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# THE ELASTICITY OF ELECTRICITY DEMAND AND CARBON EMISSIONS REDUCTIONS IN THE RESIDENTIAL SECTOR: EVIDENCE FROM A TARIFF SHIFT IN RUSSIA

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$$\frac{1!}{(m-1)!} p^{m-1} (1-p)^{n-m} = p \sum_{\ell=0}^{n-1} \frac{\ell+1}{n} \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p \frac{n-1}{n} \sum_{\ell=0}^{n-1} \left[ \frac{\ell}{n-1} + \frac{1}{n-1} \right] \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p^2 \frac{n-1}{n} +$$

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# The Elasticity of Electricity Demand and Carbon Emissions Reductions in the Residential Sector: Evidence from a Tariff Shift in Russia

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## **Abstract:**

In this paper, I estimate the price elasticity of residential electricity demand using household-level panel data for Russia. The study takes advantage of the variation in tariffs across regions and over time, as well as the introduction of increasing block rate (IBR) tariff schemes in a number of regions. I show that in those regions consumers appear to be aware of the block cut-offs, even though the latter are household and dwelling-specific, to the point that there are a total of 35 different tier cut-offs. Based on these results, I estimate the price elasticity of electricity demand to be around -0.09. I also predict the associated changes in electricity consumption, CO<sub>2</sub> emissions, and revenues if similar IBR policies are implemented countrywide.

**JEL:** Q41, Q48, L98, L94

**Keywords:** residential electricity demand, transition economy, natural experiment, increasing block rates, attentiveness, CO<sub>2</sub> emissions

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## 1. Introduction

The energy sector has been long identified as one of the largest contributors to greenhouse gas (GHG) emissions, which in turn are linked with climate change (IPCC, 2021). A number of remedies have been proposed to reduce reliance on fossil fuels and encourage the development of renewable energy sources, including tradable allowance systems and a carbon tax (OECD, 2018).

The success of a carbon tax depends crucially on the price elasticity of electricity demand. There is however little consensus on the magnitude of the price elasticity of electricity demand either in the short or the long run (see, for instance, Labandeira et al., 2017 for a literature review). The lack of consensus is due to many reasons. In the literature that spans over decades, different estimates of the price elasticity have been obtained in studies conducted at different times and locations, during periods when prices were dropping or rising, and in studies based on micro and more aggregated data (Miller and Alberini, 2015). In addition, there is a paucity of quasi-experimental studies, where one can observe both exogenous variation in prices and a suitable control group (Deryugina et al., 2018).

In this paper, I exploit the Russian Longitudinal Monitoring Survey (RLMS) conducted by the National Research University Higher School of Economics (HSE) and the Carolina Population Center at the University of Carolina. RLMS-HSE is a household-level panel data for Russia, one of the world's major exporters (and consumers) of energy. The study takes advantage of unique data and a unique setting to estimate the price elasticity of electricity demand. I combine the implementation of the increasing block rate tariff (IBR) for residential electricity in a number of experimental regions of Russia in 2013, with an instrumental variable estimation approach and estimate price elasticity for electricity demand. I show that in those

regions consumers appear to be aware of the block cut-offs, even though the latter are household- and dwelling-specific, to the point that there are a total of 35 different tier cut-offs, indicating that the households are aware and react to the marginal prices of electricity. This is in sharp contrast to the previous research (see, Borenstein, 2009; Ito, 2014) where authors argue that the consumers tend to react to the average prices, rather than marginal ones, opposing the theoretical prediction of standard consumer theory. Based on these results, I estimate the price elasticity of electricity demand to be around -0.09.

I combine the point estimates of the elasticity with information about the regional carbon intensity of electricity generation in Russia to predict the associated changes in residential electricity consumption, revenues, and CO<sub>2</sub> emissions if a similar IBR policy was extended countrywide.

I find that with the introduction of the IBR tariff scheme a typical Russian household will reduce its annual consumption of electricity by approximately 1% (25.45 KWh). This in turn results in a 17.768 kg annual reduction in CO<sub>2</sub> emission on average per household or 0.96 million tons nationwide. This negligible effect on electricity use and emissions follows from the low price elasticity. The silver lining of such low-price elasticity is that the revenues from residential electricity consumption will increase by about 700 million USD per annum.

## **2. Literature review**

The literature on the price elasticity of demand for residential electricity is vast. However, up to this date, there is little consensus on the magnitude of the parameter of the elasticity either in the short or long run. Various studies report the range of estimated elasticities anywhere between practically zero to -2.0 in the short run, and -0.07 to -2.5 in the long run (see,

Espey and Espey, 2004; Alberini et al., 2011; Alberini and Filippini, 2011, for a brief literature review).

For instance, one of the first to estimate the price elasticity of demand for residential electricity was the study by Wilder and Willenborg (1975). The authors argue that previous research (Anderson, 1973; Halvorsen, 1973; Houthakker et al., 1974) that studied the electricity demand was handicapped by the unavailability of micro-level data. Using micro-level data for a single metropolitan area in South Carolina (USA), the authors estimate the price elasticity of demand to be around -1.0.

Acton et al., (1977) also estimated the price elasticity for Los Angeles using census data for the periods of 1972 to 1974. In contrast to the previous studies Acton et al., (1977) use marginal price in their regression specification and found the price elasticity of electricity to be in the order of -0.3 to -0.7. At the same time Murray et al., (1978) gave a more careful consideration to the declining block price structure of residential electricity prices and estimated the price elasticity of electricity demand in the USA, Virginia to be in the range of -0.5 to -0.9. Walker (1979), on the other hand, employed a micro-level data estimation on randomly chosen households in College Station town of Texas and documented a more inconsiderable short-run price elasticity of -0.14.

Wills (1981) finds that inframarginal demand charge inherent in declining block rates is a statistically insignificant determinant of energy use and argues that it can be neglected in regression equations without biasing the price elasticity estimates, or any other coefficients of the regression. He finds that the price elasticity in Massachusetts (USA) is -0.18 for consumers that use primarily electricity, and -0.52 for consumers that combine electricity with some other type

of energy source. Barnes et al., (1981) also arrive at a similar magnitude of elasticity (-0.55) analyzing data for US households for the period of 1972-1973.

Using a subsample of the 1975 survey of 3249 households in the US, Dubin, and McFadden (1984) also show that if the demand for durables and their use are related decisions, the specifications which ignore this fact will lead to biased and inconsistent estimates of price and income elasticities. Moreover, Henson (1984) shows that in the presence of increasing block rate schedules inappropriate use of OLS overestimates the rate-structure premium effect on demand and underestimates the price elasticity. The author shows that in the case of the IBR schedule the use of the instrumental variable approach provides consistent parameter estimates.

In addition, Berndt and Samaniego (1984) argue that for developing countries one should make a structural distinction between access to electricity and its consumption. Their paper shows that in developing countries like Mexico increase in income has a “double whammy” effect on electricity consumption, first in terms of increasing the number of households connected to electricity services, and second in terms of increasing the consumption of households already connected to a grid. This in turn has important implications in calculating the elasticities of electricity consumption, as one can underestimate the elasticity if the structural distinction is not taken into account.

Shin (1985) investigates the consumption patterns of US consumers and finds that contrary to economic theory consumers respond to average prices rather than marginal prices in the presence of decreasing block rate tariff schemes. The author suggests that earlier studies that did not consider the consumers’ perception of price correctly should be reconsidered.

Using a rich survey panel data for the USA, Branch (1993) estimates the price elasticity of demand to be -0.20 when controlled for household characteristics, housing characteristic data,



and appliance inventory data. Herriges and King (1994) also estimate the elasticity demand of the same magnitude (-0.2 to -0.4) using a controlled experiment for the household data in the US confirming the relative inelastic electricity demand.

Bernard and Belanger (1996) estimate the price elasticity of demand for electricity in Quebec (Canada) using various econometric specifications (OLS, IV) on household-level microdata. They find that households which use only electricity as the primary energy source are insensitive to electricity price changes, as the estimated demand elasticities for these households are statistically insignificant from zero. On the other hand, households that use some combination of energy sources (gas, oil, wood, electricity) have a more elastic demand exceeding unity.

Reiss and White (2005) estimated the price elasticity for electricity in California following the introduction of a five-tier tariff scheme in this state. Using a moment estimator, they report the short-run price elasticity of -0.39. Bernstein and Griffin (2006), on the other hand, estimate both short and long-run demand elasticities for electricity across US states. They conclude that on average the price elasticity is about -0.2 in the short run and -0.3 in the long run across the states.

Fan and Hyndman (2011) analyze whether there is any variation in price sensitivity with regards to the time of day or quantile of electricity consumption taking into account the possible specification forms of the relationships that may exist in South Australia. Their reported range for a price elasticity varies from -0.363 to -0.428.

Alberini et al., (2011) estimate the elasticities of a higher magnitude in the 50 largest metropolitan areas in the US using household-level panel/multi-year cross-sections household data for 1997-2007. Their estimates range from -0.667 to -0.860. Contrary to Reiss and White

(2005) they find no evidence of significantly different elasticities across households with different energy sources.

Exploiting price variation at spatial discontinuities in electricity service areas in the US, Ito (2014) confirms the argument of Shin (1985) and shows that consumers respond to average price and do not respond to marginal or expected marginal price. He shows that this sub-optimizing behavior makes nonlinear pricing unsuccessful in achieving its policy goal of energy conservation and substantially changes the efficiency cost of nonlinear pricing.

Alberini et al., (2019) estimate the price elasticity of demand for electricity in the presence of extreme energy price changes. Analyzing a 50-% rise in energy prices in Ukraine for the period of 2013 to 2016 authors conclude that even in the presence of extreme changes in energy prices the demand remains quite inelastic (-0.2 to -0.5) with the bulk of elasticity estimates around -0.3.

Finally, Deryugina and colleagues (2020) exploit an exogenous variation of electricity prices in over 250 Illinois communities and conclude that the price elasticity of demand grows from -0.09 in the first six months to -0.27 two years later. Authors, emphasize the importance of accounting for the long-run consumption dynamics when evaluating energy policies.

As evident from the literature above, there is no clear-cut consensus among the studies on electricity demand. The lack of consensus is in part due to the absence of quasi-experimental studies, where one can observe both an exogenous variation in price and a suitable control group (Deryugina et al., 2018). Moreover, to the best of the author's knowledge, there are still no studies analyzing the residential demand for electricity in the Russian Federation, one of the major exporter and consumer of world energy sources. In this study, I attempt to close this gap

in the literature by analyzing the elasticity of electricity demand in Russia by exploiting the panel household data RLMS-HSE, and a natural experiment described below.

### **3. Background**

Russia has the fourth-largest electric power system in the world with a total capacity of 243GW. Generation is mainly (about 67%) accomplished by thermal power plants running almost exclusively on natural gas and coal. The remaining 30% of electricity generation is supplied by hydroelectric power stations (20%) and nuclear power plants (12%) (Sidorenko, 2011; Josefson et al., 2017).

Before 2003 the whole power sector was a part of a fully integrated state monopoly, RAO UES. However, after the start of liberalization of the power sector, the RAO UES was unbundled into 20 independent power companies by 2008. The trend has been reversed in recent years, as there has been seen a reconsolidation of power assets. As of 2012, the large transmission and distribution assets were reunited under a state-controlled, Russian Grids public joint-stock company (PJSC). Nowadays, power grids are largely owned and operated by Russian Grids PJSC, with transmission and distribution of power to over 70% of the Russian population and to industrial facilities that account for over 60% of the Russian GDP (Josefson et al., 2017).

The pricing of electricity has been gradually liberalized, and currently, about 80% of electric power is traded at non-regulated market prices. However, the public is still likely to continue to receive electric power at state-regulated prices in the foreseeable future, as residential tariffs are set by the Federal Antimonopoly Service (Josefson et al., 2017).

Residential electricity pricing in Russia is still primarily based on a flat tariff regime, albeit with a considerable variation in price per kilowatt across regions. In a recent attempt to

introduce a cross-subsidizing scheme, where households with relatively higher electricity consumption subsidize part of the cost of supplying households that consume less electricity, Russia introduced social norms for electricity consumption in seven pilot regions starting in September 2013, with a plan to introduce social norms in all regions of Russia (henceforth referred to as “experimental regions”) starting in July 2014 (Samofalova, 2014).

Those households that consume within the prescribed social norm pay a lower unit price for electricity, whereas those that consume above the prescribed social norm pay a higher price. The prescribed social norm is calculated on a per capita basis and is different in each of the seven experimental regions (“oblasts”). It also depends on such factors as whether the household is located in an urban or rural area, whether it receives any social benefits, and whether it has an electric stove as a primary source of cooking. The social norm varies from 50 kWh per capita in Vladimir Oblast to 190 kWh per capita in Orlov Oblast (Veretennikova, 2014). In some of the experimental regions, the calculation of the social norm is also complicated by whether the household is located in a rural or urban area, has an electric cooking stove, or has members that receive benefits (see, Table 1).

In practice, the “social norm” functions in the same way as “increasing block rate” (IBR) schemes in other countries: Consumption below a designated level is priced at a lower price per unit, whereas consumption above this level is priced at a higher price per unit. All of the seven experimental regions have thus effectively implemented a two-block tariff regime. As illustrated below ( Figure 1), the block cutoffs depend on the individual characteristics of the household and of the dwelling where they reside.

Originally the government was planning to extend the social norms and its associated IBR to all regions of Russia, but for various reasons, the implementation of this plan was

suspended for an indefinite period (Veretennikova, 2014; Antonov, 2018). The original plan called for nine pilot regions, but two of them (Primorsky Krai, and Lipetsk Oblast) opted out prior to September 2013. These regions argued that the methodology for the calculation of the social norms provided by the federal government was too vague-an argument supported by the considerable differences in social norms across some of the seven experimental regions, even though some of them have nearly identical weather, and socio-economic conditions (Veretennikova, 2014).

We use this argument to our advantage, as it shows that the calculation of the social norms was done exogenously, which in turn favors our estimation procedures. As explained below, I use several waves of the Russia RLMS-HSE (Russian Longitudinal Monitoring Survey-Higher School of Economics) to examine how consumers responded to tariff changes. It is important to note that out of the seven regions that implemented the social norm/IBR scheme, only three (Rostov Oblast, Krasnoyarsk Krai, and Nizhny Novgorod Oblast) are covered by the RLMS-HSE.<sup>1</sup> Table 1 and Figure 1 summarize the main information regarding the social norms in these three regions of Russia.<sup>2</sup>

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<sup>1</sup> The others social norms/IBR regions (not covered by the RLMS-HSE) are Zabaykalsky Krai, Vladimir Oblast, Oryol Oblast, Samara Oblast.

<sup>2</sup> The regional social norms for the residential electricity consumption were obtained from the regional energy suppliers. For more information see, Old.donland.ru (2019); Ševcov (2018), and “Social norm” (2019).

**Table 1: The prescribed social norms for electricity consumption**

Region	<i>Rostov</i>			<i>Krasnoyarsk</i>			<i>Nizhny Novgorod</i>		
	n=1	n=2	n=3+	n=1	n=2	n=3+	n=1	n=2	n=3+
<b>HH type</b>	n=1	n=2	n=3+	n=1	n=2	n=3+	n=1	n=2	n=3+
<b>urban</b>	96	156	$156+40\times(n-2)$	110	150	$75\times n$	85	100	$100+50\times(n-2)$
<b>rural</b>	186	246	$246+40\times(n-2)$						
<b>urban + electric stove</b>	186	242	$156+40\times(n-2)+43\times n$	220	300	$150\times n$	85	100	$100+50\times(n-2)$
<b>rural + electric stove</b>	276	332	$246+40\times(n-2)+43\times n$						
<b>receiving social benefits</b>	$\times 1.5$	$\times 1.5$	$\times 1.5$	$\times 1.0$	$\times 1.0$	$\times 1.0$	85	$\times 1.5$	$\times 1.5$

Source: Regional electricity suppliers. Note: “*n*” denotes the household size.

[Figure 1]<sup>3</sup>

#### 4. Data

##### 4.1. The RLMS-HSE

The study employs the Russian Longitudinal Monitoring Survey (RLMS) conducted by the National Research University Higher School of Economics (HSE) and the Carolina Population Center at the University of Carolina. RLMS-HSE is a panel dataset and includes a wide set of questions on individual and family background characteristics. The majority of the interviews for RLMS-HSE are conducted during October and November.

The survey has been conducted once a year in 38 regions of Russia since 1994 and is administered to about 6000 households each year. The sampling approach of RLMS-HSE, combined with annual replenishment, ensures that the sample is cross-sectionally representative

<sup>3</sup> All Figures can be found in Appendix A1.

for each round. The average attrition rate is about 10%, and the overall attrition after 10 years is about 50% (see Gerry & Papadopoulos, 2015, for more details).

Unfortunately, RLMS-HSE has recorded electricity consumption data only from the 14<sup>th</sup> to the 25<sup>th</sup> wave (2005 to 2016), and only for September in each year. Thus, we have electricity consumption information across 38 regions and 12 points in time (September of each year), which enables us to observe the electricity consumption before and after the introduction of the two-tier experimental tariffs.

We can also identify whether the dwelling is located in a multifamily building or is a single-family home, whether it is connected to the electricity grid, and/or the gas, water, hot water, and district heating networks. The size of the dwelling (in square meters) is divided into a total area and the area of the habitable rooms. The respondents are asked to indicate whether they own their homes. Information on the socio-economic characteristics of the household and the stock of appliances is available, along with information on subsidies on the utilities (in a form of discount and cash subsidies separately) received by the household, and arrears due (if any).

To further elaborate on the appliances, the questionnaire was revised in 2006 and 2009. For instance, starting in 2006 the questionnaire collected information only on a new type of refrigerator (no-frost), and on a new type of washing machine (automatic washing machine), as opposed to previous years when information on any type of refrigerator or washing machine was recorded. In 2009, the questionnaire added questions on the availability of air conditioners (A/C) and dish-washing machines. I use the waves from 2010 to 2016, as they bracket the time when the social norms/IBR scheme was introduced.

## **4.2 Descriptive Statistics**

Out of all of the 2010-2016 households, I retain the households that reported their electricity consumption (about 85%), and who own their home (about 90%). The study excludes households that report having an electric stove while also being connected to the central delivery of gas (about 1%). This leaves us with a total of 29551 non-singleton observations for the 2010-2016 years combined, 2292 of which ( about 8%) are in the treatment regions. Below I present summary statistics for households living in the three treatment regions and the control regions (all others).

**Table 2: Characteristics of the Home**

Variables	Control regions: Percent of the Sample or Mean (standard deviation in parentheses)	Treatment regions: Percent of the Sample or Mean (standard deviation in parentheses)	Difference in Means: Standard error in parentheses
<i>Type of dwelling:</i>			
Single-family home	27.2%	21.8%	5.4%***
Apartment in a multi-family building	72.6%	77.9%	-5.3%***
Size of the dwelling in square meters	56.014 (23.65)	54.343 (20.30)	1.671*** (0.38)
Urban	67.1%	93.9%	-26.7%***
Has an Electric stove	19.2%	37.4%	-18.2%***
<i>Has central delivery of:</i>			
Gas	70.0%	51.6%	18.3%***
Heating	70.1%	77.1%	-7.0%***
Hot water	64.7%	73.5%	-8.8%***
Cold Water	88.0%	91.2%	-3.3%***

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

**Table 3: Energy Consumption statistics: Monthly electricity usage for September.**

<i>Type of dwelling:</i>	Control regions: Mean (standard deviation in parentheses)	Treatment regions: Mean (standard deviation in parentheses)	Difference in Means: Standard error in parentheses
All households	179.58 (110.23)	186.13 (96.16)	-6.55*** (1.94)
Households living in Single-family homes	196.26	199.787	-3.527



	(125.35)	(105.23)	(4.447)
<b>Households living in apartments in multi-family buildings</b>	172.71 (102.65)	181.91 (92.70)	-9.2*** (2.1)
<b>Households in the urban area</b>	172.97 (103.38)	183.39 (95.00)	-10.4*** (1.92)
<b>Households in the rural area</b>	191.94 (121.05)	222.29 (103.96)	-30.35*** (7.82)
<b>Households with central heating</b>	174.08 (104.07)	180.61 (91.05)	-6.53*** (2.13)
<b>Households with no central heating</b>	191.31 (121.50)	202.20 (108.16)	-10.89*** (4.21)

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

**Table 4: Respondent Socioeconomics**

Variables	Control regions: Percent of the Sample or Mean (standard deviation in parentheses)	Treatment regions: Percent of the Sample or Mean (standard deviation in parentheses)	Difference in Means: Standard error in parentheses
<b>Household size</b>	2.76 (1.49)	2.808 (1.42)	-0.048** (0.024)
<b>Household monthly income (RU)</b>	67989.96 (57276)	67441.91 (45529)	548.054 (958.682)
<b>Receiving subsidies for utilities</b>	30%	25.6%	4.4%***
<b>Receiving discounts for utilities</b>	21%	23%	-2%**
<b>Have Debt for Utilities</b>	8.0%	7.6%	0.4%
<i>Education:</i>			
<b>Secondary</b>	33.4%	29%	4.3%***
<b>Professional-technical</b>	23.6%	24.8%	-1.2%*
<b>High education (MSc, BSc, DiS)</b>	24.5%	26.7%	-2.2%***
<b>Other</b>	18.2%	19%	-0.8%

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

The major difference between the IBR and non-IBR regions is that the “experimental” dwellings are located in more urbanized areas. The urbanization level of the treatment group is 93%, whereas in the control group it is 73%.

This difference in urbanization in turn is reflected in several other variables of interest. Central delivery of gas is about 16% higher in the control group (54% vs 70%), and there is a higher percentage of electric stoves in the treatment regions (34% as opposed to 18%).

Other observed characteristics are similar. The descriptive statistics show that the majority of the families reside in multi-apartment buildings. The average size of the household is

more than 50 m<sup>2</sup>, while the average number of household members is less than 3 individuals. The average household income is about 66,000 rubles (adjusted for 2019 rubles).

More than 20% of the households are receiving various “benefits” for the utilities. There are two main types of utility benefits for Russian households: subsidies, and discounts. Subsidies are short-term benefits given mostly based on household income, and specifically total utility payments as a share of total household income. Any person with permanent residents can apply for a subsidy. This subsidy is given for a period of six months, and every six months it needs to be renewed. The subsidy is given in a form of a cash-back. The household pays the monthly utility bill as usual, and then the payment for the bill is partially returned to the household by the government as cash.

Discounts, on the other hand, are permanent, and only certain segments of the population are eligible for them. These segments include but are not limited to war veterans, people with disabilities, and large families with children. The discounts are usually given in a form of reduced payment for all utilities, which typically range from 30% to 50% of the total utility bills, and are granted for a lifetime (in case of veterans, and disabled), or until the youngest child from a large family turns 16 or 18, depending on the region the family resides in (Necova, 2019; and “Benefits for paying for housing and communal services,” 2019). Table 5 reports descriptive statistics on appliances.

**Table 5: Home Appliances**

	Control regions	Treatment regions	Difference in Means:
<b>Appliance:</b>	<b>Percent of the Sample</b>		
<b>Air Conditioner</b>	8.5%	8.9%	-0.5%
<b>Dishwasher (automatic)</b>	3.2%	2.2%	1.0%***
<b>Refrigerator (no frost)</b>	54.8%	56.0%	-1.2%
<b>Washing machine (automatic)</b>	76.3%	82.8%	-6.5%***

Freezer	12.1%	21.7%	-9.6%***
Microwave	64.4%	64.5%	-0.1%
Personal computer (stationary)	43.4%	44.4%	1.0%
LCD TV	49.7%	55.1%	-5.4%***
CRT TV	73.8%	65.3%	8.5%***

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

### 4.3 Tariff Schedule

In addition to the large variation in social norms, we also observe a considerable variation in tariff schedules across both experimental and control regions. Figures 2-5 illustrate the historical monthly tariff schedules for the three experimental regions and the average tariff schedule for all control regions.

*[Figure-2]*

*[Figure-3]*

*[Figure-4]*

*[Figure-5]*

The tariff schedule in Russia changes usually once a year and simultaneously in all regions. It varies across regions substantially depending on the average income of the population and weather conditions, and across residential customers depending on access to the central gas supply. This is because households not served by the piped gas supply are forced to use electric stoves for cooking, which in turn increases their electricity consumption substantially. Thus, there were two different tariffs before September 2013—a flat tariff for households with an electric stove, and a different flat tariff for those without—and four tariffs after the introduction of the social norms in the 3 experimental regions (1<sup>st</sup> and 2<sup>nd</sup> tiers for households with electric stove, and without).

The average tariff for the first tier in all regions has increased from about 96 rubles per 100 kWh in September 2005 to 313 rubles in September 2016. The first-tier tariff in the experimental

and in the control, regions followed roughly the same patterns, increasing from 83 rubles to 334 rubles and from 97 rubles to 311 rubles 100 kWh, respectively, during the same period.

Tariffs for the second tier can be observed in the three experimental regions only starting from September 2013. The highest tariff for the second-tier consumption (consumption above prescribed social norm) was set in Nizhny Novgorod Oblast with a 212-ruble difference per 100 kWh between the first and second tiers. Rostov has a 114-rubles difference between the first and second tiers. The lowest tariff difference is observed in Krasnoyarsk, where it is only about 40 rubles.

The tariff schedule for the household with electric stoves followed an identical pattern, with a factor of roughly 0.7.

## **5. Methodology**

In the presence of block pricing schemes, marginal prices are endogenous (see, for instance, Alberini et al., 2019). A well-accepted method for dealing with endogenous marginal prices under non-linear price schedules is to instrument for (logarithm) price with the (logarithm) of the full tariff schedule (Mansur and Olmstead, 2012; Nieswiadomy and Molina, 1988), 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).

Therefore, in this study, I am exploiting exogenous variation in the tariffs, thanks to the revisions that are done to the tariffs in every region every year plus the introduction of the IBR in three of the regions covered by the RLMS-HSE. To tackle the endogeneity of prices in three

experimental regions I employ the Two-stage least squares (2SLS) model by instrumenting the (logarithm) marginal price for electricity by the (logarithm) full tariff schedule.

Thus, the study exploits the variation in tariffs across locations and time to fit the following electricity demand function:

$$\ln E_{it} = \alpha_i + \tau_t + X_{it}\gamma_1 + \ln P_{it}B_1 + S_{it}\gamma_2 + W\gamma_3 + \varepsilon_{it} \quad (1)$$

In this equation,  $\ln E_{it}$  is the natural logarithm of electricity consumption of household  $i$  in September of year  $t$ .  $\ln P$  is a logarithm of the marginal price of electricity (in 2019 rubles).  $S$  stands for the amount (in 2019 rubles) of any benefits for the utilities received by the given household.

$X$  is a vector of control variables like income of the household (in 2019 rubles), number of individuals residing in the household, and the amount of any arrears for the utilities. The terms  $\alpha_i$  and  $\tau_t$  stand for household and time fixed effects respectively. Our specification also controls for the weather conditions by including a rich set of weather variables given by the  $W$ .<sup>4</sup>

One difficulty with our sample is that the observations from the treated areas account for only about 8% of the total sample. I balance the sample by “matching” the treated households with similar households from the control regions. I use coarsened exact matching (CEM). The CEM procedure has several advantages over other matching techniques. In particular, it requires fewer assumptions and possesses more attractive statistical properties (Iacus et al., 2012). Applying matching to any particular estimator usually serves as a tool to reduce the imbalance

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<sup>4</sup> In particular, I control for the average monthly log of degree days, log of precipitation, log of wind speed, and log of humidity levels across all 38 regions under the study. The weather data was provided by [www.meteoblue.com](http://www.meteoblue.com).

between treatment and control groups, so that the empirical distribution of the covariates is more similar across the groups.

I match the treatment and control groups on the various household characteristics. More specifically, I match on the square footage and type of the dwelling (single-family home or apartment in a multi-family building), size of the household, location (urban, rural), household income, whether the household is connected to the gas, hot water, and central heating networks, and whether it has an electric stove.

## **6. Results**

### **6.1. Preliminary data checks**

Borenstein (2009), shows that with an IBR tariff regime, one should observe so-called “bunching” around the cutoffs of the consumption block rates. This bunching should be more pronounced with the price elasticity of demand is stronger, and if people can predict their consumption relatively precisely.

To check for the bunching around the consumption block cutoffs, I constructed histograms of the electricity usage in the treatment regions for the period after the introduction of the treatment. As we face different cut-off values for different regions, and different types of households, I have constructed a difference variable between the actual electricity consumption and the prescribed social norm for electricity consumption of this household. If the consumers indeed react to the marginal price as prescribed by the economic theory, then one should observe bunching around zero.

*[Figure 6]*

As evident from Figure 6, we can observe a bunching of electricity consumption in September for all post-treatment years in the experimental regions.

In addition, as we observe the electricity consumption only for one month of the year, we need to verify that the average electricity consumption in September is not abnormal, as this could potentially bias the results in general. For that purpose, I examine the monthly aggregate electricity production in Russia from 2010 to 2016.<sup>5</sup> The electricity production pattern depicted in Figure 7 looks quite similar to the production in other countries and exhibits a convex shape that spikes in December, and January while bottoming in June.

*[Figure 7]*

## 6.2 Regression results

To overcome the endogeneity of prices in the presence of the IBR tariff regime I ran two-stage least squares (2SLS) with the full tariff schedules as our instrumental variables. 2SLS is a well-established approach in dealing with endogeneity of price in the calculation of price elasticity in a presence of an IBR tariff regime (see, for instance, Alberini et al., 2019; Mansur and Olmstead, 2012; Nieswiadomy and Molina, 1989). The tariff in the price schedule is established by the authorities and is uncorrelated with the error term in equation (1), but correlated with the price household faces.

We expect a negative coefficient on logarithm price using 2SLS. By contrast, if one simply runs OLS, the price coefficient is positive and significant (Table 8), reflecting the mechanical, positive correlation between price and consumption—even if fixed effects are included.

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<sup>5</sup> We use Monthly production of electricity as a proxy for the monthly consumption. This is possible because Russia's electricity exports are almost nonexistent (as opposed to the exports of other energy sources) and comprise only about 2% of the total production (while also importing less than 1%) (TheGlobalEconomy, 2020).

The standard FE estimation and the 2SLS estimation results are reported in Table 8 in Column 1 and Column 2, respectively. Column 3 reports the 2SLS estimation results after applying the CEM procedure to make the treated households more comparable with the households in the control regions.

As the measure of the imbalance of the variables between the groups, I use a comprehensive imbalance statistics L1 (see, Blackwell et al., 2009), which shows the difference between the multidimensional histogram of all pretreatment covariates in the treated group and that in the control group given by:

$$L_1(f, g) = \frac{1}{2} \sum_{l_1 \dots l_k} |f_{l_1 \dots l_k} - g_{l_1 \dots l_k}| \quad (2)$$

Where  $f_{l_1 \dots l_k}$  and  $g_{l_1 \dots l_k}$  are the  $k$ -dimensional relative frequencies for the treated and control groups respectively calculated from the cross-tabulation of the discretized (coarsened) covariates.

The matching estimator performs reasonably well in our specification. The multivariate L1 distance statistics indicates an improvement in the balance of covariates between groups. First, I run L1 distance statistics on unmatched data which will then serve as a point of comparison (a baseline reference) for the matched data. If L1 statistics is closer to zero on a match data, as compared to its unmatched counterpart then we can argue that there was an improvement in the balance of covariates across the treatment and control groups after the matching procedure. It also should be noted that the absolute values of the L1 statistics mean less than comparisons between the matching solutions. In this sense, the L1 statistics work for imbalance as R-squared works for the model fit (Iacus et al., 2012).

In our case, the multivariate L1 distance statistics for the unmatched data is 0.77, while for the matched data it is equal to 0.716. Out of a total of 27259 observations in the control



regions, and 2292 observations in the treatment regions, 6768 observations from control regions, and two observations from treatment regions were not matched between groups. The remaining observations were matched.

**Table 8:** Regression results:

	(1) FE	(2) FE_2SLS	(3) FE_2SLS_cem
lnPrice	0.1362*** (0.042)	-0.0962* (0.049)	-0.0855* (0.050)
lnSubsidies	-0.0001 (0.001)	-0.0001 (0.001)	0.0007 (0.001)
lnDiscounts	0.0013 (0.001)	0.0012 (0.001)	0.0006 (0.001)
lnArrears	0.0028* (0.002)	0.0028* (0.002)	0.0016 (0.002)
lnIncome	0.0369*** (0.008)	0.0370*** (0.008)	0.0323*** (0.009)
HHsize	0.0969*** (0.006)	0.0963*** (0.006)	0.1081*** (0.007)
lnDD	0.0046 (0.014)	0.0045 (0.014)	0.0189 (0.016)
lnPrecipit.	-0.0107** (0.004)	-0.0120*** (0.004)	-0.0092* (0.005)
lnHumidity	0.2094*** (0.043)	0.2198*** (0.044)	0.2090*** (0.051)
lnWinds	-0.0126 (0.026)	-0.0100 (0.026)	-0.0154 (0.029)
year11	0.0053 (0.009)	0.0106 (0.009)	0.0052 (0.011)
year12	0.0158 (0.010)	0.0185* (0.010)	0.0100 (0.011)

year13	0.0485 <sup>***</sup> (0.010)	0.0697 <sup>***</sup> (0.011)	0.0639 <sup>***</sup> (0.012)
year14	0.0544 <sup>***</sup> (0.010)	0.0646 <sup>***</sup> (0.010)	0.0640 <sup>***</sup> (0.011)
year15	0.0202 <sup>*</sup> (0.011)	0.0358 <sup>***</sup> (0.011)	0.0239 <sup>*</sup> (0.013)
year16	0.0174 (0.012)	0.0202 <sup>*</sup> (0.012)	0.0176 (0.014)
_cons	2.6293 <sup>***</sup> (0.316)		
<i>N</i>	29551	29551	22781
adj. <i>R</i> <sup>2</sup>	0.029	0.0276	0.031
<i>F</i>	28.0033	26.9684	22.6823
<i>p</i>	0.0000	0.0000	0.0000

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The standard errors are clustered at the household level.

Source: Authors' calculations.

The IV diagnostics for our model performs well.<sup>6</sup> The  $F$ -statistics of excluded instruments is highly statistically significant, and most of the block-tariff schemes included as instruments are statistically significant. The Sargan-Hansen test of overidentifying restrictions with the joint null hypothesis that the instruments are valid, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation also performs well, and the null hypothesis cannot be rejected at any conventional level of confidence.

The second stages of the regressions with matching, and without matching provide fairly identical results. The estimated elasticities of electricity demand, and the elasticity of income in a context of 2SLS with matching procedure prior are close to the elasticities estimated in a context of 2SLS without matching. Both elasticities are significant at 10-% and have expected signs,

<sup>6</sup> The first stage regression results are available in the Appendix A2. Please note that due to the block cut-offs being household and dwelling specific, there are a total of 35 different tier cut-offs.

although the magnitude is about 10-% lower in the case of matching. The price elasticities are -0.0855 and -0.0962, while income elasticities are 0.0323 and 0.037 in the case of 2SLS estimations with and without matching respectively. It is interesting to note that the income elasticity is significant at 1%, which is in accord with Turdaliev (2021) where the author also estimates a highly statistically significant effect of income on the propensity of Russian households to purchase major electrical appliances. These results indicate that income plays a stable, and consistent role in the determination of the households' electricity consumption behavior in Russia.

The effect of the utility benefits both as a direct cash transfer and as a discount for household utilities is statistically insignificant. However, the presence of arrears for household utilities is significant at 10%; although, the actual coefficient is close to zero.

The family size as expected is a positive and statistically significant determinant of electricity consumption.

### **6.3 Policy Simulation**

We also conduct a policy simulation exercise for the projected changes in CO2 emissions and revenues from the projected changes in electricity consumption using the estimated coefficient of price elasticity for electricity demand.

We start the exercise by computing the change in average marginal prices for electricity paid by households in RLMS-HSE data in treatment regions (employing the sampling weights provided within the RLMS-HSE) before and after the introduction of the IBR during the period under the study, e.g., 2010-2016.

Based on household data the average marginal price in treatment regions during the pre-treatment period (2010-2012) is equal to 306.22 rubles per 100 kWh, and the average marginal

price in the same regions during the post-treatment period (2013-2016) is equal to 334.62 rubles per 100 kWh. Therefore, the average difference between the average marginal prices before and after the introduction of IBR is equal to 9.3% in real terms.

Using the information above, and the price elasticity of demand estimated above, I calculate the average percentage change in electricity consumption in Russian households if the IBR pricing system would be implemented nationwide. It should be noted, however, that this exercise assumes that the households in the control regions will react similarly to the introduction of the IBR as the households in the treatment regions. In other words, the price elasticity for electricity demand is identical in treatment and control regions.

Having calculated the average change in electricity consumption allows us to calculate the average change in CO<sub>2</sub> emissions and revenue from electricity consumption per household. For that purpose, I use the regional carbon intensity of electricity generation presented in Table 10, and the average yearly residential electricity consumption data provided by the International Energy Agency (2015).

**Table 10: Carbon intensity of electricity generation, by region in Russia**

Region:	Electricity generation from using ...				Carbon intensity, in kg CO <sub>2</sub> per kWh
	Gas %	Coal %	Hydro %	Nuclear %	
North West	43	15	14	28	0.374394837
Central	60	11	4	25	0.421110277
South	64	1	29	6	0.339690513
Volga	67	2	22	9	0.365336605
Urals	72	25	0	3	0.625707484
Siberia	6	46	48	0	0.500148683
Far East	17	50	33	0	0.59758478

Source: McKinsey & Company (2009)

All the calculation results are summarized in Table 11 below:

**Table 11: Simulation of the impact on energy use, CO<sub>2</sub> emissions, and utility revenues**

Projected yearly	Per household change	Country-level change
Electricity consumption	(-) 24.716 kWh	(-) 1.33 bln kWh
Co2 emission	(-) 17.768 kg	(-) 0.96 mil.T
State Revenue	(+) 791 rubles	(+) 42.54 bln rubles (691 mil. USD)

The yearly average reduction in electricity consumption of approximately 1% is calculated based on the coefficient on the price elasticity of demand and the average change in marginal prices before and after the introduction of IBR in treatment regions. The country-level changes are calculated by multiplying the average household change by the total number of households (approx. 55 mln) in the Russian Federation (Worldometer, 2020).

Table 11 shows that the average annual reduction in household electricity consumption is 24.716 kWh, while the nationwide reduction in electricity consumption that results from the simulated policy is 1.33 bln kWh a year. This accounts for less than 1% (0.9%) of 139.971 bln of total residential electricity consumption in Russia (International Energy Agency, 2015). This in turn results in 0.96 mln tons in CO<sub>2</sub> reduction, which is 0.06% of total yearly CO<sub>2</sub> emissions in Russia (Statista, 2020).

Having a relatively inelastic price elasticity of demand (-0.9) also implies that introducing the same IBR policy that was implemented in treatment regions (and which resulted in an average 10% increase in electricity price) would also result in increased residential electricity revenues for the state. I estimate that the state will receive an additional 691 mln USD (in 2016 US dollars) per year as a result of the introduction of the IBR policy nationwide.

## 7. Conclusion

In this study, I have estimated the price elasticity for residential electricity demand in Russia using household-level survey data and exogenous variation resulting from the introduction of the IBR tariff scheme in a number of regions. The estimated price elasticity of demand is roughly -0.09. The study documents that households react to the marginal price, and

appear to be aware of the block cut-offs, even though the latter are household and dwelling-specific, to the point that there are a total of 35 different tier cut-offs. This is in sharp contrast to the findings in other studies which show that households actually respond to average price rather than marginal block price (see, Borenstein, 2009; Ito, 2014).

Using the estimated point elasticity I predict the annual changes in electricity consumption, CO<sub>2</sub> emissions, and revenues if a similar IBR pricing scheme would be introduced countrywide. I find that the average Russian household will reduce its consumption by about 1%, which taking into account the regional carbon intensity of electricity generation results in 17.768 kg of annual reduction in CO<sub>2</sub> emissions per household or 0.96 mln tons nationwide. Taking into consideration the relatively inelastic electricity demand, I also document that the associated changes for annual electricity revenues in the residential sector will be approximately equal to 700 mln USD.

Finally, some limitations of this study must be acknowledged. We do not observe households' electricity consumption in any months other than September in RLMS-HSE. Therefore, the estimated price and the income elasticities are based on the differences in the observed electricity consumptions across Russian cities for September. I show, however, that September is not an abnormal month in terms of electricity consumption by displaying the monthly total electricity generation across Russia. Nonetheless, we still cannot genuinely observe the electricity consumption in any months other than September for the households that actually take part in the calculation of the point elasticities.

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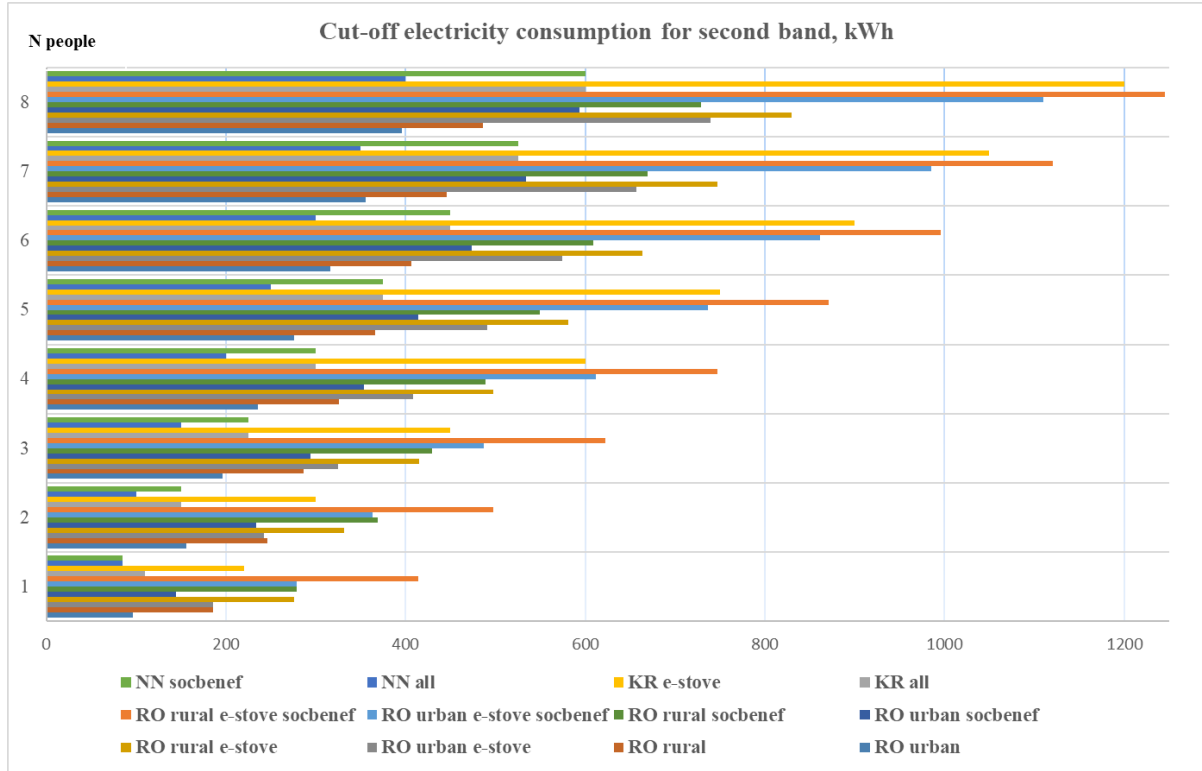


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# Appendix A1:

**Figure 1**



**Note:** Since in Nizhny Novgorod (NN) the second band cut-off differs only for households with social benefits, the graph depicts the second band cut-off for all households and those on social benefits. The same reasoning applies to Krasnoyarsk (KR), where the graph depicts cut-offs for households with electric stoves and all others. On the other hand, the calculation of the cut-off in Rostov (RO) is more complex and depends on such factors as location (rural or urban), electric stove, social benefits, and all possible combinations of these three factors.

Source: Regional electricity suppliers.

**Figure 2.** Source: Federal State Statistics Service, (2020).

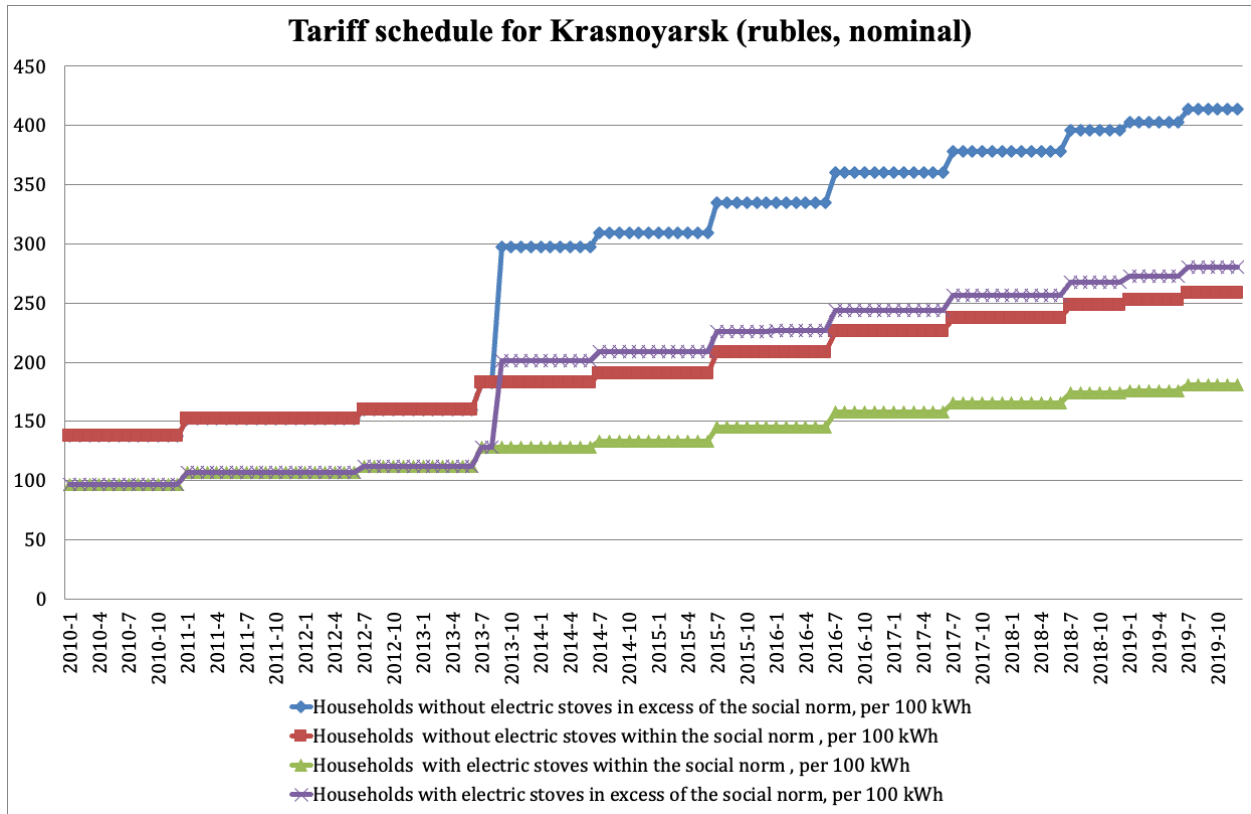
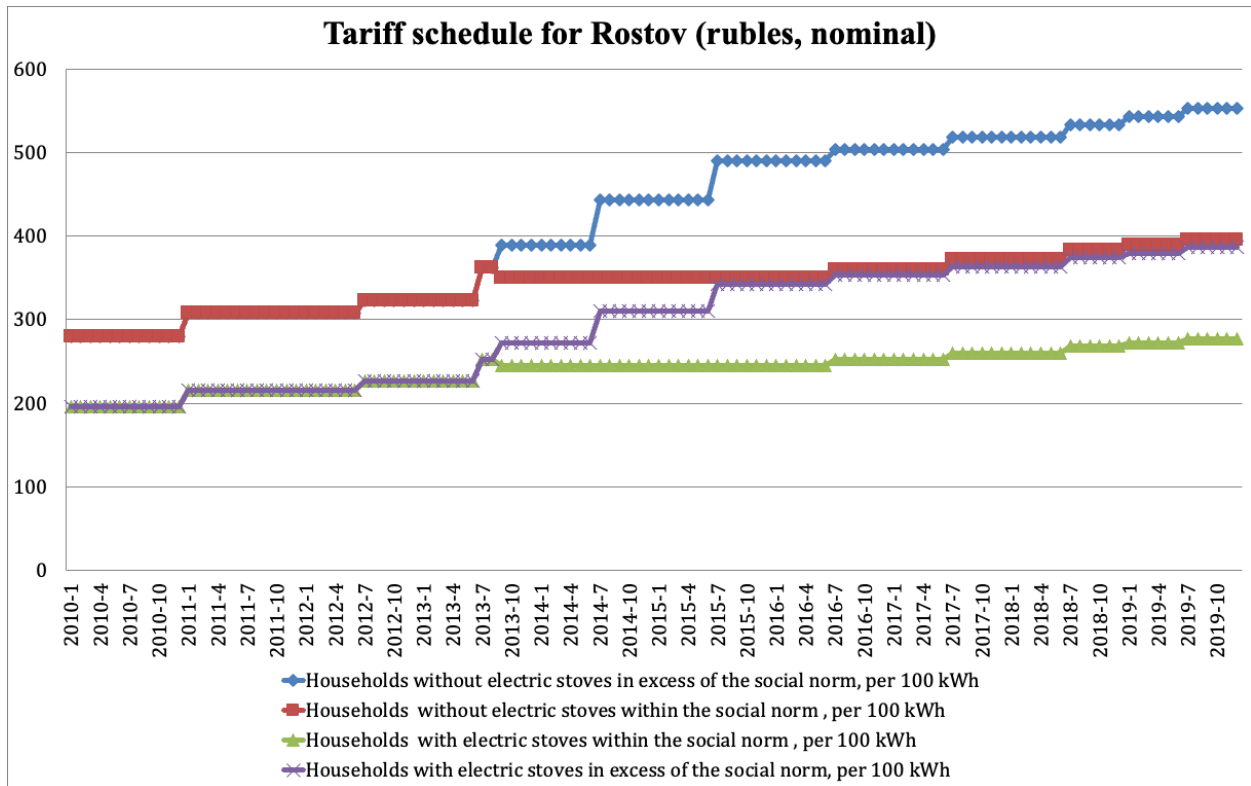
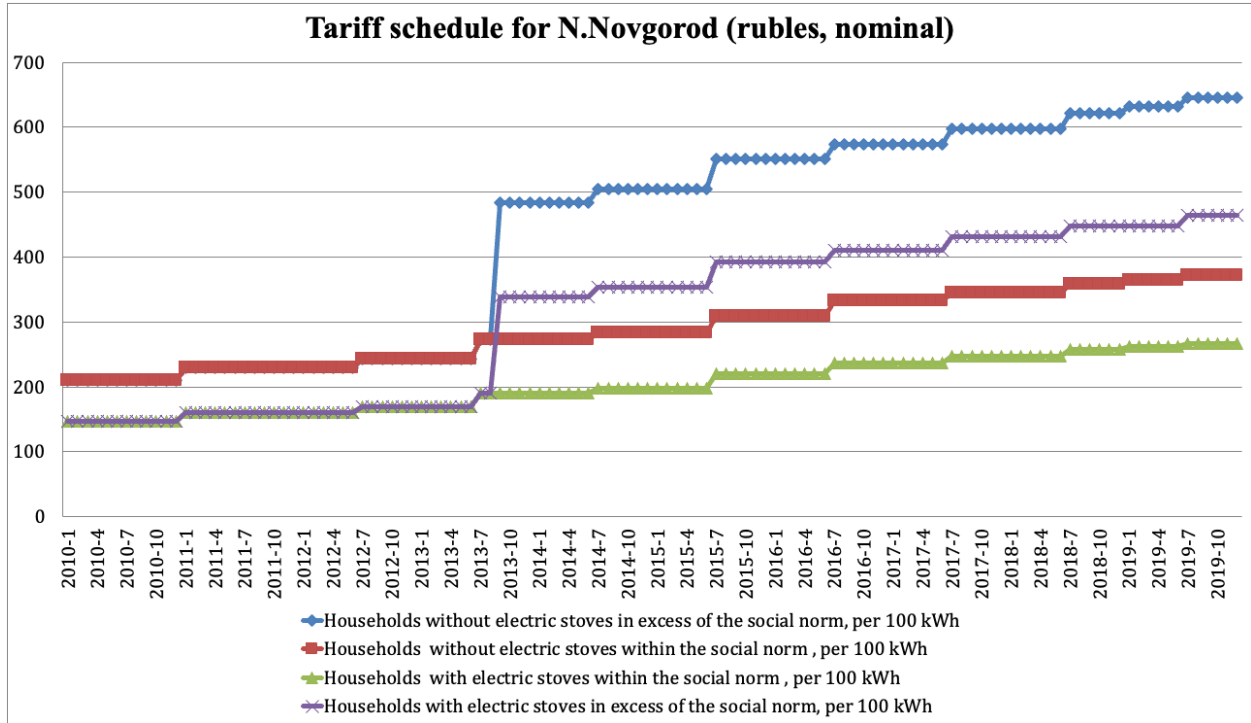


Figure 3. Source: Federal State Statistics Service, (2020).



**Figure 4.** Source: Federal State Statistics Service, (2020).



**Figure 5.** Source: Federal State Statistics Service, (2020).

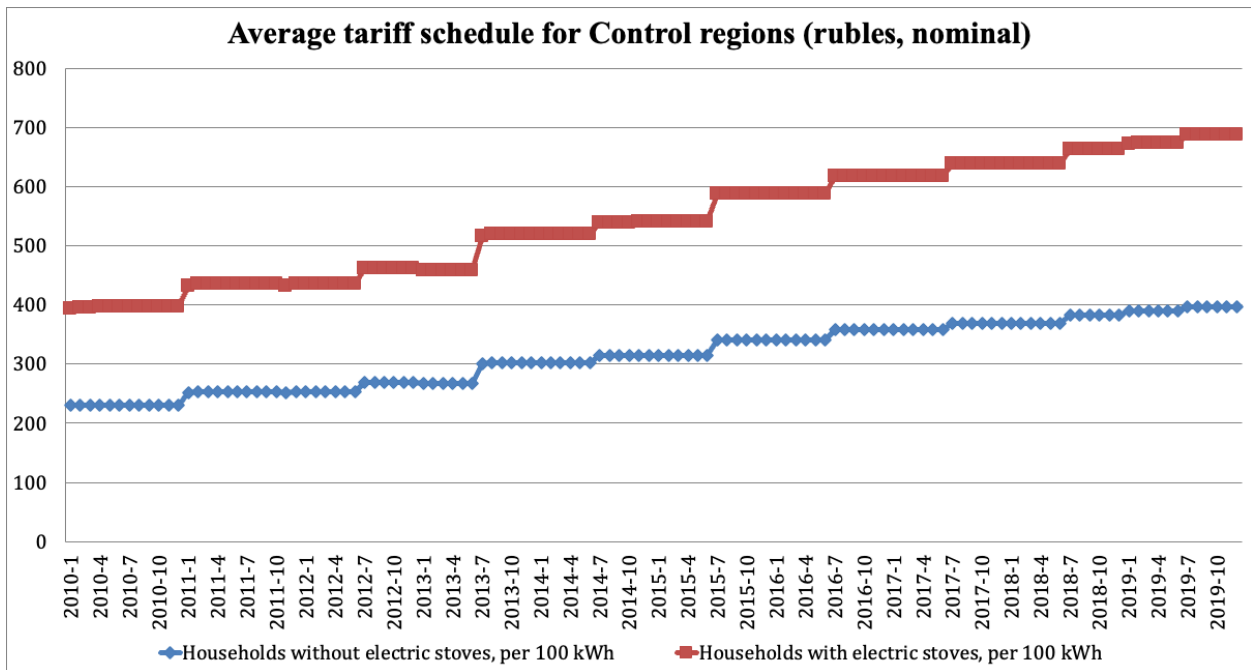
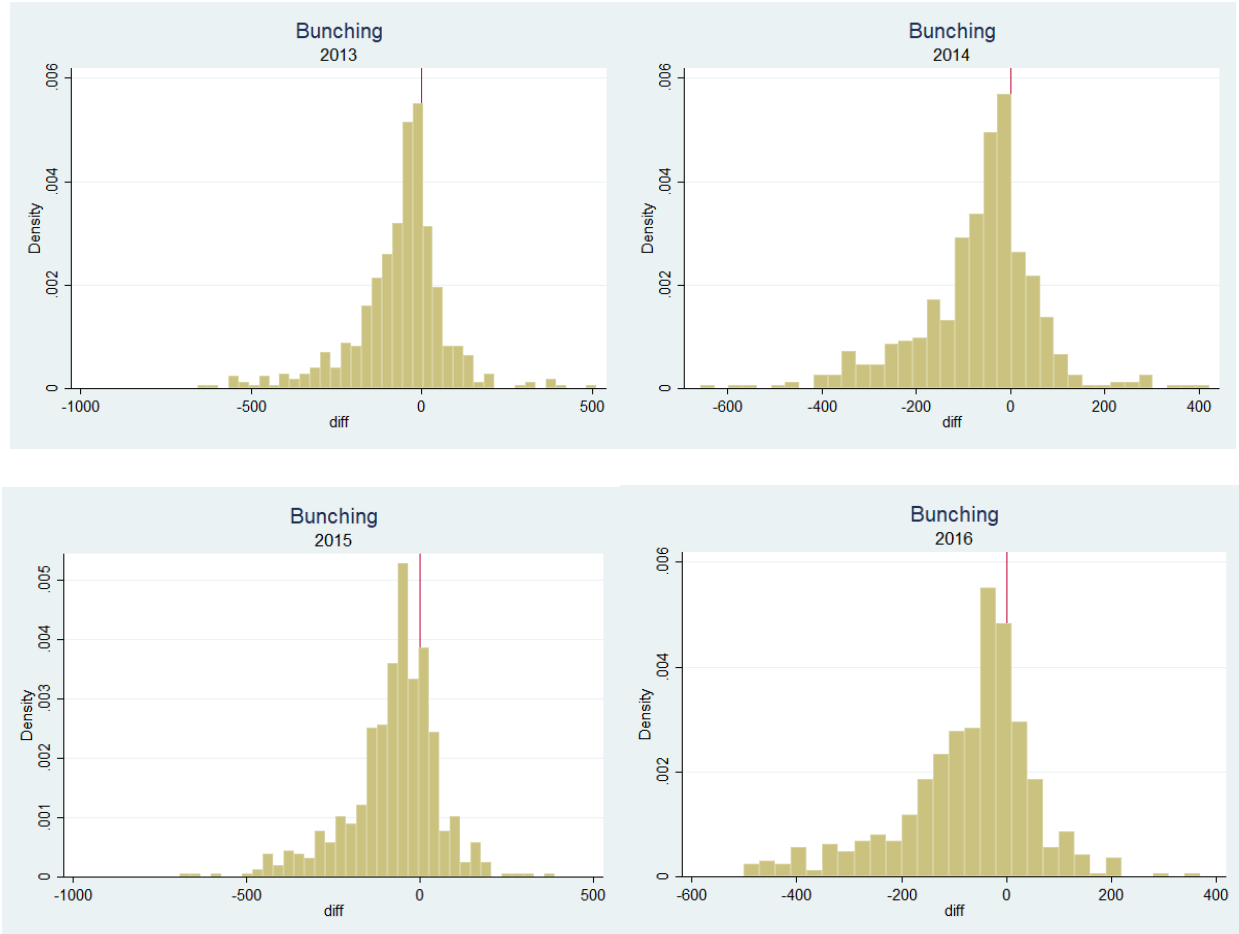
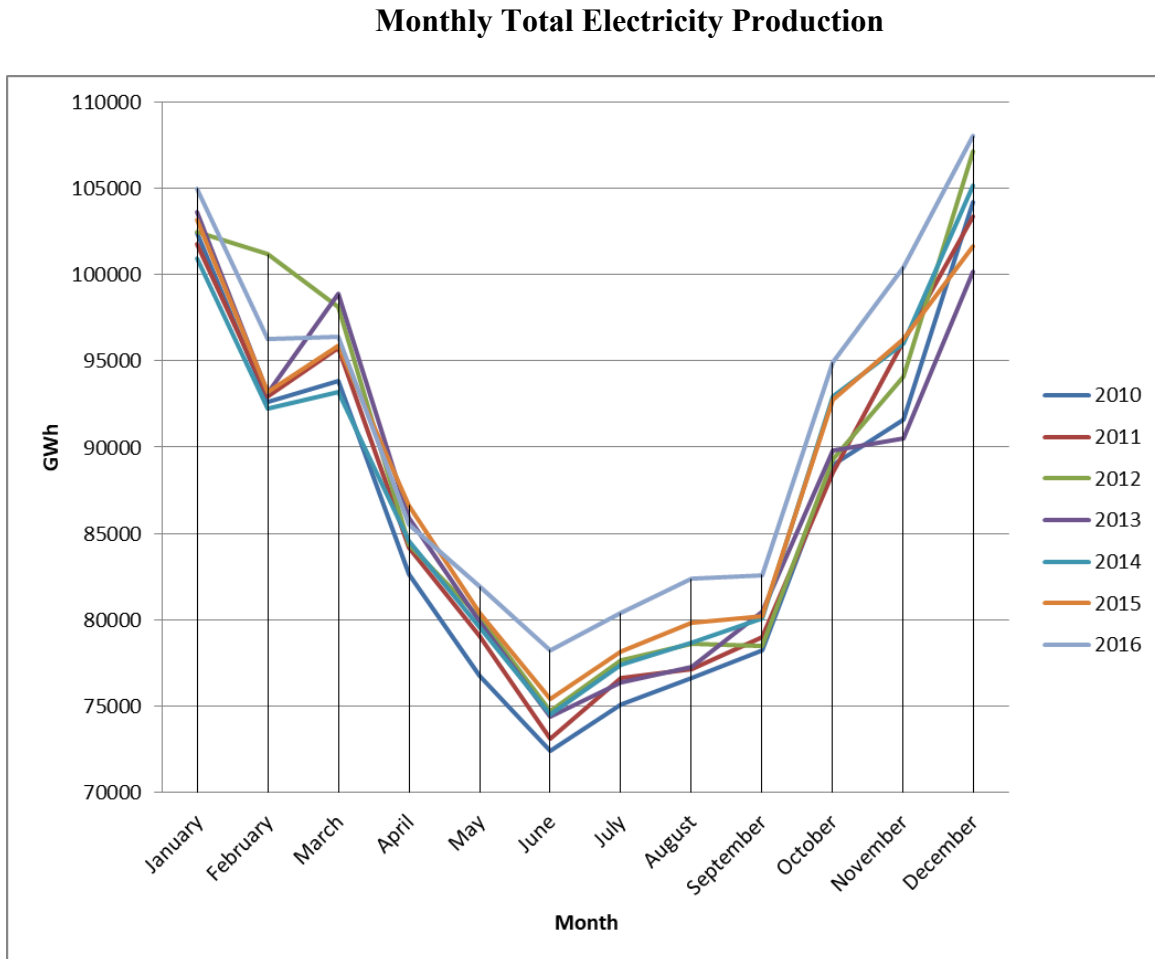


Figure 6



Source: Author's own construction.

**Figure 7.** Source: The Global Economy, (2020)

A2: 1<sup>st</sup> Stages of 2SLS regressions:

VARIABLES	2SLS Matching lnPrice	2SLS lnPrice
band85	0.540*** (0.0872)	0.539*** (0.0871)
band96	-0.185 (0.137)	-0.184 (0.137)
band100	0.120 (0.126)	0.120 (0.126)
band110	0.00938 (0.115)	0.00864 (0.115)
band127	0.393*** (0.117)	0.394*** (0.117)
band144	0.128 (0.110)	0.126 (0.110)
band150	-0.502*** (0.0961)	-0.500*** (0.0964)
band156	0.116 (0.0947)	0.115 (0.0948)
band196	-0.230 (0.158)	-0.258* (0.154)
band200	0.375** (0.163)	0.405** (0.160)
band220	0.155* (0.0862)	0.155* (0.0863)
band225	-0.254*** (0.0982)	-0.254*** (0.0982)
band234	0.247** (0.123)	0.246** (0.123)
band236	-0.145 (0.120)	-0.146 (0.120)
band250	0.0746 (0.152)	0.0778 (0.152)
band276	-0.337* (0.190)	-0.337* (0.190)
band294	-0.0973 (0.205)	-0.132 (0.201)
band300	0.526*** (0.146)	0.560*** (0.141)
band316	-0.116 (0.310)	-0.112 (0.310)



band350	0.410 (0.350)	0.410 (0.350)
band354	-0.202 (0.266)	-0.219 (0.261)
band356	-0.313 (0.231)	-0.293 (0.224)
band375	0.190 (0.213)	0.185 (0.212)
band396	0.106 (0.187)	0.105 (0.187)
o.band400	-	-
band414	-0.624** (0.302)	-0.622** (0.301)
band436	0.399 (0.305)	0.396 (0.304)
band450	0.238*** (0.0554)	0.238*** (0.0532)
band474	-0.0195 (0.0286)	-0.0182 (0.0283)
o.band525	-	-
band600	0.00332 (0.00716)	0.00222 (0.00668)
band654	-0.00787 (0.00772)	-0.00566 (0.00704)
o.band675	-	-
band750	0.00522 (0.00444)	0.00369 (0.00345)
band900	0.00211 (0.00206)	0.00171 (0.00154)
lnSubsidies	-0.000180 (0.000150)	-0.000130 (0.000112)
lnDiscounts	0.000113 (0.000128)	8.72e-05 (0.000101)
lnArrears	-0.000480** (0.000199)	-0.000361** (0.000150)
lnIncome	0.000944 (0.000897)	0.000667 (0.000667)
HHsize	-0.00138** (0.000701)	-0.000961* (0.000496)
lnDD	0.000900 (0.00148)	0.000816 (0.00120)
lnPrecipit.	-0.000459 (0.000588)	-0.000290 (0.000441)

lnHumidity	0.00438 (0.00509)	0.00225 (0.00368)
lnWinds	0.00304 (0.00371)	0.00207 (0.00293)
year11	0.000290 (0.000848)	0.000248 (0.000616)
year12	0.000424 (0.000965)	0.000385 (0.000686)
year13	0.00150 (0.00104)	0.00101 (0.000832)
year14	-0.000209 (0.000932)	-0.000269 (0.000734)
year15	0.000744 (0.00132)	0.000518 (0.000965)
year16	-0.000369 (0.00138)	-0.000258 (0.000914)
Observations	22,781	29,551
F statistics	1207.52	1712.88
P-value	0.0000	0.0000
Hansen J statistic	34.423	35.218
P-value	0.3072	0.2753

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The standard errors are clustered at the household level.

Source: Authors' calculations.

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