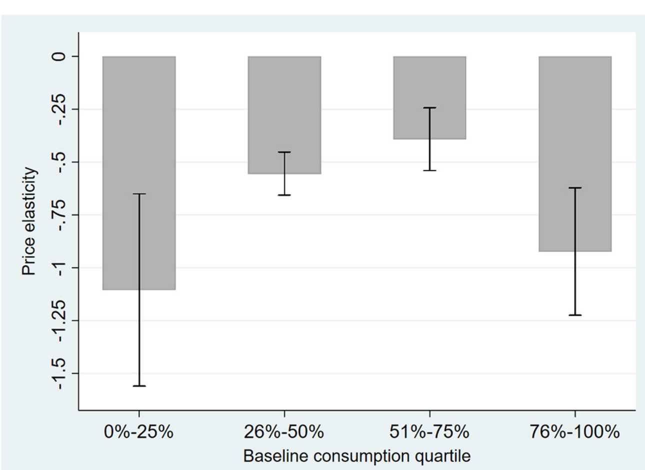

Fig. 2. Price elasticities of demand by consumption quartile. *Notes*: Figure above illustrates price elasticity estimates for each quartile plotted with 90% confidence interval. At the 10% level, price elasticity estimates are significantly different from one another. There is a slight overlap in the error bands for quartile 2 and 3. The *p*-values from Z-test for the difference in the demand elasticity between two quartiles are as follows: 0.131 (quartiles 1 and 2), 0.056 (quartiles 1 and 3), 0.672 (quartiles 1 and 4), 0.247 (quartiles 2 and 3), 0.138 (quartiles 2 and 4), 0.043 (quartiles 3 and 4).

5. Robustness checks

We perform some additional analyses to test the robustness of the estimates to potential misspecification. First, we introduce an alternative instrumental variable to examine whether the original IV – the simulated price – does not satisfy the exogeneity condition for a valid instrument. Second, we include a set of suburb and survey round interaction dummy variables to control for potential unobserved city or suburb specific characteristics that change over time.

Recall that the proposed IV, the simulated price, was constructed using the one-period lagged consumption of each household together with the current tariffs. If the error term in the demand equation is serially correlated even after controlling for household and time fixed effects, our IV that utilizes the lagged consumption could potentially violate the exogeneity condition $E(\epsilon_{it}|z_{it}, \alpha_i, \alpha_t) = 0$. To address this potential endogeneity concern, we construct an alternative IV that combines the lagged electricity consumption of other households in the same quartile as the surveyed household and the marginal prices from the electricity price slab system of neighboring Myanmar to test the consistency of our results. This approach allows us to rule out two possible concerns of bias. First, as we use the lagged average usage of households in the same quartile at round *t* to replace household *i*'s lagged usage $q_{it-1,\ k}$ in the construction of the IV, these unrelated households' past consumption is unlikely to be correlated with the errors, ϵ_{it}, in household *i*'s current demand (after controlling for household and time fixed effects). Yet, lagged average usage of households in the same quartile at round *t* is likely to be relevant as these households face similar current prices given that their consumption in round *t* are similar to household *i*. Second, by using the marginal prices from Myanmar, a low-income neighbor country of Bangladesh with similar average prices of electricity, we further remove any potential correlation between the average price and the error term ϵ_{it}.

Specifically, this alternative IV for household *i* is constructed in the following order:

i. We check at which quartile household *i* belongs to in round *t* (round 2 or round 3).
ii. We calculate the average electricity consumption in round $t-1$ of all households in the same quartile, excluding household *i*. (Note that some of those households that are in the same quartile with *i* in round t may not be in the same quartile in round $t-1$. Call this average consumption $avgqq_{it}$.
iii. We apply Myanmar's electricity price slabs to the usage $avgqq_{it}$ to calculate the new simulated price, $\widetilde{z}_{it}$, say the simulated quartile price, and then take its natural logarithm.

Having this additional IV, $\widetilde{z}_{it}$, provides an additional advantage, as it allows us to test the joint significance of both instruments using the overidentification test. Passing this overidentification test will indicate that the threat of serial correlation is not severe. However, because the alternative IV becomes a weak IV when we estimate heterogeneous price elasticity by consumption group, we only use the full sample to perform the robustness tests.

Next, to account for potential bias due to time-varying city-specific factors and differential weather changes across areas over time that affect electricity demand, we include a set of suburb and survey round interaction dummy variables as additional control variables. Our main estimates are robust to the potential bias arisen from misspecification and omitted variables, if including these additional control variables alone or jointly with the use of the alternative IV.

Table 8 reports the estimation results based on the FE-IV estimation for the sample of all households. In column (1), we present the estimates using the alternative IV. The estimated demand elasticity is −0.577, which is almost identical to the original estimate −0.574 in Table 8. This alternative IV also strongly predicts the average price given the partial *F*-statistic of 26.35. In column (2), we include both

Table 8
Robustness checks.

	(1)	(2)	(3)	(4)	(5)
	Log kWh	Log kWh	Log kWh	Log kWh	Log kWh
Log average price	−0.577 (0.183)	−0.574 (0.083)	−0.607 (0.083)	−0.638 (0.184)	−0.606 (0.083)
F-stat	26.35 [0.000]	38.09 [0.000]	74.81 [0.000]	26.82 [0.000]	38.18 [0.000]
Overidentification test (*p*-value)	–	0.987	–	–	0.858
Original IV	No	Yes	Yes	No	Yes
Alternative IV	Yes	Yes	No	Yes	Yes
Round FE	Yes	Yes	No	No	No
Suburb-round FE	No	No	Yes	Yes	Yes
Observations	4492	4492	4492	4492	4492

Notes: The dependent variable is the logarithm of total units of electricity (kWh) consumed by household *i* in round *t*. The key explanatory variable is the logarithm of average price charged to household *i* in round *t* for current electricity usage. The *original IV* is the simulated price that was constructed using one-period lagged (round $t-1$) consumption and current (round *t*) tariffs [Refer to Eq. (8)]. The *alternative IV* is the simulated quartile price described in Section 5. F-stat and the corresponding *p*-value are reported for the F-test of excluded instrumental variable(s). The *p*-value corresponding to Hansen's J statistic is provided for the Sargan-Hansen test of overidentifying restrictions. *Round FE* represents the survey-round fixed effect that captures a trend in electricity consumption over two survey rounds, rounds 2 and 3. *Suburb-round FE* represents suburb and round interaction dummy variables that control for any city or suburb specific characteristics that change over time. Robust standard errors clustered at the household level are reported in parentheses. * $p < 0.10$. ** $p < 0.05$. *** $p < 0.01$.

the original IV and the alternative IV at the same time. The elasticity estimate is again similar to the original estimate. The overidentification test indicates that the two IVs are jointly exogeneous.

In columns (3)–(5) of Table 8, we further include the suburb and survey-round interaction dummy variables as additional control variables and employ different sets of IVs. Column (3) uses the original IV, column (4) uses the alternative IV, and the last column includes both IVs. The estimated demand elasticities are all statistically significant and they range between −0.606 and −0.638, which are close to our original estimate.[9] The overidentification test result in column (5) again shows that our IVs are jointly exogenous.

Overall, our main estimates based on the original simulated price instrument and the specification with round fixed effects are robust to potential endogeneity, misspecification, and omitted variable bias.

6. Policy simulations

The Bangladeshi government has taken steps to subsidize electricity – by pricing electricity lower than the cost of production – in the past few years. The pricing of electricity in Bangladesh follows two steps. First, the Bangladesh Power Development Board (BPDB) fixes the bulk tariff rate for electricity distribution companies. Second, retail tariff rates imposed on final consumers are fixed. However, the cost of electricity production in Bangladesh has doubled in seven years as of 2015 (Islam and Khan, 2017). Similar to many other developing countries, where electricity is typically viewed as a right (Burgess et al., 2019), BPDB and the electricity distribution companies incur significant financial losses over the years (Islam and Khan, 2017).

The Bangladeshi government has implemented a range of reforms to minimize financial losses from distribution inefficiency, power theft, supply mismanagement issues, and subsidies. Although progresses have been made in several fronts, subsidies remain a significant financial concern (Zhang, 2018). These subsidies inflate demand, especially among the rich, and increase the fiscal burden on the government limiting their ability to expand and improve supply side management. To improve the financial situation of BPDB, policymakers aim to narrow the gap between the selling prices and supply costs (Mujeri et al., 2014). There have been several attempts to adjust the number of steps and the marginal prices since 2007. However, the weighted average retail tariff is still well below the cost of production (Islam and Khan, 2017). Therefore, it is worthwhile to consider policy scenarios that involve alternative tariffs.

Although increasing electricity tariffs may improve the financial situation of related governmental bodies and electricity distribution companies, increasing tariffs for all consumption levels worsens inequality in electricity consumption between the poor and rich by making electricity less affordable for the poor. Facing the dilemma between improving financial situation and reducing inequality in electricity consumption, the Bangladeshi government relies on the price slab system by charging high-end consumers higher marginal prices (tariffs) and low-end consumer lower marginal prices. It is however unclear whether the government can effectively improve financial situation while addressing the problem of inequality in electricity consumption. Our findings indicate that whether they are able to simultaneously achieve these policy challenges depends on the extent to which they are able to maintain low electricity tariffs for low consumption households while raising tariffs for moderate to high consumption households to generate more revenue.

We compare several policy scenarios and illustrate their impacts on overall demand and revenue using simulation exercises. We first consider an actual policy change – the national price hike – introduced in December 2017. Next, we use the increased revenue and reduction in consumption generated by the actual national price hike as the benchmark and consider alternative price changes that can reduce inequality in electricity consumption. The goal is to demonstrate how the differential price elasticities estimated can better inform the way the policymakers address the dilemma between improving financial situation and reducing inequality in electricity consumption.

6.1. Actual national level price hike

For the first policy scenario, we consider the actual national-level price hike that took place in December 2017, where tariffs for all consumption steps were increased.

Table 9 outlines the changes. The rightmost column shows the rate at which electricity tariffs increase during the nationwide price hike. Tariffs for all consumption steps increase by approximately 5.1% to 7.2%. The pattern of marginal price progression across different consumption steps remains similar after the price hike. Interestingly, the changes in the marginal prices faced by the most price inelastic households (i.e., those in the second and third quartiles) are not the greatest. What this means is that there is a potential to achieve the same revenue increase and consumption reduction as the national price hike with better outcome for inequality in electricity of consumption.

Table 10 illustrates the predicted impact of the national price hike on overall electricity demand and revenues of the electricity retailer. We replicate a representative household for each quartile by computing average electricity consumption for the respective quartile. Table 10 reports information such as raw bill, final electricity bill, and the average price for the representative households before and after the policy implementation. The table also reports the change in average price – due to policy implementation – and the resulting effect on electricity consumption of the representative (average) household in each quartile.

When we calculate the change in average price, we use the following approach: Let $i = 1, 2, 3, 4$ be a representative household in the *i*th quartile. We use $q_{i,\,old}$ and $q_{i,\,new}$ to denote electricity consumption of *i* before and after the policy, respectively. Let $\overline{p}_{i,old}$ and $\overline{p}_{i,new}$ be the average

[9] Note that we could estimate the price elasticities of electricity demand by consumption group on the basis of a specification that includes the suburb and round interaction dummies and the original IV. The estimates which we do not report here are similar to those in Tables 6 and 7.

Table 9
New electricity tariffs – National price hike.

Tariff rates in sample period		Change in marginal price	New tariffs	Change in marginal price	Change in tariffs
Consumption steps	Tk. per unit	%	Tk. per unit	%	%
Lifeline: 00–50	3.33	–	3.50	–	5.11%
1st step: 00–75	3.80	14.11%	4.00	14.29%	5.26%
2nd step: 76–200	5.14	35.26%	5.45	36.25%	6.03%
3rd step: 201–300	5.36	4.28%	5.70	4.59%	6.34%
4th step: 301–400	5.63	5.04%	6.02	5.61%	6.93%
5th step: 401–600	8.70	54.53%	9.30	54.49%	6.90%
6th step: 601+	9.98	14.71%	10.70	15.05%	7.21%

Notes: This table illustrates the change in electricity tariffs following the national price hike that took place in December 2017. The electricity units are measured in kilowatt-hour (kWh). Column 1 outlines the different consumption steps in the price slab system. Electricity tariffs during the sample period – before December 2017 – is given in column 2. Column 3 shows the evolution of marginal price across different consumption steps before the national price hike. Column 4 reports the new electricity tariffs. Column 5 shows the new progression of marginal price across different consumption steps. The final column shows the percentage increase in marginal price at different consumption steps.

Table 10
Predicted impacts – national price hike.

Price elasticity	Quartile 1	Quartile 2	Quartile 3	Quartile 4
	−1.102	−0.554	−0.391	−0.922
A. Pre-policy implementation				
Consumption (kWh)	216	259	335	458
Raw bill (Tk.)	1013.26	1243.74	1660.55	2531.10
Electricity bill (Tk.)	1190.25	1455.30	1934.63	2935.77
Average price (Tk.)	5.51	5.62	5.78	6.41
GINI Index	0.1581			
B. Post-policy implementation				
Consumption (kWh)	204.21	251.12	327.52	441.08
Raw bill (Tk.)	1005.20	1272.60	1716.90	2535.30
Electricity bill (Tk.)	1180.98	1488.49	1999.44	2940.60
Average price (Tk.)	5.78	5.93	6.10	6.67
GINI Index	0.1608			
C. Predicted impact of policy implementation				
Change in consumption (kWh)	−11.79	−7.88	−7.48	−16.92
Change in raw bill (Tk.)	−8.06	28.86	56.35	4.20
Change in electricity bill (Tk.)	−9.27	33.19	64.80	4.83
% change in average price	4.95%	5.49%	5.71%	4.01%
Overall effect on demand (kWh)	−11.02			
Overall effect on revenue (Tk.)	20.34			
Overall effect on GINI Index	0.0027			

Notes: This table illustrates the overall predicted impact of the national price hike that took place in December 2017 on electricity demand, revenue of electricity suppliers, as well as, electricity consumption inequality. The 'Price elasticity' row reports the respective average price elasticities for each consumption quartile. Panel A outlines the initial conditions, panel B reports simulated results after the price hike, and panel C reports the changes as a result of the price hike. Each column reports the average figure for the respective quartile computed to replicate a representative household for that quartile, with the exception of GINI index and overall effects where the figures are for an average household in the sample.

prices for *i*, which correspond to $q_{i,\ old}$ and $q_{i,\ new}$, respectively. We calculate a new equilibrium duple $(q_{i,new}, \overline{p}_{i,new})$ that satisfies $\frac{(q_{i,new} - q_{i,old})}{(\overline{p}_{i,new} - \overline{p}_{i,old})}$ being equal to *i*'s price elasticity. We also use the following GINI Index to measure the inequality in electricity consumption:

$$G = \frac{\sum_{i=1}^{4} \sum_{j=1}^{4} |q_i - q_j|}{4 \sum_{i=1}^{4} q_i}$$

Our analysis shows that the average price increases by 4.95% for quartile 1, 5.49% for quartile 2, 6.10% for quartile 3, and 6.67% for quartile 4 as a result of the national-level price hike. Consequently, households in all quartiles reduce their electricity consumption. The overall effect on demand is negative (−11.02 units on average). We also measure the overall effect on revenue of the electricity retailer by computing the change in raw bill amount paid by households. As seen in Table 10, the national price hike increases overall revenue by 20.35 Taka on average.

This simulation exercise demonstrates that the national price hike reduces overall electricity demand and increases revenue of the retailer. It appears that the goal of the policymakers is to simultaneously address the problems with demand-supply mismatch and financial situation. However, increasing tariffs for lower consumption steps worsens inequality in electricity consumption as low consumption households reduce their consumption considerably. As seen in Table 10, inequality in electricity consumption worsens (GINI index increases from 0.1581 to 0.1608) with this policy decision as it makes electricity expensive for low consumption households, forcing them to reduce their already low electricity consumption. Lastly, as the percentage changes in marginal prices faced by the least price elastic households are not the greatest, there are likely to be alternative pricings to improve inequality in electricity consumption while achieving the same revenue increase and consumption reduction as the national price hike.

6.2. Minimize inequality

The main problem with the actual national price hike introduced in December 2017 is that despite maintaining the progressive nature of the tariffs, inequality in electricity consumption exacerbates. A sensible alternative would be to improve revenue, reduce consumption, and maintain the progressive nature of the tariffs while not exacerbating inequality in electricity consumption as much as the national price hike does. We, therefore, consider two alternative policy interventions that minimize inequality in electricity consumption. The first minimizes inequality in electricity consumption while achieving the same revenue increase, consumption reduction, and maximum percentage change in marginal price as the actual national price hike. The second minimizes inequality in electricity consumption while achieving the same revenue increase and consumption reduction, but with greater maximum percentage change in marginal price, as the actual national price hike. Our goal is to show whether these two alternative scenarios can both generate lower inequality in electricity consumption.

Recall the price slab system with $p = (p_0, p_1, p_2, p_3, \ldots, p_6)'$, where p_k corresponds to the *k*th consumption step. The revenue *R* that the electricity retailer obtains is the sum of expenditure E_i that the average household at the *i*th quartile pays, i.e., $R = \sum_{i=1}^{4} E_i$, where

$$E_i = \begin{cases} (p_0 q_i)(1.15) + 25 & \text{if } q_i \le 50 \\ (p_1 q_i)(1.15) + 25 & \text{if } 50 < q_i \le 75 \\ [50p_1 + (q_i - 50)p_2](1.15) + 25 & \text{if } 75 < q_i \le 200 \\ [50p_1 + 150p_2 + (q_i - 200)p_3](1.15) + 25 & \text{if } 200 < q_i \le 300 \\ [50p_1 + 150p_2 + 100p_3 + (q_i - 300)p_4](1.15) + 25 & \text{if } 300 < q_i \le 400 \\ [50p_1 + 150p_2 + 100(p_3 + p_4) + (q_i - 400)p_5](1.15) & \text{if } 400 < q_i \le 600 \end{cases}$$

(continued on next page)

$$+ 25$$
$$[50p_1 + 150p_2 + 100(p_3 + p_4 + p_5) + (q_i - 500)p_6] \quad \text{if } q_i > 600$$
$$(1.15) + 25$$

Let $x = (x_0, x_1, x_2, x_3, \ldots, x_6)'$ be changes in the price slab system, where x_k corresponds to the percentage change in the marginal price at step k for $k = 1, \ldots, 6$. In this simulation, the goal of a social planner (or a policymaker) is to find the optimal level of price change x^* and the resulting new price slab system $p_{new} = diag(p) \cdot (1 + x^*) = (p_0(1 + x_0^*), p_1(1 + x_1^*), \ldots, p_6(1 + x_6^*))'$ that minimizes the GINI Index subject to the constraints that the new revenue level R_{new} of the electricity firm being equivalent to the revenue after the national price hike (R_{ns}), the new total consumption $\sum_{i=1}^{4} q_{i,\,new}$ being equivalent to the total consumption after the national price hike $\sum_{i=1}^{4} q_{i,\,ns}$, and the tariffs remain progressive with each price step changes within a certain range. We consider two alternative ranges: within 7.2% (i.e., $\underline{x} = -7.2\%$ and $\bar{x} = 7.2\%$) and within 10% (i.e., $\underline{x} = -10\%$ and $\bar{x} = 10\%$). We restrict the change in tariffs up to the 7.2% range to ensure that the percentage change in each marginal price is not greater than the largest change under the national price hike. While we do not observe the exact constraints of the policymaker's optimization problem, we try to mimic the constraints as closely as possible. The within 10% range is to provide the possibility for inequality in electricity consumption to fall.

We write the social planner's problem formally as follows:

$$\min_x \frac{\sum_{i=1}^{4} \sum_{j=1}^{4} \left| q_{i,new}(diag(p) \cdot (1 + x), q_{i,old}) - q_{j,new}\left(diag(p) \cdot (1 + x), q_{j,old}\right) \right|}{4 \sum_{i=1}^{4} q_{i,new}(diag(p) \cdot (1 + x), q_{i,old})}$$

$$\text{s.t.} R_{new} = R_{ns},$$

$$\sum_{i=1}^{4} q_{i,new} = \sum_{i=1}^{4} q_{i,ns},$$

$$x_{-} \le x_k \le \bar{x} \forall k.$$

6.2.1. Minimize inequality given price step changes within 7.2%

Table 11 shows the optimal levels of tariffs that minimize the inequality in electricity consumption subject to the constraints that the new revenue level is equivalent to the expected revenue after the actual national price hike, the tariffs remain progressive, and each price step changes within a range 7.2%. The results indicate that to minimize the inequality, the marginal prices at steps 4 and 5 must increase by the maximum 7.2%, the marginal prices at steps 1, 2, and 3 increase by no more than 6.45%, the marginal price at step 6 increases by 2.44%, while marginal price for those at the lifeline level remains unchanged. Thus, the increases are greatest at marginal prices faced by households with price elasticities that are relatively inelastic.

Table 12
Predicted impacts – minimize inequality with price changes within 7.2%.

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Price elasticity	−1.102	−0.554	−0.391	−0.922
A. Pre-policy implementation				
Consumption (kWh)	216	259	335	458
Raw bill (Tk.)	1013.26	1243.74	1660.55	2531.10
Electricity bill (Tk.)	1190.25	1455.30	1934.63	2935.77
Average price (Tk.)	5.51	5.62	5.78	6.41
GINI Index	0.1581			
B. Post-policy implementation				
Consumption (kWh)	204.39	251.19	327.51	440.84
Raw bill (Tk.)	1005.40	1272.39	1716.97	2535.30
Electricity bill (Tk.)	1181.21	1488.25	1999.52	2940.60
Average price (Tk.)	5.78	5.92	6.11	6.67
GINI Index	0.1605			
C. Predicted impact of policy implementation				
Change in consumption (kWh)	−11.61	−7.81	−7.49	−17.16
Change in raw bill (Tk.)	−7.86	28.65	56.42	4.20
Change in electricity bill (Tk.)	−9.04	32.95	64.88	4.83
% change in average price	4.88%	5.44%	5.72%	4.06%
Overall effect on demand (kWh)	−11.02			
Overall effect on revenue (Tk.)	20.35			
Overall effect on GINI Index	0.0024			

Notes: This table illustrates the overall predicted impact of the alternative hypothetical price reform discussed in Table 11 on electricity demand, revenue of electricity suppliers, as well as, electricity consumption inequality. The 'Price elasticity' row reports the respective average price elasticities for each consumption quartile. Panel A outlines the initial conditions, panel B reports simulated results after the price hike, and panel C reports the changes as a result of the price hike. Each column reports the average figure for the respective quartile computed to replicate a representative household for that quartile, with the exception of GINI index and overall effects where the figures are for an average household in the sample.

Table 12 shows the predicted consequences of the price changes in terms of simulated levels of electricity consumption, electricity bill, average price, and GINI Index when the maximum change in each price step is within 7.2%. For ease of comparison, we show the pre-policy levels, the post-policy levels, as well as the changes. As expected, given that average prices increase for consumers in all quartiles, electricity consumption decreases for consumers in all quartiles. The percentage increases in average prices are relatively higher for price inelastic consumer groups (i.e., quartile 3 and quartile 2), although the percentage increase in average price for the most price elastic consumer group (i.e., quartile 1) is not the lowest. The decrease in consumption is the highest for consumers in the fourth quartile and lowest for consumers in the third quartile. The price changes lead to a reduction in revenue coming from consumers in the first quartile, but increases in

Table 11
New electricity tariffs – minimize inequality with price changes within 7.2%.

Tariff rates in sample period		Change in marginal price	Policy suggestion	Change in marginal price	Change in tariffs
Consumption steps	Tk. per unit	%	Tk. per unit	%	%
Lifeline: 0–50	3.33	–	3.33	–	0.00%
1st step: 00–75	3.8	14.11%	4.01	20.42%	5.53%
2nd step: 76–200	5.14	35.26%	5.44	35.66%	5.77%
3rd step: 201–300	5.36	4.28%	5.71	4.96%	6.45%
4th step: 301–400	5.63	5.04%	6.03	5.60%	7.20%
5th step: 401–600	8.7	54.53%	9.33	54.73%	7.20%
6th step: 601+	9.98	14.71%	10.22	9.54%	2.44%

Notes: This table illustrates the change in electricity tariffs following an alternative hypothetical national price hike. The electricity units are measured in kilowatt-hour (kWh). Column 1 outlines the different consumption steps in the price slab system. Electricity tariffs before December 2017 is given in column 2. Column 3 shows the initial evolution of marginal price across different consumption steps. Column 4 reports the new electricity tariffs as per the alternative hypothetical price reform. Column 5 shows the new progression of marginal price across different consumption steps. The final column shows the percentage increase in electricity tariffs. Bound for price change [−7.2%, 7.2%].

Table 13
New electricity tariffs – minimize inequality with price changes within 10%.

Tariff rates in sample period		Change in marginal price	Policy suggestion	Change in marginal price	Change in tariffs
Consumption steps	Tk. per unit	%	Tk. per unit	%	%
Lifeline: 0–50	3.33	–	3.33	–	0.00%
1st step: 00–75	3.8	14.11%	3.98	19.52%	4.74%
2nd step: 76–200	5.14	35.26%	5.38	35.18%	4.67%
3rd step: 201–300	5.36	4.28%	5.77	7.25%	7.65%
4th step: 301–400	5.63	5.04%	6.19	7.28%	10.00%
5th step: 401–600	8.7	54.53%	9.57	54.60%	10.00%
6th step: 601+	9.98	14.71%	10.44	9.09%	4.61%

Notes: This table illustrates the change in electricity tariffs following an alternative hypothetical national price hike. The electricity units are measured in kilowatt-hour (kWh). Column 1 outlines the different consumption steps in the price slab system. Electricity tariffs before December 2017 is given in column 2. Column 3 shows the initial evolution of marginal price across different consumption steps. Column 4 reports the new electricity tariffs as per the alternative hypothetical price reform. Column 5 shows the new progression of marginal price across different consumption steps. The final column shows the percentage increase in electricity tariffs. Bound for price change [−10%, 10%].

revenue coming from consumers in all other quartiles. The electricity retailer experiences the greatest increase in revenue coming from consumers in the third quartile, which is the consumer group with the most price inelastic demand. As consumers in the first quartile experience quite a significant reduction in consumption, the GINI Index increases slightly from 0.1581 to 0.1605. Although inequality in electricity consumption worsens, it is slightly better than under the national price hike. The reason for this is primarily because the reduction in consumption among consumers in the first quartile is not as much as that under the national price hike and the reduction in consumption among consumers in the fourth quartile is much greater than that under the national price hike. Thus, the simulation demonstrates that by raising the marginal prices faced by consumer groups with the most price inelastic demand, policymakers can achieve the same effects on revenue and consumption without worsening inequality in consumption as much as the national price hike.

6.2.2. Minimize inequality given price step changes within 10%

We now report simulation results when the changes in marginal prices are allowed to increase by up to 10%.[10] By allowing the percentage change in marginal prices to increase by more than the 7.2% under the national price hike, this alternative scenario can potentially reduce inequality in electricity consumption.

Table 13 reports the optimal levels of tariffs that minimize the inequality in electricity consumption subject to the constraints that the new revenue level and new consumption level are equivalent to the expected revenue and consumption levels after the actual national price hike, the tariffs remain progressive, and each price step changes within a range 10%. The results indicate that to minimize the inequality, the marginal prices at steps 4 and 5 must increase by 10% (the maximum), the marginal price at step 3 increases by around 7.65%, the marginal prices at steps 1, 2 and 6 increase by between 4.6% and 4.75%, and the marginal price at the lifeline level remains unchanged. Similar to the case when changes in marginal prices are capped at no more than 7.2%, the increases are larger at marginal prices faced by households with price elasticities that are relatively inelastic.

Table 14 shows the predicted consequences of the price changes in terms of simulated levels of electricity consumption, electricity bill, average price, and GINI Index when the maximum change in each price step is within 10%. As expected, given that average prices increase for consumers in all quartiles, electricity consumption decreases for consumers in all quartiles. The percentage increase in average price is the greatest for those with the most inelastic demand (quartile 3) and the lowest for those with the most elastic demand (quartile 1). Similarly, the sources of revenue increase follow the same pattern. The GINI Index decreases slightly from 0.1581 to 0.1577. Thus, by allowing the marginal prices to increase by more than 7.2% among the higher-end consumers and those with relatively inelastic demand, policymakers can achieve the same effects on revenue and consumption while further reducing inequality in consumption.

6.3. Comparison of national price shock and inequality-minimization policies

In this subsection, we compare our suggested policy scenarios with the actual national-level price hike. In terms of the marginal price change in each step, the national-level price hike increases all the marginal prices without a large difference even if the increment becomes larger at a higher consumption step. By contrast, the optimal policies

Table 14
Predicted impacts – minimize inequality with price changes within 10%.

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Price elasticity	−1.102	−0.554	−0.391	−0.922
A. Pre-policy implementation				
Consumption (kWh)	216	259	335	458
Raw bill (Tk.)	1013.26	1243.74	1660.55	2531.10
Electricity bill (Tk.)	1190.25	1455.30	1934.63	2935.77
Average price (Tk.)	5.51	5.62	5.78	6.41
GINI Index	0.1581			
B. Post-policy implementation				
Consumption (kWh)	206.21	251.84	327.42	438.46
Raw bill (Tk.)	1006.99	1270.15	1717.66	2535.27
Electricity bill (Tk.)	1183.04	1485.67	2000.31	2940.56
Average price (Tk.)	5.74	5.90	6.11	6.71
GINI Index	0.1577			
C. Predicted impact of policy implementation				
Change in consumption (kWh)	−9.79	−7.16	−7.58	−19.54
Change in raw bill (Tk.)	−6.27	26.41	57.11	4.17
Change in electricity bill (Tk.)	−7.21	30.37	65.68	4.80
% change in average price	4.11%	4.99%	5.79%	4.63%
Overall effect on demand (kWh)	−11.02			
Overall effect on revenue (Tk.)	20.36			
Overall effect on GINI Index	−0.0004			

Notes: This table illustrates the overall predicted impact of the alternative hypothetical price reform discussed in Table 13 on electricity demand, revenue of electricity suppliers, as well as, electricity consumption inequality. The 'Price elasticity' row reports the respective average price elasticities for each consumption quartile. Panel A outlines the initial conditions, panel B reports simulated results after the price hike, and panel C reports the changes as a result of the price hike. Each column reports the average figure for the respective quartile computed to replicate a representative household for that quartile, with the exception of GINI index and overall effects where the figures are for an average household in the sample.

[10] We have also tested many different scenarios. For example, we restrict the maximum rate of increase in tariffs by 8%, 9%, 11%, 15%, etc. All these scenarios give us similar economic consequences, and consequently, we do not report other scenarios with a price increase beyond 10%.

that minimize the inequality in electricity consumption exhibit a much larger gap in terms of changes in tariffs between high consumption steps and low consumption steps, particularly when we impose the restriction of maximum 10% changes in marginal prices. For example, for the fifth consumption step, the optimal policy (under 10% restrictions) increases the tariff by 10%, whereas the national hike raises it by only 6.9%. For the second consumption step, the tariff increases by 4.67% in the optimal policy, but it increases by 6.0% in the national price hike. It is intuitive that the inequality-minimization policy imposes a higher increase at high-consumption steps to reduce inequality. As a result, the inequality-minimization policy with the 7.2% restriction yields the GINI coefficient of 0.1605, and the same policy with the 10% restriction yields the GINI coefficient of 0.1577, which is lower than that of national price hike, 0.1608. Hence, these policies effectively minimize the inequality while maintaining the firm's revenue and the level of consumption, compared to the national hike.

Overall, our simulations demonstrate that information about heterogeneous price elasticities of demand can be more effectively used to achieve the goal of increasing revenue and reducing consumption without worsening inequality in electricity consumption. Indeed, if policymakers are willing to consider sharper increases in marginal prices that higher-end consumers face, they can further reduce inequality in electricity consumption.

When it comes to the real-world application of our simulation results, a careful consideration of potential supply-side constraints in the electricity market is necessary. Our simulation results may not map well with reality when supply shortage is severe and widespread. Specifically, if supply shortage is severe and widespread, demand would be largely unmet for the given prices. When prices are raised, our simulations predict reduced consumption, while consumption might actually stay unchanged in reality. We do not have the data to compare the actual average consumption right before and after the national price hikes considered in the simulations. Nonetheless, average consumption actually fell between round-2 survey and round-3 survey when average prices increased as a result of the VAT hike (see Table 1). This pattern indicates that at least for the urban sample that we consider, the simulation results can be informative.

7. Conclusion

The UN stresses the importance of its Sustainable Development Goal (SDG) 7 as it interlinks with other SDGs. The main target for Goal 7 is to ensure universal access to affordable, reliable and modern energy services by 2030. Some of the main challenges for developing countries in their attempts to achieve this target include electricity demand-supply mismatch and inequality in electricity access and consumption. Burgess et al. (2019) argue that reforms that aim to make electricity more like a private good rather than a right as currently viewed in most developing countries can potentially help solve the problems. Policymakers may consider tariff reforms that allow prices charged to cover more appropriately the costs to address the demand-supply mismatch problem, but such strategy may worsen inequality in electricity access and consumption in the absence of credible estimates about price elasticities of demand for different types of consumers.

Taking Bangladesh as an example and using a newly collected household-level panel data set, this paper estimates the short-term price elasticity of urban residential electricity demand and examines how it may differ by consumption level by exploiting a VAT shock that took place in between different rounds of surveys. The estimated short-term average price elasticity is −0.577 on average, suggesting that residential electricity demand is on average inelastic to price changes. However, we also find evidence of substantial heterogeneity in price elasticities of electricity demand across households with different consumption levels. Low consumption households are the most responsive to price changes, followed by the highest consumption group of households. The moderate consumption households are relatively inelastic to price changes.

On the basis of the estimated price elasticities, we perform a policy simulation and find that an actual national price hike occurring after our survey period increases the revenue of electricity retailers and improves the demand-supply mismatch of electricity by reducing the overall demand for electricity. Concurrently, the policy worsens inequality of electricity consumption and may further deprive poor households from having affordable and reliable electricity access. Using insights drawn from the heterogeneity in price elasticity estimates, we perform policy simulations for two alternative pricing schemes that offer as much revenue increase and consumption reduction as the actual national price hike, but much better outcomes in terms of inequality in electricity consumption.

There are several important caveats to note about our estimation approach, simulation results, and applicability of our findings. First, although we find that our main estimates are robust to including suburb and round fixed effects and using an alternative IV, we were unable to estimate heterogeneous price elasticities using the alternative IV because the alternative IV is weak when we estimate price elasticity by consumption group. Second, because we exploit the exogenous VAT change to estimate price elasticities and only have a relatively short panel, we were unable to separately estimate price elasticities for the period before the policy change and the period after the policy change. Third, the relevance of our policy simulations require that supply shortage is not severe. For areas with severe supply shortages and demands largely unmet, what our simulations show may not match to what may happen in reality because a price increase may not necessarily lead to a reduction in demand. In this sense, our simulation results are more useful for understanding the implications of alternative pricing policies in places where supply shortage is not particularly severe. Fourth, although the average price in our sample is similar to the overall average price in Bangladesh during the sample period, our sample primarily consists of urban households in relatively affluent areas in Dhaka, the capital city, which tend to consume more electricity than households in other parts of Bangladesh. Thus, our estimates are more applicable for urban areas where electricity consumption levels are relatively high. To the extent that policymakers are considering tariff reforms that introduce price variations across regions, our estimates and simulations provide some useful benchmarks for comparisons in urban areas. Fifth, the purpose of our simulations and policy scenarios is to demonstrate that we can use price structures that consider the heterogeneous price elasticities across consumption groups to reduce demand-supply mismatch and inequality in electricity consumption. We do not argue that pricing strategy alone can fully address these energy challenges. Instead, it is important to implement a range of reforms that aim to reduce distribution inefficiency, mismanagement, corruption, theft, and other supply-side infrastructure issues.

This paper contributes to a better understanding of residential electricity demand in urban Bangladesh and other similar settings. A key innovation lies in the use of household panel data together with exogeneous price variation to estimate short-term price elasticities of electricity demand. Future research may also consider such an approach to estimate price elasticities of electricity in other settings where a price slab system is in use. Given that the lack of electricity access among rural households tends to be more severe in developing countries, applications of our approach in a rural setting will be particularly useful. Lastly, we also conducted a follow-up survey in 2018 and obtained information regarding electricity conservation knowledge and behaviors of the sampled households. Future research may examine whether average price changes have longer term effects on electricity conservation behaviors.

Author contribution Statement

Hemawathy Balarama: Data curation; Formal analysis; Visualization; Writing - original draft; Writing - review & editing. Asad Islam:

Conceptualization; Data curation; Funding acquisition; Investigation; Project administration; Resources; Supervision. Jun Sung KIm: Conceptualization; Data curation; Formal analysis; Methodology; Visualization; Writing - original draft; Writing - review & editing. Liang Choon Wang: Conceptualization; Formal analysis; Methodology; Validation; Visualization; Writing - original draft; Writing - review & editing.

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Appendix A. Supplementary data

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