Response to Extreme Energy Price Changes: Evidence from Ukraine

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ABSTRACT

Large but temporary price increases are sometimes deployed on days when the demand for electricity is extremely high due to exceptionally warm or cold weather. But what happens when the extreme price changes are permanent? Between January 2013 and April 2016, natural gas and electricity prices in Ukraine increased dramatically (up to 300% of the initial rates). We exploit variation in tariffs over time and across customers to estimate the price elasticity of electricity demand using a panel dataset with monthly meter readings from households in Uzhhorod in Ukraine.

The price elasticity of electricity demand is –0.2 to –0.5, with the bulk of our estimates around –0.3. The elasticity becomes up to 50% more pronounced over the first three months since prices change. We find only limited evidence that persons who are attentive about their consumption levels, their bills, or the tariffs are more responsive to the price changes.

Keywords: Residential electricity demand, Short-run price elasticity, Increasing block rates, Attentiveness, CO_2 emissions reductions.

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1. INTRODUCTION

The response to energy price changes—summarized into the price elasticity of demand—is key to understanding the effectiveness of a number of policies meant to moderate demand, shed peak load, encourage consumers to adopt energy efficiency equipment, and hence reduce emissions of CO_2 and other pollutants. Estimating the price elasticity of demand requires datasets with sufficient cross-sectional or longitudinal variation in prices, and generally presumes that users know the prices they are faced with.

In earlier literature, extreme price changes have been studied, for example, in Herter and Wayland (2010), Wolak (2011), Jessoe and Rapson (2014) and Bell and Blundell (2016). In these cases, however, the extreme price changes were temporary and infrequent (5–15 times a summer), and were experienced during either pilot or broad-based critical peak pricing programs.

But what happens when the extreme price changes are permanent? This is what we set out to explore using residential energy consumption records from a sample of households in Ukraine. In our analysis, we examine whether the response to such changes is complicated or otherwise altered by consumers' imperfect knowledge of their consumption level, energy expenditure, or prices.

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That consumers may find it onerous to process complicated pricing systems or kinked budget constraints has been observed in other utilities-related contexts (e.g., Hortaçsu et al., 2017) and in the taxation literature (Liebman and Zeckhauser, 2004), where this may lead to inertia or to the development of simplifying heuristics ("schmeduling"). Shin (1985) argues that consumers may have limited ability to process block tariff schemes and/or seasonal tariff changes, and for that reason may rely on the average price paid instead of basing consumption decisions on the marginal price. Borenstein (2009) derives the consumption patterns that can be expected under block pricing and Ito (2014) finds empirical evidence that households in California respond to average price rather than marginal block price.

McRae and Meeks (2016) document households' difficulty with computing bills and recognizing the correct marginal price at large levels of consumption after a tariff reform in Kyrgyzstan that replaced uniform pricing with increasing block rates. Consumption adjustment after the reform was more pronounced for households with a better understanding of the price schedule, with the effect being the strongest for low-tier consumers who were "inattentive" (i.e., did not correctly perceive the block that their usage levels fell in).

Kahn and Wolak (2013) conduct an experiment where residential electricity customers in California receive an on-line education course about the nature of increasing block pricing, and find that, even with no price changes, the provision of information is sufficient to trigger a behavioral response: Households who learn that high consumption leads to high marginal prices reduce consumption, while those who learn that they face low marginal prices increase consumption. The overall effect is a 1.5–3% reduction in electricity usage.

In this paper, we seek to estimate the price elasticity of residential energy demand in a setting with extreme price changes—Ukraine over the last 3–4 years. As a consequence of conflict with Russia, its main supplier of natural gas, natural gas prices for residential and manufacturing customers alike increased by almost 300% over a very short period of time. Electricity prices rose quickly too, as coal supplies fell under the control of Russian supporters and the government agreed to meet demands by the International Monetary Fund. The tariff hikes were blamed for impoverishing people, causing loss of competitiveness in the manufacturing sector, and even closing energy-intensive plants.[1] Some observers note that the price increases are implicitly removing the inefficient system of energy subsidies in Ukraine (Rozwalka and Tordengren, 2016), which has one of the highest rates of CO_2 emissions per unit of GDP in the world (International Energy Agency, 2016).

We exploit variation in tariffs over time and across customers to estimate the price elasticity of electricity using a panel dataset that documents monthly meter readings from households in the city of Uzhhorod in Ukraine over about three years.[2] We ask three research questions. First, what is the price elasticity of consumption implicit in the response (if any) to electricity price changes? At least in the short run, residential electricity demand is usually thought to be relatively inelastic with respect to price, although a recent review (Miller and Alberini, 2016) uncovers a wide range of empirical estimates. We expect households in Ukraine to use minimal amounts of electricity, since their homes, stock of appliances and incomes are generally smaller than in Western Europe or the

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[1] See http://24tv.ua/ukrayintsi_vz_yevropeytsi_chiya_komunalka_tyazhcha_n793633 and https://www.newcoldwar.org/ukrainian-gas-bills-double-electricity-up-25-in-exchange-for-imf-aid/.

[2] Bastos et al. (2011) take advantage of the difference in the price of natural gas charged to households with more and less than 1500 m^3 of cumulative consumption to apply a regression discontinuity design. They estimate that a 25% increase in price reduced consumption by 3.8%, which entails a price elasticity of –0.15. One limitation of this approach is that it is strictly local and lacks external validity.

US. But since they experienced large tariff increases, might one expect to observe large changes in consumption?

Second, is there evidence of heterogeneity in the price elasticity of electricity demand driven by dwelling or household characteristics, or by consumer recall of own bills and/or consumption levels? Third, how quickly do households adjust their consumption after a price change?

Briefly, histograms of the monthly usage records suggest that our Ukrainian consumers were aware of the increasing block pricing system and responded to marginal prices, with bunching observed at the current as well as future block cutoffs.

We find that the short-run price elasticity of electricity consumption is approximately –0.2 to –0.5, depending on the subsample of households included in the estimation sample, with the bulk of our estimates around –0.3. The elasticity becomes up to 50% more pronounced over the first few months since a price change.

Persons who are quantity-attentive (have a good grasp of their consumption in physical units) appear to have somewhat a more elastic demand for electricity, even though they don't differ from the rest of the sample in terms of most dwelling and household characteristics and mode of bill payment, and even if they actually use less electricity than the others to start with. Those who are bill-attentive (recall their recent bills correctly) are similar in their responsiveness to price to those are not bill-attentive. Persons who are both quantity- and bill-attentive display a price elasticity of –0.56, but this finding should be interpreted with caution due to the small number of respondents in this group. Only about 15% of the respondents indicated that they did not know the tariffs they were currently paying; dropping them from the sample or, conversely, limiting the sample exclusively to this group has little effect on the price elasticity. In sum, even accounting for attentiveness and awareness of tariffs, the estimated price elasticity remains within a narrow range. This is in sharp contrast with McRae and Meeks (2016), who report price elasticities ranging from –1.20 to –0.24, and likely due to the options available to consumers: Electric heat is used by only 16% of the sample, and no one appears to have switched away from it during our study period, presumably because of the constraints imposed by the existing infrastructure (e.g., no connection to the gas lines).

The remainder of this paper is organized as follows. We provide background information in section 2. Section 3 presents the data collection and section 4 the econometric models. Section 5 describes the data and section 6 the results. Section 7 concludes.

2. BACKGROUND

As in many other former Soviet Republics, in Ukraine electricity is generated and supplied to industrial, commercial and residential customers by state-owned companies. Tariffs are set by an independent regulator (INOGATE, 2015).

From 2006 to the end of January 2011, residential electricity customers paid a uniform price of 24.36 UAH cents for each kWh consumed. Increasing block rates (IBR) were first introduced on February 1, 2011, in part to help cover the increasing costs of generation, which had been adversely impacted by the 2006 natural gas supply disruption from Russia. The early IBR system was comprised of only two blocks. Within the first 150 kWh/month, residential customers paid the same price per unit as before (24.36 UAH cents/kWh), and for every kWh in excess of 150 kWh the price was 31.48 UAH cents/kWh (raised to 28.02 and 36.68 UAH cents/kWh, respectively, in April 2011).

The three-block system was first introduced in May 2012. The marginal block rates were the same as before, but for each unit in excess of 800 kWh/month customers would pay 54.72 UAH cents/kWh. The price in the third tier was almost doubled to 96.76 UAH cents/kWh in July 2012.

By the beginning of our study period, which spans from January 2013 to April 2016, residential customers had thus had plenty of time to get accustomed to the IBR system, and some experience with large price increases, although the most pronounced one (that of July 2012) was presumably experienced only by a small share of the households.

Table 1 displays the electricity tariffs for the Uzhhorod region from 2012 to 2016.[3] Ukraine has one-part tariffs for gas and electricity, with no fixed fee and increasing block pricing. The tariffs are set by a government agency and the same tariff scheme applies to everyone. In other words, consumer do not select into supply plans as they might in the US or other countries, and the tariffs are exogenous to the single consumer.

During our study period (January 2013 to April 2016), electricity prices rose several times: In the lowest tier, for example, the nominal tariffs doubled over this period. The most significant price increases took place in 2015–16. The structure of the blocks was also changed during this period, with the cutoff between the first and the second tier lowered from 150 to 100 kWh per month, and that from the second to the third block reduced from 800 to 600 kWh per month.[4]

Table 1 also shows one important feature of the electricity tariff system, namely that homes where the main heating fuel is electricity face different tariffs and tiers during the heating and the summer seasons. Table 1, however, refers solely to "regular" households and reports general rates. In practice, certain persons (such as members of the military, civil servants, persons who participated in World War II or more recent armed conflicts, or were younger than 18 during World War II, Chernobyl decontamination workers, etc.) are eligible for and do receive "benefits," which means a modified tier system and reduced rates per kWh.[5]

Figure 1 displays the tariff schemes in force during two periods within our study, namely January 2013-May 2014, and April-August 2015, to "regular" households that do not use electricity for heating purposes (solid lines). The dashed line represents the tariff scheme for an illustrative "benefits" consumer who enjoys an allowance of 90 kWh/month and receives a 25% tariff reduction. For usage less than 90 kWh, this consumer would pay only 75% of the regular price per kWh, but would be charged the full price per kWh for each kWh thereafter.

In sum, two important pieces of information are displayed in Figure 1. First, in April 2015 the blocks were changed. Second, persons on benefits face a different block structure and tariff system. This means that there are three groups with different block structure and tariffs: "Regular" customers, households who receive "benefits" allowances and reduced rates, and customers living in homes with electric heat.

Figure 2 displays the timing and magnitude of the tariff increases for customers with no electric heat and no "benefits," showing that in 2014 there were modest increases in the first and second tier (10% and 15%, respectively) and a 40% increase in the tariff for the third tier. In April 2015, it was the second tier that was hit the most heavily (50% increase), whereas the first and third

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[3] PJSC Zakarpattiaoblenerho is the electricity supplier with different distributor in each region within Zakarpattia (Transcarpathia). In Uzhhorod the distributor is Uzhhorodskyi MREM (Uzhjorodskyi City Region Electrical Chain), and electricity bills are paid to Uzhhorodskyi MREM.

[4] Electricity prices rose dramatically over our study period, but these increases are dwarfed by those observed for nominal natural gas prices, which grew by 285% since April 2015 (Ukrainian National Regulatory Commission of Energy and Utilities [NERC]). The block system for natural gas was likewise changed several times during our study period.

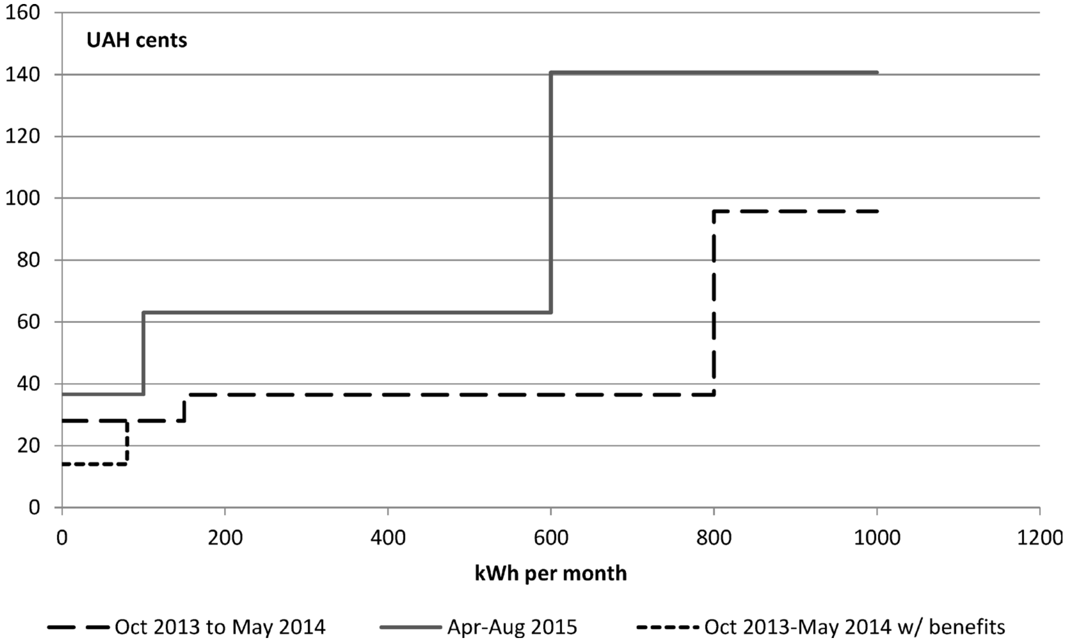
[5] Benefits are granted based on profession or war experience, and are not income-based. Eligible persons are enrolled automatically by the government.

Table 1: Electricity tariffs for urban households in the Uzhhorod region, 2012–2016

	Units	1 Oct. 2012– 30 May 2014	1 June 2014– 30 Sept. 2014	1 Oct. 2014– 31 Mar. 2015	1 Apr. 2015– 31 Aug. 2015	1 Sept. 2015– 29 Feb. 2016	1 Mar. 2016– 31 Aug. 2016
General rates							
upper bound of block 1	kWh	150	150	150	100	100	100
upper bound of block 2	kWh	800	800	800	600	600	600
fixed fee	UAH/month	0	0	0	0	0	0
variable cost 1	UAH cents/kWh	28.02	30.84	30.84	36.6	45.6	57
variable cost 2	UAH cents/kWh	36.48	41.94	41.94	63	78.9	99
variable cost 3	UAH cents/kWh	95.76	134.04	134.04	140.7	147.9	156
Homes with electric heating in residential homes OR multi-family houses with no gas connection (May 01-September 30)							
upper bound of block 1	kWh	250	250	250	100	100	100
upper bound of block 2	kWh	800	800	800	600	600	600
fixed fee	UAH/month	0	0	0	0	0	0
variable cost 1	UAH cents/kWh	21.54	23.7	23.7	36.6	45.6	57
variable cost 2	UAH cents/kWh	28.02	32.22	32.22	63	78.9	99
variable cost 3	UAH cents/kWh	95.76	134.04	134.04	140.7	147.9	156
Homes with electric heating in residential homes OR multi-family houses with no gas connection (October 01-April 30)							
upper bound of block 1	kWh	3600	3600	5000	3600	3600	3600
upper bound of block 2	kWh						
fixed fee	UAH/month	NA	NA	NA	NA	NA	NA
variable cost 1	UAH cents/kWh	21.54	23.7	23.7	36.6	45.6	57
variable cost 2	UAH cents/kWh	95.76	95.76	95.76	140.7	147.9	156

Note: Tariffs include VAT. (20%)
Source: http://www.nerc.gov.ua/?id=15006

Figure 1: Electricity tariffs in Ukraine over selected periods.



Notes: The tariffs shown apply to households that do not use electricity as the main heating fuel. The benefit scheme is for an allowance of 90 kWh and a 25% discount on the regular tariff up to the first 90 kWh consumed.

experienced price hikes by 19% and 5%, respectively. This 50% price hike (along with others experienced by other sectors) triggered massive increases in the prices of many goods and services. The consumer price index adjusted accordingly, implying that in real terms the price increase from one month to the next was of about 33%.[6] Subsequent increases were by 25% (nominal) in the first and second tier, and 5% (nominal) in the third.

Unlike many other locales where electricity or gas bills are obscure and difficult to interpret (which has prompted many observers to suggest that it would be easy to promote responsible consumption if pricing and usage information was displayed more clearly and more frequently; Pon, 2017), in Ukraine the electricity bills are very easy to read. They display the billing period, consumption during the billing period as per the meter reading by a utility representative, the tariff, a description of the benefits scheme (if any), adjustments to reflect benefits, and of course the total amount due (see Figure 3 for an example). This feature of the bill suggests that it is feasible for many households to inspect the bill carefully[7] and greatly simplified our data collection effort, which we describe in the next section.

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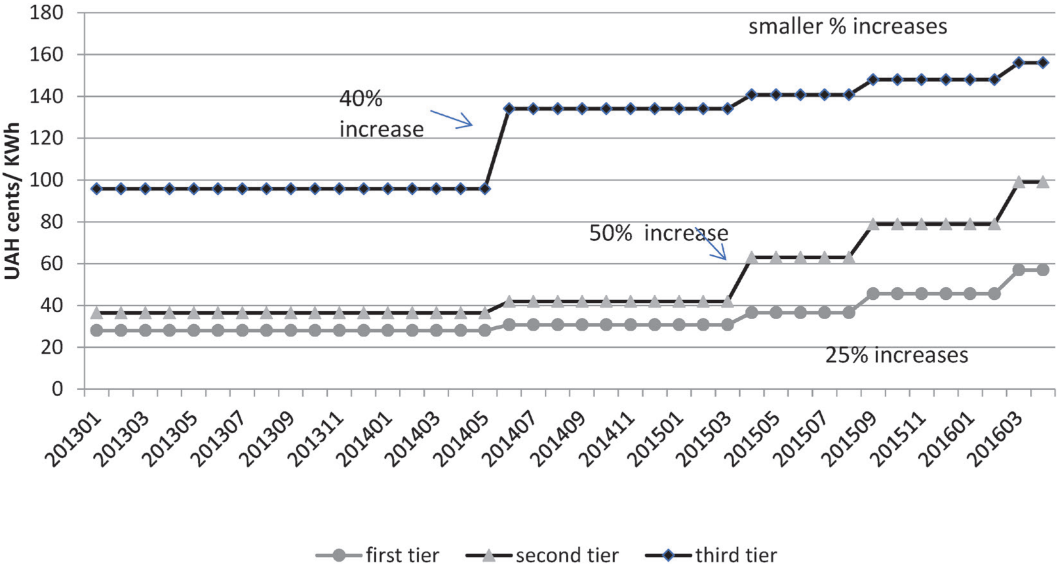
[6] Indeed, the CPI rose by 45% in Ukraine in 2015, with a disproportionate contribution to this increase coming from residential energy. Prior to that, there had been virtually no inflation in Ukraine in 2012 (annual inflation rate 0.6%) and 2013 (annual rate –0.3%), with noticeable price increases in 2014 (annual inflation rate 12%). See https://data.worldbank.org/indicator/FP.CPI>TOTL.ZG. .

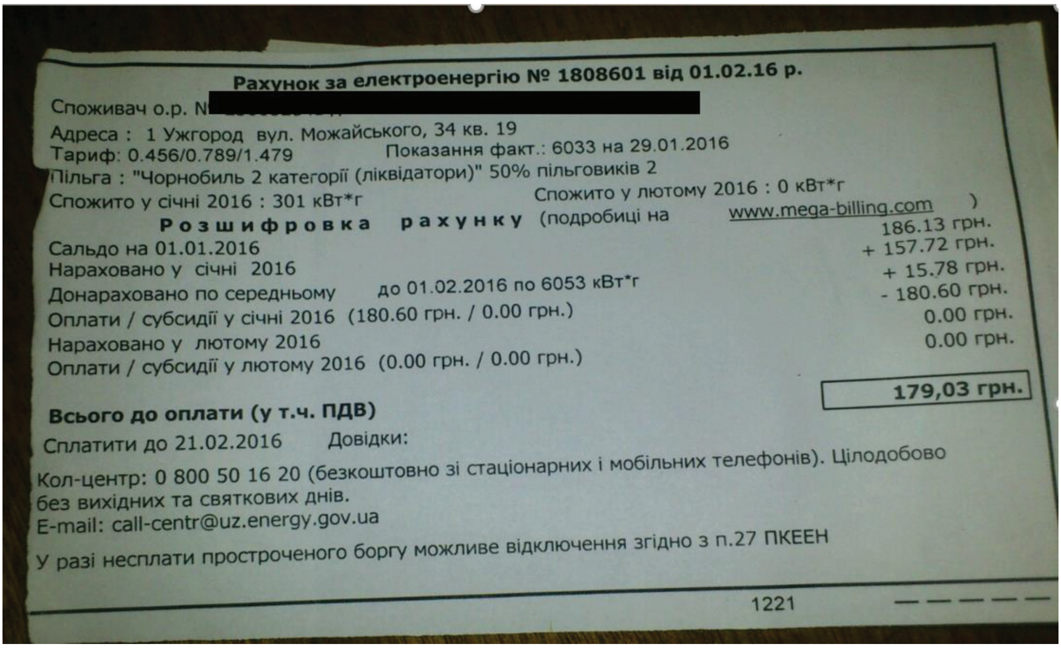
[7] In Uzhhorod the electricity and gas bills are issued monthly and are based on actual meter readings by a representative of the utility. On occasion, the state utility may ask some customers to read the meter and record the reading on its behalf. Meters are generally located in easily accessible places. The utility later sends an agent to reconcile its own readings with that made by a member of the household.

Figure 2: Nominal tariffs by consumption tier.



Notes: The tariffs shown apply to households that do not use electricity as the main heating fuel and do not receive benefits.

Figure 3: Sample electricity bill.



Рахунок за електроенергію № 1808601 від 01.02.16 р.

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Тариф: 0.456/0.789/1.479 Показання факт.: 6033 на 29.01.2016
Пільга : "Чорнобиль 2 категорії (ліквідатори)" 50% пільговиків 2
Спожито у січні 2016 : 301 кВт*г Спожито у лютому 2016 : 0 кВт*г
Розшифровка рахунку (подробиці на www.mega-billing.com)
Сальдо на 01.01.2016 186.13 грн.
Нараховано у січні 2016 + 157.72 грн.
Донараховано по середньому до 01.02.2016 по 6053 кВт*г + 15.78 грн.
Оплати / субсидії у січні 2016 (180.60 грн. / 0.00 грн.) - 180.60 грн.
Нараховано у лютому 2016 0.00 грн.
Оплати / субсидії у лютому 2016 (0.00 грн. / 0.00 грн.) 0.00 грн.

Всього до оплати (у т.ч. ПДВ) **179,03 грн.**

Сплатити до 21.02.2016 Довідки:
Кол-центр: 0 800 50 16 20 (безкоштовно зі стаціонарних і мобільних телефонів). Цілодобово без вихідних та святкових днів.
E-mail: call-centr@uz.energy.gov.ua
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3. DATA COLLECTION

We use data collected through a survey of 500 households in the Uzhhorod, Ukraine, metropolitan area. The survey was conducted in the respondents' homes in May-early June 2016 by enumerators recruited and trained by a survey research firm affiliated with the local university.

We chose Uzhhorod because it is the administrative center of the Zakarpatska region and because in 2005 it was disconnected from district heating as a part of a project to improve energy efficiency in Ukraine. As part of this program, all homes were equipped with electricity and gas meters, and as a result the electricity and gas consumption of the household are measured exactly. As residents of Uzhhorod, virtually all of the households covered by the survey use either natural gas or electricity for heating, with only a small share using solid fuels (see Table 2).

The enumerators were instructed to contact a pre-defined sample of homes selected at random from the universe of residential addresses of Uzhhorod. The final sample was representative of the universe for type of home (multi-family buildings, single-family and semi-detached homes), household size, and the various neighborhoods of the city.[8]

The enumerators recorded information about the location and type of dwelling. They also invited the member of household who pays the energy bills and is presumably most informed about the household's gas and electricity consumption to participate in the survey. The questionnaire then elicited information about 1) energy efficiency renovations or retrofits done in the last 3 and/or 4–10 years, their costs and any financial support from the government, and 2) the main (and secondary, if any) heating system, its age and the reasons for its recent replacement if that was the case.

The respondents were also asked to show their gas and electricity bills from January 2013 to April 2016. The enumerator recorded consumption in cubic meters and kWh, respectively, for each month when such bill was available, the relevant tariffs, and whether the respondent received "benefits rates." Expectations about future prices and statements about the respondent's ability to reduce energy consumption were also collected. The final section of the questionnaire gathered information about household's socio-demographics.

Just *before* asking the respondents to produce their utility bills, the questionnaire asked them how many kilowatt-hours they consumed on average in the winter and summer months, respectively, and how much their average winter and summer electricity bills were. The enumerator recorded the exact response (e.g., "180 kWh"), or, when a respondent was not sure, offered interval categories ("less than 100 kWh," "101–200 kWh," etc.) from which the respondent was to pick one.

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[8] We instructed our survey firm to collect 500 completed questionnaires. The sample was to be representative of the housing stock in the city of Uzhhorod and to include only homeowners, who are presumably responsible for energy consumption and bills, and in charge of any decisions about home energy efficiency upgrades, appliance purchases, etc. There is no reliable information about the homeownership rate in Ukraine, but it seems reasonable to assume that it is very high, much like those in other former Soviet republics in Europe (Lithuania: 89.4%; Russia: 84.0%; Estonia: 81.5%; Latvia: 80.2%) and former Eastern bloc countries (Romania: 96.4%; Hungary: 86.3%; Poland: 83.5%; Bulgaria: 82.3%) (see https://en.wikipedia.org/wiki/List_of_countries_by_home_ownership_rate). The city of Uzhhorod is divided into nine districts and has a total population of 93,354 persons aged 18 and older (the total population is 113,000). We wished to draw a sample of approximately half of one percent (=500/93,354) from the resident population in each district. The most populous district, New Town, has a total of 38,142 eligible residents, and half of one percent of them yields some 200 households. Four more districts resulted in a planned sample of 50 each, and the remaining four had 25 each. The sample was to mirror the distribution of housing types in Uzhhorod—57% apartments in multi-family buildings, 40% single-family homes, and some 3% row homes. A list of candidate addresses was drawn from each district using the Uzhhorod's resident registry, which documents the head of the household and the number of family members that live in each dwelling. The registry does not specify whether the family on the premises owns or rents the premises. The enumerators visited or attempted to visit a total of 936 dwellings. They could not physically locate the dwelling in 16 cases, were unable to gain access to the building in 77 cases, did not find anyone at home in 182 cases, and ran into an ineligible household (a renter) in 53 cases. In 182 other cases, the person they spoke to at the premises simply declined to participate in the survey. Based on valid contacts, the response rate is thus 500/608, or 82.22%. To encourage participation in the survey, we offered prospective respondents a card that entitled them to \$3 worth of phone calls from their cellular phones. About half of the participants declined this offer and still completed the interview.

We use the responses to these questions—compared to the information contained in the actual bills that the respondent subsequently showed the enumerator—to form measures of "attentiveness" to quantity consumed and bills paid. The respondents were also asked whether they knew the tariffs per kWh (in the first, second, and third tier, if applicable) they paid at the time of the survey.

4. THE MODEL

The information recorded by the enumerators means that we have an unbalanced panel of 500 households with up to T=40 monthly observations on electricity and natural gas consumption. In this paper, attention is restricted to electricity usage. We use these data to fit the regression equation:

$$lnE_{it} = \alpha_i + \beta \cdot lnP_{it}^E + \mathbf{W}_t\boldsymbol{\gamma} + \mathbf{X}_{it}\boldsymbol{\theta} + \tau_t + \varepsilon_{it} \tag{1}$$

where E denotes electricity consumption by household i during period t (which is here the month and year), P^E is the price of electricity (expressed in April 2016 Ukrainian hryvnias [UAH]), **W** a vector of weather variables,[9] **X** a vector of time-varying factors thought to affect demand, α a household fixed effect and τ is a month-by-year time fixed effect. We have income at the time of the survey, but not for each month of the study period, which means that it must be interacted with time-changing variables if we wish to include it in the right-hand side of equation (1), as part of the **X** vector.[10]

One important question is what price P is—the marginal block price (as conventional economic theory suggests), or the average price, as in Ito (2014)? Both marginal and average price are endogenous in the presence of block pricing schemes. Failure to account for such endogeneity typically results in a positive association between price and electricity demanded.

The most natural way to address this issue is to instrument for either (log) marginal or average price with the (log) full tariff schedule. This is a well-accepted method for dealing with endogenous marginal (or average) prices under non-linear price schedules such as those frequently found with residential electricity, gas and water consumption (Mansur and Olmstead, 2012; Nieswiadomy and Molina, 1989). This is because the full set of marginal prices in the price schedule is established by the authorities and is uncorrelated with the error term in (1), but correlated with the price a household faces (Mansur and Olmstead, 2012). Using the (logs of the) full tariff schedule as our excluded instruments means that they must capture i) the reform in the block structure that took place in April 2015, ii) the different tariffs and blocks applied to homes that rely on electricity as their main source of heating, and iii) the different effective block sizes and prices per kWh charged to individuals who receive "benefits."

We thus construct a total of six block price instruments, namely the logs of the block 1, block 2 and block 3 rates faced by each respondent before April 2015 (assigning to these variables a value of zero for April 2015 and subsequent months), and the logs of the block 1, block 2 and block

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[9] **W** includes log degree days (with base 65° F) during the billing period, plus i) the percent of the time during the billing period with no wind, ii) the percent of the time with no clouds, iii) the number of days in the billing period when the maximum temperature was above 30° C (86° F), iv) the number of days in the billing period when the minimum temperature was below 0° C (32° F), and v) three dummies denoting whether the average relative humidity in that month was less than 25%, 25–75%, and more than 75%.

[10] The unbalanced nature of the panel prevents us from using a model with household-by-month, month-by-year, and household-by-year fixed effects, i.e., a triple-difference type of specification.

3 prices faced by each respondent in or after April 2015 (and zero for the earlier periods).[11, 12] To further capture the full tariff schedule, we use three additional excluded instruments—namely the allowance, the discount on the full tariff (different from zero only if someone receives benefits), and an interaction term between the two. (For households not on benefits, the allowance is zero and the percent tariff reduction is likewise zero.)[13]

As an additional specification and estimation strategy consideration, we note that in the presence of increasing block pricing, it is often assumed that electricity consumed E is a function of weather, dwelling and household characteristics, marginal price and virtual income. Virtual income (also called the "difference" variable; see Nieswiadomy and Molina, 1989) captures the savings realized when a household's consumption falls in a block other the first. For example, if consumption E falls in the first block, virtual income is zero; if it falls in the second block, it is $(p_2\text{-}p_1)\cdot E$, where p_1 and p_2 denotes the prices per kWh in the first and second block, respectively.

It is not clear how virtual income should be entered in a log-log model, as the theoretical framework that advocates its inclusion is based on a linear model of consumption. Nieswiadomy and Molina (1989) discuss difficulties encountered by earlier literature when interpreting the estimated coefficients on this variable. Mansur and Olmstead (2012) instrument for it using household income. In this paper, we simply choose to proxy it with house type-by-month and income-by-month effects, i.e., the $\mathbf{X}$ vector in equation (1).

In sum, we estimate a log-log demand model using two-stages least squares and a rich set of effects. In all of our regressions, the standard errors are clustered at the household level. To see whether the elasticity depends on the type of home or on characteristics of the household, we estimate equation (1) separately for different subsamples. To see how the responsiveness to price changes adjusts over time, we estimate equation (1) after we restrict the sample to one month before and one month after a price change, two months before and two months after a price change, etc. Because prices were changed frequently during our study period, we are forced to stop this exercise at three months before and three months after a price change. Note that this procedure assumes that the one-month elasticity is the same, regardless of when during the study period the price change took place. The same is true for the two-month elasticity and the three-month elasticity, but the three elasticities are allowed to be potentially different from one another, which allows us to examine the issue of how quickly households adjust to the new prices.

5. THE DATA

Descriptive statistics from our sample of 500 Uzhhorod households are reported in Tables 2, 3 and 4. Briefly, Table 2 shows that 57% of the respondents live in multi-family buildings and

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[11] Note that for electric heat users, the prices in block 2 and 3 are identical during the heating season (October to April).

[12] This is virtually identical to constructing eight instruments that indicate the price faced by each respondent if his or her consumption falls within 0–100, 101–150, 151–250, 251–600, 601–800, 801–3600, 3601–5000, and more than 5000 kWh/month. With this approach, two instruments get dropped from the first stage because of complete collinearity with the month-year effects. With the approach we choose to follow and report about in this paper (the one with the six instruments), one instrument gets dropped from the first stage because of complete collinearity with the month-year effects.

[13] McFadden et al. (1977) propose an alternate approach, where one first regresses electricity consumption on exogenous dwelling and household characteristics, forms a predicted level of usage, and then selects the marginal price that would apply for this predicted level of consumption. This marginal price is the instrumented marginal price to include in regression (1). Finally, another approach yet is to use a structural discrete-continuous choice approach (Hewitt and Hanemann, 1995; Reiss and White, 2005; McRae, 2015). In this paper we do not apply the discrete-continuous choice approach to avoid relying on stringent distributional assumptions and because we simply lack detailed information about the household's appliances, which play an important role in Reiss and White's (2005) and McRae (2015) "adding up" constraints.

Table 2: Characteristics of the Homes.

Variables	Percent of the Sample or Mean (standard deviation in parentheses)
Type of Home:	
Single-family home	39.8%
Apartment in multi-family building	56.8%
Semi-detached or row home	3.4%
Size of the dwelling in square meters	79.95 (54.85)
Main heating fuel:	
Gas	73.0%
Electricity	15.8%
Solid fuels	8.8%
Other	2.8%
Has done energy-efficiency upgrades (attic or wall insulation, double- or triple-glazed windows, jackets around hot water pipes) in the last three years	27.20%

Table 3: Energy Consumption statistics: Monthly electricity usage (in kWh).

Description	Mean	Std Devn
All households	224.66	197.00
Households living in Single-family homes	232.56	148.76
Households living in apartments in multi-family buildings	217.62	224.37
Households living in semi-detached or row homes	251.39	204.84
Households with gas heat	185.18	149.27
Households with electric heat	383.76	301.20

Table 4: Respondent Socioeconomics.

	Average or percent of the sample (standard deviation in parentheses)
Household size	3.386 (1.4809)
Household monthly income (UAH)	5063.46 (2417.30)
Did not report information about income	6.4%
Education:	
Secondary	16.7%
Professional-technical	25.9%
High education (MSc, BSc, DiS)	56.0%
Other	1.43%

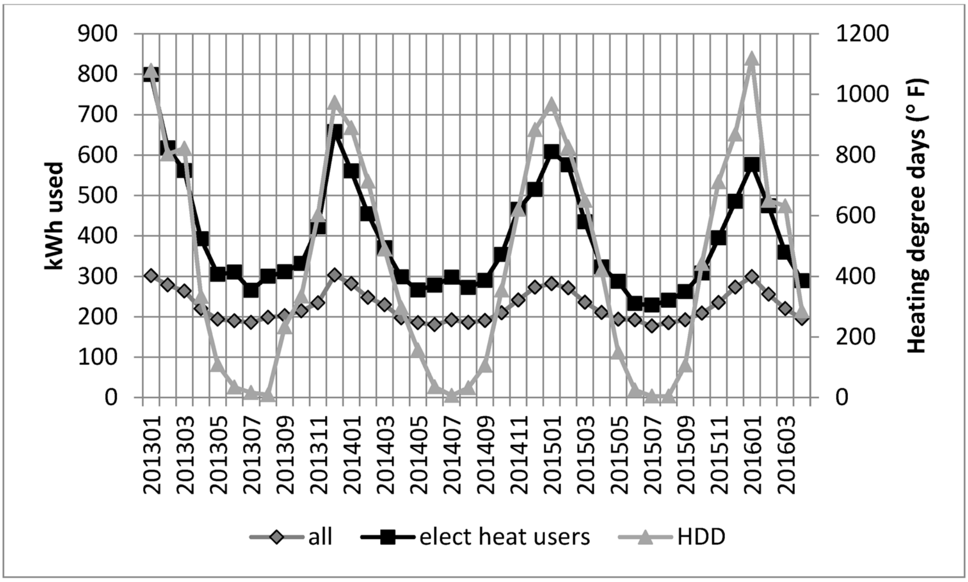
almost 40% in single-family homes. The average dwelling size is approximately 80 square meters. As expected, natural gas is the prevalent heating fuel. About 16% of the homes in our sample are heated using electricity. Some 27% of the respondents indicated that they had done energy efficiency renovations at their homes (insulation, double- or triple-glazed windows, jackets around hot water pipes) in the last three years.

Electricity consumption information was provided by 482 out of 500 respondents, with one person providing a single bill. As shown in Table 3, the average monthly usage of electricity is about 225 kWh, or about 2,700 kWh per year. Households with electric heat consume twice as much electricity as households with gas heat.

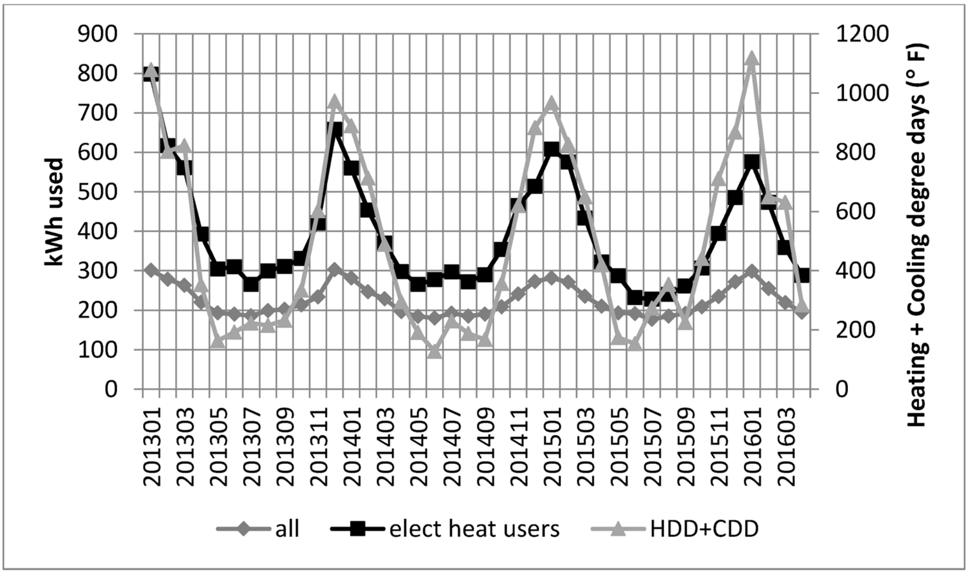
The two panels of Figure 4 shows that, as expected, electricity usage is highly seasonal, and that this seasonality is extremely pronounced for households who rely on electricity to heat their homes. The peaks are in the winter, as is consistent with a location with some 5300 Fahrenheit heat-

Figure 4: Average monthly electricity consumption and weather.

(A)



(B)



ing degree days (with 65° F base) per year during our study period. While summer days can be hot, there are a total of only about 630 annual cooling degree days, and few homes are equipped with air conditioning systems, which keeps summer electricity consumption low. See panel (B) of Figure 4.

Figure 4 also suggests that there was some decline in usage after the tariff hike of April 2015, despite the comparatively cold winter of 2015–16. In general, in most billing periods consumption falls in the second block (63%), with 36% of the monthly usage in the first block and only 4% in the third. (These figures refer to the homes with gas heating, or 73% of the sample.)

Table 5: Government assistance towards utility bills: "Benefits."

Description	Mean or percent of the sample	Standard deviation	Min.	Max.
Receives "benefits"	9.93%	—	—	—
Allowance (max. consumption level priced at discount tariff) (kWh/month)	514.38	527.06	90	1876
Percent reduction with respect to regular tariff	35.60	14.35	25	75

Table 4 reports income and education information. Official statistics indicate that in 2015 the average monthly household income in Ukraine was 5232 UAH. At 5063 UAH (approximately 200 US$ at the exchange rate of the time of the survey, namely 25.4 UAH to the US dollar), our sample is thus similar to the Ukraine population average.

Table 5 summarizes information about the recipients and nature of the "benefits." Families on benefits account for some 10% of sample. Their allowance ranges from 90 to 1876 kWh/month, averaging 514 kWh/month. This means that for some households the allowance may fall in the second or third of the regular tiers. Sixty-two percent of them get a 25% discount on the tariff within the allowance, 34% a 50% tariff reduction, and 4% a 75% reduction.

We wish to emphasize that benefits eligibility is based on present or past profession (e.g., career military, retired police officers), service done to the government (e.g., Chernobyl decontamination workers), or war experience, and is not based on income. "Children of the War," for example, are those who were younger than 18 during World War II. They receive a 25% discount on the tariff (for the portion of their usage that falls within the allowance), regardless of what their profession is or was prior to retirement. "Participants of battle actions" covers members of the military (career or draftees) or government-recognized volunteer militias who served in recent or past wars. The allowance is calculated by the government using the same formula for all benefits categories. House size (in square meters), household size, and whether the heating system is electric must be entered in the formula, which is adjusted for the heating season (October through April) and the number of storeys of the building (if the household lives in a multi-family building).

One key research question in this paper is whether responsiveness to price changes is different among persons who have a stronger grasp of their consumption levels or their bill amounts. We construct two measures of attentiveness: Quantity-attentiveness and Bill-attentiveness.

Specifically, we define as quantity-attentive someone who, when asked about average monthly consumption during the winter and summer months, either i) provides correct bounds around both his or her winter *and* summer months (e.g., says "100–150 kWh" and the true average based on the utility bills is around 120 kWh), or ii) provides an exact figure, and that figure is within 10% of the true level (e.g., says "100 kWh" and the true average is 104.87 kWh). We find that 35.40% of the respondents meet this definition and are thus quantity-attentive.

We use the same criteria (referred to the "What is your average electricity bill…?" question) to define a bill-attentive person, but, due to the frequent tariff revisions during our study period, we i) restricted the calculation of "true" bills to the most recent heating season prior to the survey (October 2015 to April 2016), and ii) used nominal bills to compute the respondent's true average. We classified as bill-attentive 29.40% of the respondents. About 14% of the respondents are both quantity- and bill-attentive. Quantity- and bill-attentiveness may be thought of as rough proxies for awareness of the IBR system and recent tariff changes.

Quantity-attentive and bill-attentive consumers tend to provide more observations to the sample, but do not differ from the rest of the respondents in terms of housing type, size and vintage of the dwelling, recent renovations, education, income, being a benefits recipient, and mode of payment of their bills.[14] They are however significantly less likely to be using electric heat, and, if quantity-attentive, they tend to use less electricity each month.[15]

Finally, about 15% of the respondents indicated that they simply "did not know" the tariffs per kWh that applied to them at the time of the survey. The remainder appears to be listing the tariffs in force at the time of the survey correctly. In practice, we judge only the "don't know" responses to be genuine and credible, as the other respondents may have simply recited the tariffs off the bills as they were handing them to the enumerators.

6. RESULTS

A. Preliminary Data Checks: Is There Attrition Bias?

Since our study subjects were asked to show their bills during the survey, our first order of business is to check for any evidence of selection into the sample or other anomalies that may invalidate our demand estimation effort. The enumerators assured us that the respondents did their best to produce their records, and we would of course expect most people to have kept, and be able to quickly find, primarily the most recent bills.

Indeed, we have a total of 11,706 valid observations on monthly electricity usage, and 14.57% came from a 2016 billing period (recall that the most recent bill possible at the time of the survey is from April 2016, since the survey was conducted in May 2016), 42.98% from 2015, 26.77% from 2014, and 15.08% from 2013. Figure 5 shows that 22.77% of the households were able to provide usage information for all of the 40 months covered by our study period, 7.87% between 30 and 39, 25.88% between 20 and 29, 42.33% between 10 and 19, and 1.24% between 1 and 9.

This is an unbalanced panel, and we wish to make sure that estimation is not affected by attrition bias, with respondents that produce more bills having, all else the same, systematically different (larger or smaller) consumption levels that those who contributed fewer observations to the panel. We started with running a simple logit model where the dependent variable is a dummy denoting whether electricity usage information is available for respondent i in period t, and the independent variables are house characteristics, time dummies and weather. The results are shown in Table 6. There are indeed statistically significant associations between the type of home and the availability of the bill, but the most important predictors are the year dummies. The logit regression confirms that availability is best for 2015 bills.

We do not expect the "attrition" in our sample to invalidate our demand estimates. When we regress log electricity usage on its usual determinants (except for price, as this would require instrumenting for) in a pooled data framework, the number of valid electricity observations available for a household is not a significant predictor of the dependent variable (Table 7, panel (A)). This finding does not change when we further control for whether the respondent is quantity-attentive (panel (B)).

When we revise this model to include household-specific fixed effects as well as a dummy denoting whether the electricity usage information was present in the previous period (see Wooldridge, 2010, page 832–833), the coefficient on this latter variable is insignificant at the conven-

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[14] About 45% of the respondents pay their electricity bills at the post office, and 48% at their bank. Online payments and automatic debt systems are only now starting to be used in Ukraine, and are used by only 5% and 1% of the respondents, respectively.

[15] Quantity-attentive households use about 14% less electricity each month than the other families, and bill-attentive about 5.7% less, but in the latter case the difference is not statistically significant at the conventional levels.

Figure 5: Length of the longitudinal component of the panel.

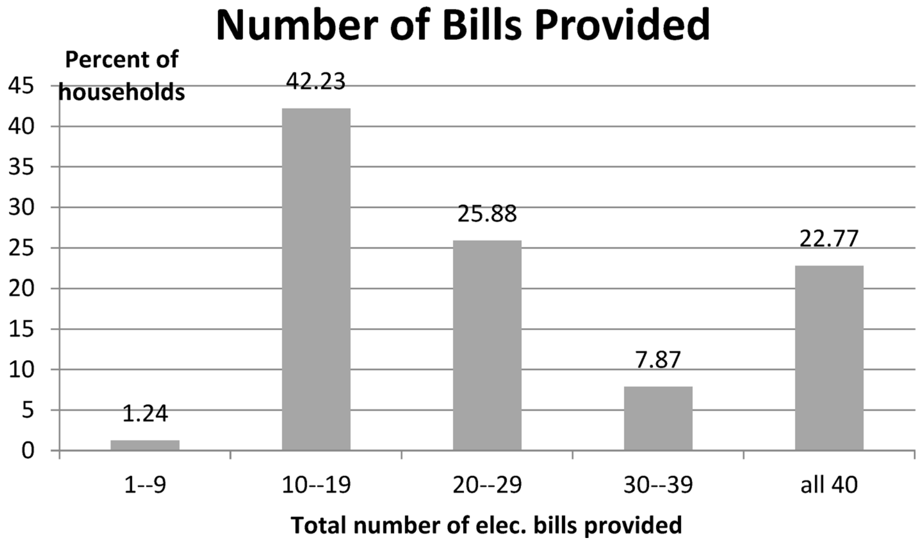

Table 6: Determinants of panel length: Logit model.

	Coeff.	Std. Err.	t stat	
constant	–1.49518	0.124612	–12.00	***
SFhome	0.344991	0.092035	3.75	***
multifamily	0.248359	0.092886	2.67	**
Month				
2	0.041571	0.074452	0.56	
3	0.128026	0.074627	1.72	
4	0.052685	0.074473	0.71	
5	0.275798	0.079311	3.48	***
6	0.353258	0.079381	4.45	***
7	0.346513	0.079373	4.37	***
8	0.417442	0.079466	5.25	***
9	0.39377	0.079432	4.96	***
10	0.424212	0.079477	5.34	***
11	0.550068	0.079726	6.90	***
12	0.75429	0.080355	9.39	***
Year				
2014	0.92098	0.038397	23.99	***
2015	2.496028	0.045293	55.11	***
2016	2.84848	0.073609	38.70	***
square meters	–0.00082	0.000335	–2.46	**
Gas heat dummy	0.175797	0.053218	3.30	***
Elec heat dummy	0.083812	0.066796	1.25	
log likelihood		–11235.9		
LR test that all slopes=0		4669.18		
p value		<0.000001		

Note: Dependent variable: electricity usage of household i is present/absent in period t.

tional levels (Table 7, panel (C)). The coefficient on this key regressor remains insignificant when we add the quantity-attentive dummy interacted with whether electricity information was present in the previous period. The coefficient on the interaction itself is statistically insignificant at the conventional levels (panel (D)).

Table 7: Tests of attrition bias: Tests of the null that coefficient on key regressor is zero. Standard errors clustered at the respondent levels.

	OLS		within estimator	
Key regressor:	(A) Coeff. (t stat.)	(B) Coeff. (t stat.)	(C) Coeff. (t stat.)	(D) Coeff. (t stat.)
Total number of observations provided by the household	0.000495 (0.22)	0.00040 (0.18)		
Present in previous period dummy			0.02009 (1.09)	0.0331 (1.32)
controls (square meters, type of home, HDD, gas heat, elec heat)	Yes	Yes	Yes	Yes
Quantity-attentive dummy	No	Yes[a]	No	Yes[b]
month FE	Yes	Yes	Yes	Yes
year FE	Yes	Yes	Yes	Yes
household FE	No	Yes	Yes	Yes

[a] Coefficient on quantity-attentive dummy: 0.0113 (t stat. 0.22)

[b] The quantity-attentive dummy is interacted with the dummy denoting whether the observation was present in the previous period. The coefficient on the interaction is –0.0390 (t stat. –1.17).

B. Evidence of Bunching

Standard economic theory is based on the marginal price, which in the presence of block pricing is the price in the tier where the consumer's usage falls. Borenstein (2009) shows that under this assumption one should expect "bunching"—a spike in the observed frequency of usage levels—at the threshold between one block and the next. Only with large measurement and optimization errors would such a tendency disappear. Bunching was also studied—and documented with different intensity at different kink points in the tax schedule—by Saez (2010) with household income taxes.

Ito (2014) uses residential electricity consumption data from Southern California and finds no evidence of bunching at the block thresholds, which prompts him to propose that households actually respond to the *average* price. He finds empirical support for this conjecture, and shows that consumer reliance on the average price has the potential to offset the conservation incentives implicit in block pricing and actually increase consumption with respect to the level that would be selected if the consumer focused on marginal price.

In an effort to determine whether the consumers in our sample respond to the average or marginal price, we construct usage histograms. Since the utility applies blocks of different size, depending on whether a consumer has electric or non-electric heat, and artificial blocks are further created by the "benefits" schedule, attention is restricted to households with gas or other non-electric heat (over three quarters of our households) and no "benefits." We further separate the sample into the observations from January 2013 to March 2015 (when the block cutoffs were 150 and 800 kWh/month), and from April 2015 (when the block cutoffs were moved to 100 and 600 kWh/month) to April 2016.

The corresponding histograms are striking—although sometimes difficult to interpret. For example, the one in Figure 6 (earlier period, until March 2015) seems to suggest that there is bunching at 150 kWh/month, but also a much more pronounced spike in the frequency of the data at 100 kWh/month, even though the latter was not a tier cutoff in that period. It is possible that people were already reacting to future revisions that had already been announced.[16] There are also minor spikes in the distribution at various other consumption levels.

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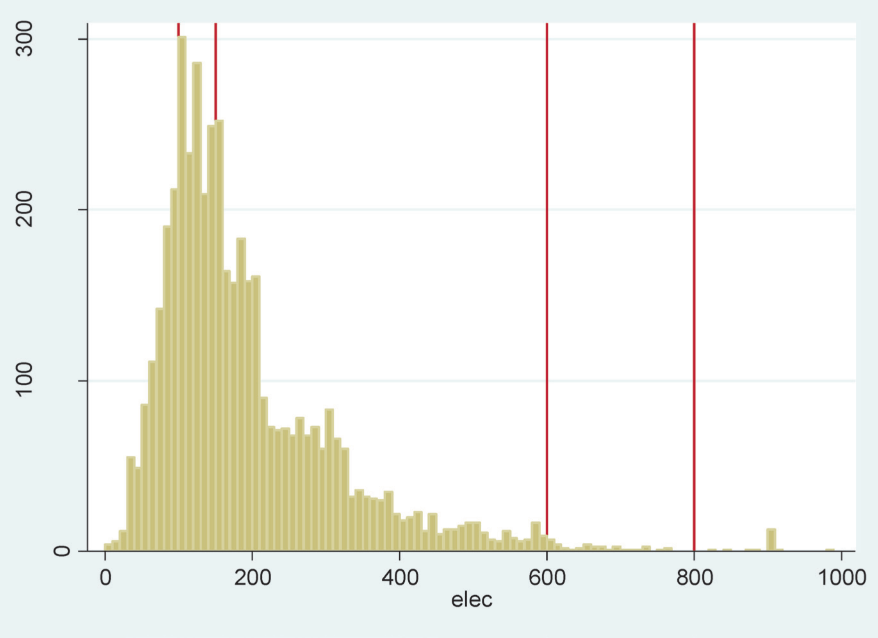
[16] Formal McCrary tests indicate that there are significant discontinuities in the density at 100 and 150 kWh/month (statistics 8.16 and 6.50, respectively), but do not find evidence of a discontinuity at 600 kWh/month (statistic 1.30) and cannot be computed for any reasonable bandwidths around 800 kWh/month.

Figure 6: Histogram of usage for households without electric heat and without benefits, January 2013–March 2015.



Notes: The block cutoffs are 150 and 800 kWh per month. Also shown are vertical lines at 100 and 600 kWh.

Figure 7 (later period, starting with March 2016) suggests strong evidence of bunching at the 100 and 600 levels (the thresholds in the revised block system)—but a clearly visible spike remains at 150 kWh, suggesting that perhaps not everyone reacted right away to the new system.[17] Taken together, the two histograms suggest to us that people pay attention to the consumption tiers and presumably to the marginal price in each block, although in some cases the "perceived" block cutoffs may be different from the actual ones.[18]

C. Estimation Results.

In the presence of increasing block rates, the marginal price is endogenous and positively correlated with quantity consumed. This means that if one were to run an OLS regression of (log) quantity on (log) marginal price, we would expect the coefficient on (log) price to be positive (and of course biased and inconsistent). This is indeed the case with our data: Even with household and time fixed effects, plus a full set of weather controls, the OLS coefficient on log marginal price is 0.5427 (t statistic based on clustered standard errors 10.24). On furthering entering single-family (SF) home-by-month and income-by-month terms, the coefficient on log marginal price remains positive (0.5530; t statistic 10.93). Clearly, one must use instrumental variable techniques to get results in line with economic theory.

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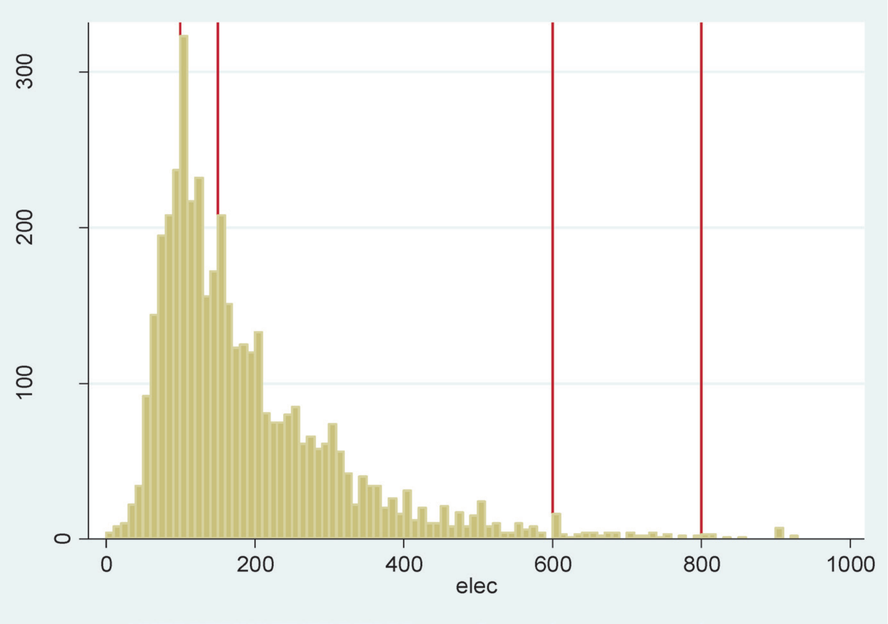
[17] The McCrary test rejects the null of no discontinuity at 100 and 150 kWh/month at the conventional levels (statistics 8.86 and 6.10, respectively) and cannot be computed for 600 and 800 kWh/month.

[18] When the histograms of figures 6 and 7 are constructed for quantity-attentive respondents and all others, they display patterns like the ones in figures 6 and 7.

Figure 7: Histogram of usage for households without electric heat and without benefits, April 2015–April 2016.



Note: The blocks cutoffs are 100 and 600 kWh per month.

Table 8 summarizes the results from the first stage, showing that the full tariff schedule (augmented with the allowance, the discount on the tariff for benefit recipients, and the interaction between these two terms) *is* a strong predictor of log marginal price. In both specifications shown in Table 8, the F statistic for the excluded instruments is well over 200, indicating that the excluded instruments are strong instruments. We also report the difference-in- Sargan statistics, which test the null that the allowance and the allowance interacted with the tariff discount are valid instruments. For large samples and under the null, this so-called C statistic is distributed as a chi square with two degrees of freedom. For each of the two specifications of Table 8, the C test fails to reject the null that those two excluded instruments are exogenous.[19]

Table 9 reports the second-stage results for equation (1), for the full sample and a variety of subsamples. We use log marginal price, on reasoning that the histograms of Figures 6–7 suggest that consumers generally pay attention to the tariff system tiers, real or imagined. (For good measure, we re-run all regressions using log average price. The results, displayed in Appendix A, are generally very similar to those based on log marginal price, in part because the average and marginal price are identical for the 40% of the observations that fall within the first block.)

When the full sample is used, the (short-run) price elasticity is estimated to be –0.31. Adding SF home-by-month and income-by-month terms brings the price elasticity to –0.25. Running weighted least squares with weights equal to $1/T_i$, where T_i is the number of observations contributed by household *i* to the panel dataset, yields a price elasticity of –0.30. That people respond to prices seems to be coming primarily from households living in apartments in multi-family buildings, as families living in single-family homes are unresponsive to price changes (price elasticity

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[19] The outcomes of the F and C tests are similar when the sample is restricted to certain groups of people or residents in certain types of homes as shown in Table 9. See Baum et al. (2003) and Wooldridge (2010, p. 134–137).

Table 8: Electricity demand estimation: First stage.

Excluded instruments	(A) Base specification	(B) Augmented set of non-excluded instruments
Log price in block 1 × before April 2015 dummy	1.4655	1.4726
	(12.03)	(12.07)
Log price in block 2 × before April 2015 dummy	–0.1570	–0.1652
	(–6.50)	(–6.87)
Log price in block 3 × before April 2015 dummy	0.1748	0.1941
	(4.37)	(4.78)
Log price in block 1 × on or after April 2015 dummy	3.4005	3.4108
	(31.77)	(31.83)
Log price in block 2 × on or after April 2015 dummy	–0.9850	–1.0059
	(–22.92)	(–23.11)
Log price in block 3 × on or after April 2015 dummy*	—	—
Allowance (monthly allowance in kWh)	–0.0013	–0.0013
	(–4.32)	(–4.31)
Fraction of block 1 price paid (less than 1 only if household receives benefits)	0.0855	0.0905
	(0.98)	(1.06)
Allowance × fraction of block 1 price paid	0.0016	0.0016
	(3.10)	(1.06)
Nobs	11672	11672
Number of households	482	482
F test on excluded instruments	264.43	243.44
	(p value < 0.00001)	(p value < 0.00001)
C test of the null that allowance and allowance × percent price paid are exogenous	0.943	1.674
	(p value=0.6242)	(p value=0.4329)

Notes: Selected coefficients from the first stage, where the dependent variable is log marginal price, and the independent variables include household-specific fixed effects, month-by-year fixed effects, a full set of weather controls, plus the instruments listed in the table. Specification (A) is our base specification. Specification (B) also includes SF home-by-month and income-by-month terms as non-excluded instruments. T statistics based on standard errors clustered at the household level in parentheses.

*: omitted for collinearity reasons.

–0.09, with a t statistic of –0.71). Identification appears to rely heavily on the tariff revisions that took place after March 2015: When the sample is restricted to the observations from January 2013 to March 2015, the estimation routine produces an implausibly large elasticity (–0.93), most likely due to the limited variation in prices.[20]

The elasticity gets stronger when benefit recipients are removed from the sample (–0.40) and when we drop households with electric heat who have not undertaken energy efficiency upgrades in the last three years (row (M) of Table 9), and weaker when we exclude households with electric heat who *have* done energy-efficiency renovations in their home in the last three years (row (L)). It is in line with the figure for the full sample (–0.29) when we drop the observations from homes who recently underwent energy efficiency upgrades (rows (K) and (L)).

Splitting the sample into groups roughly corresponding to the terciles of the distribution of income produces price elasticities that are similar across the first and third tercile, and a bit weaker in the second tercile. The elasticity drops when one uses the instrumenting approach suggested by McFadden et al. (1977) (row (Q)).

[20] The F test statistics for the joint significance of the excluded instruments are 120 or more, reject the null at the conventional levels, and greatly exceed the Stock-Yogo critical values for biases up to 30% and size of the test up to 25%, for all of the regressions summarized into Table 9 (and Appendix Table A.1), *except* for the one in row (G). Similarly, the F test points to weak instruments when the sample excludes all households with electric heat, which results in a likewise implausible price elasticity of –1.45. McRae and Meeks (2016) report elasticities close to one or even greater than one for specific subsets of their sample in Kyrgyzstan, even though we understand their study period to contain only two price change events.

Table 9: Electricity demand estimation: Selected coefficients from the log-log model with household fixed effects, month-by-year effects, and a full set of weather controls.

Description of the sample or specification	Coeff. on log marginal price	t statistic	Nobs	Households
(A) All	–0.3115	–4.33	11672	481
(B) add SF home-by-month fixed effects and income interacted with month dummies	–0.2533	–3.72	11672	481
(C) All, using weights equal to $1/T_i$	–0.3022	–3.80	11672	481
(D) add SF home-by-month fixed effects and income interacted with month dummies; use weights equal to $1/T_i$	–0.2575	–3.40	11672	481
(E) Single family homes	–0.0877	–0.71	4689	195
(F) Apartments in multi-family buildings	–0.2750	–3.45	6625	270
(G) Jan 2013-Mar 2015	–0.9330	–3.35	6087	415
(H) April 2015 and later	–0.2066	–3.14	5571	475
(I) No recipients of benefits	–0.4026	–5.04	10461	435
(J) Drop bottom and top 1%	–0.2301	–2.95	11411	481
(K) Exclude families that have done energy-efficiency upgrades in the home in the last 3 years	–0.2944	–3.90	8677	349
(L) Exclude families with electric heat who have done energy-efficiency upgrades in the home in the last 3 years	–0.2859	–3.85	11068	457
(M) Exclude families with electric heat who haven't done energy-efficiency upgrades in the last 3 years	–0.3834	–2.27	10466	431
(N) Income in the bottom tercile of the distribution in the sample	–0.3527	–2.17	2844	
(O) Income in the middle tercile of the distribution in the sample	–0.1797	–1.91	3612	
(P) Income in the top tercile of the distribution in the sample	–0.3866	–3.37	3991	
(Q) Use McFadden approach to computing expected marginal price	–0.1160	–3.35	11672	481
(R) place allowance and allowance × discount among the non-excluded instruments	–0.3669	–4.90	11672	481
(S) place allowance and allowance × discount among the non-excluded instruments; specification is augmented with SF home-by-month and income-by-month terms	–0.3114	–4.33	11672	481

Notes: Log marginal price is instrumented for. T statistics based on standard errors clustered at the respondent level.

One may wonder whether the allowance for persons on benefits, which we regard as exogenous for institutional reasons and based on the Sargan difference C tests, is a true excluded instrument, on reasoning that the allowance depends on house size, and house size is generally a strong predictor of electricity consumption (see, for example, Alberini et al., 2011). In rows (R) and (S) of Table 9 we report the IV-estimated price elasticities when allowance and allowance interacted with the tariff discount are regarded as non-excluded instruments. The elasticities are stronger, but still within 20% of their counterparts in rows (A) and (B), respectively.

In Table 10 we examine whether attentiveness affects the responsiveness to prices, and find that quantity-attentive respondents tend to have a somewhat more elastic demand than non-attentive respondents. But bill-attentive persons differ little in their price sensitivity from persons who not bill-attentive. Persons who are both quantity- and bill-attentive exhibit stronger elasticity (–0.5630) but this result should be interpreted with caution, as it might an econometric artifact due to the somewhat more limited variability in price for this group than for the full sample and small sample size. It is, of course, entirely possible that quantity- and bill-attentive households became attentive *because* they were looking for ways to reduce their usage and to save money. The possibility of reverse causality is also acknowledged in McRae and Meeks (2016). Excluding from the sample persons who admit that they do not know the current electricity tariffs doesn't affect the estimated

Table 10: Effect of attentiveness to consumption or expenditure levels.

	(A) Quantity-attentive respondents	(B) Non quantity-attentive respondents	(C) Bill-attentive respondents	(D) Non bill-attentive respondents	(E) Both quantity- and bill-attentive	(F) No respondents who do not know current tariffs	(G) Only respondents who do not know current tariffs
Coefficient on log marginal price	–0.3486	–0.2393	–0.2903	–0.2903	–0.5630	–0.3054	–0.3094
t statistic	–2.18	–3.16	–2.11	–3.76	–2.33	–4.09	–1.14
Nobs	4667	7005	3693	7980	1935	10133	1560
households	304	146	146	336	70	407	75

Notes: Models include household fixed effects, month-by-year fixed effects, and detailed weather controls. Log price is instrumented for. T statistics based on standard errors clustered at the respondent level.

Table 11: Effects over time.

	(A) 1 month before + 1 month after	(B) 1 month before + 2 months after	(C) 2 months before + 2 months after	(D) 3 months before + 3 months after
Coefficient on log marginal price	–0.1775	–0.2047	–0.2723	–0.3024
t statistic	–2.48	–3.24	–3.81	–4.04
Nobs	3591	4705	6470	8716
Households	480	481	481	481

Notes: Log-log model with household fixed effects, month-by-year effects, detailed weather controls. Log price is instrumented for. Data are restricted to a narrow window before and after the tariff revision. T statistics based on standard errors clustered at the respondent level.

price elasticity. Limiting the sample to just those persons who do not know the tariffs results in a similar, but statistically insignificant, elasticity (–0.3094).[21]

Turning to the question of how quickly households adjust their electricity demand to price change, Table 11 suggests that the estimates are reasonably stable when the sample is restricted to observations within a narrow window around the price change (one month before and one month after, etc.). The elasticity does become about 50% more pronounced as we move from the one-month to the three-month bandwidth. This is consistent with the notion that one new bill at the higher tariffs is sufficient to provide feedback that prompts the consumers to limit usage.[22]

For comparison purposes, we also fit a dynamic panel model, obtaining a short-run price elasticity of –0.2114 and a "mid-run" elasticity of –0.40 (Appendix B). The elasticities are more pronounced when log average price is used (–0.27 and –0.52, respectively).

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[21] Surprisingly, when we estimate our model with log average price from the same agnostic or uninformed sample, the price elasticity is stronger (–0.6554), but statistically significant only at the 10% (Table A.2 in Appendix A). Perhaps these respondents pay more attention to the bill amount, and hence to the average price, than to the marginal block prices.

[22] Since the sample of column (D) in Table 11 includes observations from the samples in columns (C), (B) and (A), it is not possible to do a Wald test of the null that the respective price elasticities are equal, as the samples lack independence. However, the 95% confidence interval around the price elasticity in (D) is (–0.4491, –0.1557), which implies that the point estimate from column (A) falls—barely—at the upper end of it. Likewise, the 95% confidence interval around the price elasticity from column (A) is (–0.3178, –0.0372), which means that the point estimate from column (D) falls—barely—at lower end of it. Even though this is not conclusive in a statistical sense, we interpret this as consistent with the notion that the longer the time to adjust, the stronger the responsiveness to price changes.

D. Consumer Welfare and Environmental Implications

At the average monthly usage level (224 kWh), which falls in the second block, the marginal price was on average 0.6276 UAH/kWh in March 2015 (in April 2016 UAH). By October 2015, when the next heating season started, it had jumped to 0.9804 UAH/kWh (April 2016 UAH), or a 56% increase in real terms. We compute that the corresponding loss of consumer surplus was 73.50 UAH per month. The loss of surplus is thus just over half the average monthly bill, which is 126 UAH. We get similar results when we use the average price per kWh, which likewise rose by 56% between March and October.

Based on our results, we predict that such a pronounced price hike would produce a 0.3048×56=17.07% decline in electricity consumption. This translates into 2700×0.1707=461 kWh for the average household on an annual basis. Since the CO_2 content of each kWh generated in Ukraine is 0.5631 kg,[23] this is equivalent to 0.260 fewer tons of CO_2 emitted for the average household in our sample. The cost of each ton avoided would be very high: Dividing the lost consumer surplus (73.50 UAH per month) by the corresponding CO_2 emissions reduced (0.022 tons per month) gives a cost per ton of some 3341 UAH, or 131 US$.[24, 25]

5. DISCUSSION AND CONCLUSIONS

We have used a unique dataset documenting monthly electricity meter readings from Ukrainian households to study the responsiveness to large tariff increases. Residential electricity demand is generally thought to be price inelastic, and one would expect this to be the case at a locale with comparatively smaller homes and fewer appliances than in Western Europe or the US. Yet, the tariff changes were very substantial, and we estimate a short-run price elasticity of –0.2 to –0.5, with values getting stronger as when we allow for some time to elapse since a tariff revision. In sharp contrast to other studies (e.g., Reiss and White, 2005; McRae and Meeks, 2016), our estimates of the short-run price elasticity are within a narrow range, even among respondents who were attentive to consumption or the bills, or admitted not knowing what the tariffs are. Only for few subsets of respondents do we find a price elasticity that approaches one, but those estimates appear to be due an artifact of the poor performance of the instrumental variable estimation procedure.

People were thus willing and able to reduce usage promptly, but the price elasticity of demand is much less than one. With only 15% of our sample using electricity as the main heating fuel and only 9 families using electricity as a secondary heating fuel, it is unlikely that electricity usage reductions would have been achieved through major energy-efficiency upgrades such as new windows, insulation, etc. Indeed, households who report using electricity for heating purposes are no more likely to do those renovations than the rest of the sample. Excluding the homes with electric

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[23] See https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf. The carbon dioxide emissions rate is thus very high for a country that relies on nuclear for 51% of its electricity generation, with the remainder from coal (39%), natural gas (7%) and hydro (5%) (figures for 2014; see http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine.aspx and https://data.oecd.org/energy/electricity-generation.htm). For comparison, the corresponding rate in the US is 0.547, in France 0.07, in Italy 0.41, and in Germany, as of 2011, 0.67.

[24] Even under the most inelastic demand (at an estimated price elasticity of –0.11, as per the McFadden et al. approach), we would predict a decline in usage per household by 166 kWh a year, for a 6.16% reduction in CO_2 emissions.

[25] In Ukraine a carbon tax is currently applied to energy commodities used by stationary sources (primarily industrial users) (Frey, 2015). This tax was first levied in 2011 and its amount rose from 0.2 UAH/ton of CO2 (in 2011) to 0.26 UAH/ton of CO_2 (2015). Frey predicts that the tax would have to be raised by two orders of magnitude (to 40 UAH/ton) for it to achieve the 10% reduction in emissions set by the Ukrainian government.

heat and/or recent renovations from the sample has little effect on our estimates of the electricity. We also found only one respondent that may have been a former electricity heat user and converted his heating system to gas during our study period, only one person who reports replacing his electrical heating system (presumably with a more efficient one) in this last three years, and no respondents at all who use electricity as a secondary heating system and replaced the main or secondary heating system in the last three years. Anecdotal evidence suggests that people managed to save electricity by being even more careful turning off lights, unplugging appliances when not in use, running clothes washers and dishwashers only with full loads, purchasing more efficient appliances, and, even more important, replacing light bulbs with LEDs.

Our calculations suggest that the price changes entailed meaningful welfare losses for most families. For example, for consumers in the second block—the majority—the rate increase in April 2015 implied that in October of that month the average consumer experienced a loss of consumer of surplus of 73.50 UAH—a little over half the average monthly bill, which is 126 UAH. We estimate the same price increase to result in a 17.07% decline in electricity consumption and 0.260 fewer tons of CO_2 per household per year. The cost of each ton, based on the consumer welfare loss alone, would thus be a high 3341 UAH, or 131 US$.

We have estimated the price elasticity of electricity demand from a relatively small area in Ukraine where meters measure consumption for each individual dwelling. The results from our study offer suggestions for the possible response to tariff reforms at other locales—in Ukraine, other transition economies, and middle-income countries. We emphasize that the homes in our sample, like all households in the Uzhhorod area, are individually metered. The response to tariff hikes may be completely different in settings with master metering, such as other parts of Ukraine or with district heating elsewhere in Ukraine or other transition countries.

A common problem at many of these locales is that the utilities' revenues are insufficient to cover the cost of generating and delivering electricity or making improvements to the grid. If a sufficiently large share of the population is relatively price-inelastic, and can afford to pay, part of the revenues from these customers can be used to subsidize poorer consumers—or energy efficiency investments. McRae (2015) discusses the potential pitfalls of such an approach, which, unless carefully designed, may lock poor households into a low-quality, high-interruption equilibrium.

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REFERENCES

Alberini, A., W. Gans, and D. Velez-Lopez (2011). "Residential Consumption of Gas and Electricity in the U.S.: The Role of Prices and Income," *Energy Economics* 33(5): 870–881. https://doi.org/10.1016/j.eneco.2011.01.015.

Baum, C.F., M.E. Schaffer, and S. Stillman (2003),."Instrumental variables and GMM: Estimation and Testing." *The Stata Journal* 3(1): 1–31. https://doi.org/10.1177/1536867X0300300101.

Bastos, P., L. Castro, J. Cristia, and C. Scartascini (2011),.“Does Energy Consumption Respond to Price Shocks?” IDB working paper IDB-WP-234, Inter-American Development Bank, Washington, DC, January.

Bell, E., and M. Blundell (2016). “2015 California Statewide Critical Peak Pricing Evaluation,” DRMEC Spring 2016, San Francisco, California.

Borenstein, S. (2009). “To What Electricity Price Do Consumers Respond? Residential Demand Elasticity Under Increasing-Block Pricing.” University of California Berkeley.

Frey, M. (2015). “Assessing the Impact of a Carbon Tax in Ukraine,” available at https://www.gtap.agecon.purdue.edu/resources/download/7495.pdf

Herter, K. and S. Wayland (2010). “Residential Response to Critical-peak Pricing of Electricity: California Evidence.” *Energy* 35: 1561–1567. https://doi.org/10.1016/j.energy.2009.07.022.

Hewitt, J.A., and W.M. Hanemann (1995). “A Discrete/Continuous Choice Approach to Residential Water Demand under Block Rate Pricing.” *Land Economics* 71(2): 173–192. https://doi.org/10.2307/3146499.

Hortaçsu, A., S.A. Madanizadeh, and S.L. Puller (2017). “Power to Choose? An Analysis of Consumer Inertia in the Residential Electricity Market.” *American Economic Journal: Economic Policy* 9(4): 192–226. https://doi.org/10.1257/pol.20150235.

INOGATE (2015). *A Review of Energy Tariffs in INOGATE Partner Countries*, available at http://www.inogate.org/documents/A_Review_of_Energy_Tariffs_in_INOGATE_Partner_Countries.pdf

International Energy Agency (2016). *CO_2 Emissions from Fuel Combustion. Highlights*, available at https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustion_Highlights_2016.pdf (last accessed 21 October 2017).

Ito, K. (2014). “Do Consumers Respond to Marginal or Average Price? Evidence from Nonlinear Electricity Pricing.” *American Economic Review* 104(2): 537–63. https://doi.org/10.1257/aer.104.2.537.

Jessoe, K. and D. Rapson (2014). “Knowledge is (Less) Power: Experimental Evidence from Residential Energy Use.” *American Economic Review* 104(4): 1417–1438. https://doi.org/10.1257/aer.104.4.1417.

Kahn, M.E. and F.A. Wolak (2013). “Using Information to Improve the Effectiveness of Non-Linear Pricing: Evidence from a Field Experiment,” available at http://web.stanford.edu/group/fwolak/cgi-bin/sites/default/files/files/kahn_wolak_July_2_2013.pdf (last accessed 1 November 2017)

Liebman, J.B. and R.J. Zeckhauser (2004). “Schmeduling,” available at https://sites.hks.harvard.edu/jeffreyliebman/schmeduling.pdf

Mansur, E.T. and S.M. Olmstead (2012). “The Value of Scarce Water: Measuring the Inefficiency of Municipal Regulations.” *Journal of Urban Economics* 71(3): 332–346. https://doi.org/10.1016/j.jue.2011.11.003.

McFadden, D., C. Puig, and D. Kirshner (1977), “‘Determinants of the Long-Run Demand for Electricity.” *Proceedings of the American Statistical Association* 109–19. 17.

Miller, M. and A. Alberini (2016), “Sensitivity of Price Elasticity of Demand to Aggregation, Unobserved Heterogeneity, Price Trends, and Price Endogeneity: Evidence from US Data.” *Energy Policy* 97: 235–246. https://doi.org/10.1016/j.enpol.2016.07.031.

McRae, S. (2015). “Infrastructure Quality and the Subsidy Trap.” *American Economic Review* 105(1): 35–66. https://doi.org/10.1257/aer.20110572.

McRae, S. and R. Meeks (2016). “Price Perception and Electricity Demand with Nonlinear Tariffs,” mimeo, September.

Nieswiadomy, M.L. and D.J. Molina (1989). “Comparing Residential Water Demand Estimates under Decreasing and Increasing Block Rates using Household Data.” *Land Economics* 65(3): 280–289. https://doi.org/10.2307/3146672.

Pon, S. (2017). “The Effect of Information on TOU Residential Use: An Irish Residential Study.” *The Energy Journal* 38(6): 55–79. https://doi.org/10.5547/01956574.38.6.spon.

Reiss, P.C. and M.W. White (2005), “Household Electricity Demand, Revisited.” *Review of Economic Studies* 72: 851–883. https://doi.org/10.1111/0034-6527.00354.

Rozwalka, P. and H. Torfengren (2016). “The Ukrainian Residential Gas Sector: A Market Untapped.” The Oxford Institute for Energy Studies paper NG 109, University of Oxford, July. https://doi.org/10.26889/9781784670603.

Saez, E. (2010). “Do Taxpayers Bunch at Kink Points?” *America Economic Journal: Economic Policy* 2(3): 180–212. https://doi.org/10.1257/pol.2.3.180.

Shin, J. (1985). “Perception of Price When Price Information is Costly: Evidence from Residential Electricity Demand.” *Review of Economics and Statistics* 67: 591–598. https://doi.org/10.2307/1924803.

Wolak, F.A. (*2011). “*Do Customers Respond to Hourly Prices? Evidence from a Dynamic Pricing Experiment**.”** *American Economic Review* 101(3): 83–87. https://doi.org/10.1257/aer.101.3.83.

Wooldridge, J.M. (2010). *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.