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DISSERTATION

Residential Energy Consumption in Ukraine:

Does Energy Price Matter for Energy Savings?

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Declaration of Authorship

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Prague, October 13, 2023 Olha Khymych, DSc. ___________

Abstract

The dissertation, which consists of three chapters, combines two chapters that explain the effect of electricity and gas prices on energy savings in Ukraine and a third chapter that describes the implementation of energy-efficient measures in Ukraine as a result of such price increases. All three chapters are based on the data from original household surveys conducted before and after sharp and repeated energy price fluctuations in Uzhhorod, Ukraine. The first chapter focuses on extreme tariff variations over time and across household customers to estimate the price elasticity of electricity demand from dwellings in Uzhhorod, Ukraine. The findings suggest that the price elasticity of electricity demand is −0.2 to −0.5, with the majority of the estimates around −0.3. The elasticity becomes stronger over the first three months after prices change. Only modest evidence shows that the response to the price variations is more pronounced for respondents who were attentive to their bills, consumption levels, or the tariffs. The second chapter addresses the tariff reforms in gas prices, aiming to understand whether consumers adapt their consumption in response to such changes, and estimates the price elasticity of gas demand. To separate the behavioral aspect, only dwellings without energy-efficient renovations were used. The results suggest that consumers can decrease gas consumption over time, even without renovations. The price elasticity of natural gas demand is around −0.16. The demand becomes more inelastic for households with higher incomes and heavy users. The third chapter describes the types, rates, and prices of various energy-efficiency measures implemented by households between 2008 and 2018 in Ukraine. Data indicates that households follow a step-by-step approach and implement energy-efficiency measures on average over three years, deciding to implement up to five different upgrades. Additionally, homeowners with lower education and income levels, larger household sizes, and at least one child living in multi-family buildings with a larger number of rooms are more prone to invest in energy-efficient renovations. This probability increases for households that recently moved into their dwelling and if one or more household members work abroad.

JEL Classification codes: H70; I22; J24; J40; Q33; R23; D12; Q41; Q48; H3; O33; Q41; Q50; Q56

Keywords: Residential electricity demand; Short-run price elasticity; Increasing block rates; Attentiveness; CO_2 emissions reductions.
Residential gas demand; Energy transition; Tariff reforms; Salience.
Households; Developing Countries; Technology Adoption; Energy-efficiency.

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Content

List of Tables

Chapter 1.

Response to extreme energy price changes: Evidence from Ukraine

Chapter 2.

Responsiveness to energy price changes when salience is high: Residential natural gas demand in Ukraine

Chapter 3. Drivers of energy-efficiency renovations in Ukraine: A case study of the city of Uzhhorod

Chapter 4. Replies to Opponents' Reports on Dissertation Thesis

List of Figures

Chapter 1.

Response to extreme energy price changes: Evidence from Ukraine

Chapter 2.

Responsiveness to energy price changes when salience is high: Residential natural gas demand in Ukraine

Chapter 3.

Drivers of energy-efficiency renovations in Ukraine: A case study of the city of Uzhhorod

Acronyms

BTUs	British Thermal Units
CIA	The Central Internal Agency United States of America
CPI	Consumer Price Index
CO_2	Carbon dioxide
EBC	Energy in Buildings and Communities
EBRD	The European Bank for Reconstruction and Development
EUR	Euro (currency)
EE	Energy efficient
EU	The European Union
FE	Fixed effect
GCPF	The Global Climate Partnership Fund
GHG	Green House Gas
GDP	Gross domestic product
HDD	Heating degree days
HOA	Homeowners' association
HUS	Housing and Utility Subsidy
IBR	Increasing block rates
IQ energy	The Ukrainian Residential EE Financing Facility
IEA	The International Energy Agency
IMF	The International Monetary Fund
IV	Instrumental variables
kWh	Kilowatt-hour
kg	Kilogram
m^3	Cubic meter
m^2	Square meter
NERC	The National Commission for State Regulation of Energy
NEFCO	The Nordic Environment Finance Corporation
OECD	The Organization for Economic Co-operation and Development
OLS	Ordinary least squares
SAEE	The State Agency of Energy Efficiency and Energy Saving in Ukraine
SSSU	The State Statistic Service of Ukraine
SF	Single-family homes
SUBS	Subsistence level per household member
SR	Short run
UAH	Ukrainian hryvnia (currency)
USD	United States dollar (currency)
US	United States
VAT	Value-added tax
WB	The World Bank
WLP	"Warm loans" program
2SLS	Two-stage least squares

Dissertation Summary

"Energy conservation is the foundation of energy independence."

Tom Allen

Energy demand is increasing in response to growing consumer needs, technological developments, and policy changes. The need for energy savings has received significant attention in the last few decades. With the recent changes in the world, energy savings are not only an instrument to fight climate change but also a tool with which countries can enhance their energy security, independence, and economic and social development. A feasible reduction in energy demand can be reached by the primary consumers of energy in the industrial and domestic sectors. On the global scale, since 2000, energy use has decreased by 13% after almost two decades via energy-efficient improvements (IEA, 2019). For Ukraine, which is one of the most energy-intensive countries, transformations of energy strategies can bring a sizable contribution to the net-zero carbon economy. The country has been moving in this direction, though the main reforms started only in 2014. The changes were forced by the armed conflict with Russia, which resulted in economic fluctuations and a decline in the country's development. This has been confirmed in the study of Vasylieva et al. (2021). Their findings suggest that the most significant drop in the average level of the energy efficiency gap was in 2009 after the world financial crisis and in 2015 after the escalation of geopolitical conflicts. The authors emphasized the importance of employing green innovations, a green lifestyle, and energy-saving behavior by policymakers. The Ukrainian government developed a detailed plan on how to reach the expected targets and balance the economy of Ukraine. It required considerable changes in the energy sector to have a secure energy supply and decrease dependence on Russian gas. The elaborated "Energy Strategy of Ukraine 2035" sets targets to transform the energy market, support energy-efficiency renovations of buildings, and raise awareness of energy-saving behavior. Ukraine aims to reduce GHG emissions by 50%, using 1990 as a reference point. To handle economic crises and fulfill these goals, Ukraine requested financial support from the IMF, conditioned on the recommendation to increase gas and electricity prices for consumers, corresponding to the international energy market level. Such rapid and repeated price changes in gas and electricity created a natural experiment and an opportunity to study how demand for these utilities will change.

Furthermore, these price fluctuations have prompted positive developments in the energy efficiency sector in Ukraine, generating considerable interest within the scientific community. The residential sector of Ukraine is the second largest consumer of energy (IEA, 2020). Given that the housing stock is old and only a small share of the buildings was constructed after 1991, the need to apply energy-efficient measures is striking. The potential for energy savings by the domestic sector is estimated at around 33% (IEA, 2021). Understanding what drives households to implement renovations can help to increase energy savings.

The three chapters of the dissertation are based on the study of the residential energy sector of Ukraine. This dissertation represents significant research based on unique household data from original pen-and-paper surveys conducted in Uzhhorod, Ukraine. The data gathered in the surveys provided exact information on gas and electricity meter readings, information on tariffs and implemented energy-efficient measures, and detailed information on socio-demographics and behavioral motivations. The research chapters present a unique analysis that has not been previously done in Ukraine. These studies contribute to the literature on the price elasticity of energy demand and determinants of energy-efficient renovations. Consumers exhibit significant heterogeneity in their behavior, making it crucial to understand better the factors that can motivate them to save energy, insulate their homes, or install more efficient equipment.

The dissertation summary describes the motivation and insights of the thesis. Chapter 1 and Chapter 2 of the thesis represent a study of the price elasticity of electricity and gas demand. Chapter 3 presents a study on determinants of energy-efficient upgrades.

Chapter 1 describes an empirical analysis of the residential demand for electricity in a time of rapid and significant price fluctuations in Ukraine. Between January 2013 and April 2016, household consumers faced a 300% increase in electricity prices at the initial rates and a change in the block rates. Using a panel dataset from 500 households with 11,706 observations of monthly electricity usage, we estimated the elasticity of electricity demand in Uzhhorod. The aim was to see if electricity consumption by residents changed after a price increase; if households that are more attentive to their bills and more attentive to their consumption reacted differently to the price rise; and how quickly families reacted to the price change. The results show that household consumers responded to marginal electricity prices; the price elasticity in the short run was around −0.2 to −0.5. In the first months after a price increase, the elasticity became 50% stronger. This weak proof suggests that bill-attentive and quantity-attentive households are more sensitive to price shifts.

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Chapter 2 addresses gas price variations and their influence on gas use by household consumers in the period between 2013 and 2017 in Uzhhorod, Ukraine. Using individual monthly gas meter readings and information on governmental support (subsidies, "benefits"), a study examined how households respond to changes in gas prices, paying particular attention to whether households are salient to the price hikes. Salience influences the attentiveness of the consumers to the prices in both directions. In this study, the consumers were facing high salience since prices increased over 700%; this suggests great awareness of the price changes. Furthermore, the gas bills are received and paid monthly, so residents keep track of their consumption and expenditures.

Additionally, the study design excluded households that invested in energy-efficient measures to remove any possible behavioral effects that could influence attitudes toward gas reduction. This research focused on whether people can reduce gas consumption when facing such price escalation; whether these effects differ between households; and what the effect of government-supporting mechanisms is on gas usage. The findings indicate that the price elasticity of gas use is around −0.16, suggesting that families can reduce gas usage even when receiving subsidies and "benefits." Secondly, heavy users, those living in multi-family apartments, and those with a higher income have less elastic demand in the short term. There is still only a narrow knowledge of gas demand response to price changes in the domestic sector in developing countries like Ukraine. The outcomes of this research could be used as a reference for future studies since they may indicate that higher salience influences the understanding of consumption and tariffs affecting gas consumption.

This article, co-authored with Anna Alberini and Milan Ščasný, was published in Energy Policy: Alberini, A., Khymych, O., and Ščasný, M. (2020). Responsiveness to energy price *changes when salience is high: Residential natural gas demand in Ukraine. Energy Policy, 144.* *https://doi.org/10.1016/j.enpol.2020.111534*

Price is one of the instruments that influences energy consumption. The effect can vary substantially; it can result in a decrease in demand via a decline in the purchasing power of consumers or the implementation of energy-efficient technologies. Residential electricity and gas demand are generally thought to be inelastic, at least in the short term. It depends on the share of income spent on this commodity, as well as how much time has passed after a price change; nevertheless, it should be pointed out that demand for such a necessary commodity can hardly be reduced below the minimum that is required for basic needs if there is no substitute for it. The effect of energy prices on electricity and gas demand has been studied in previous literature, for example in Alberini and Filippini (2011), Auffhammer and Rubin (2018), Burke and Abayasekara (2018), Deryugina et al. (2020), Lanot and Vesterberg (2021). Many studies emphasize the importance of estimating price elasticity to accurately forecast energy demand and establish appropriate pricing policies. Numerous studies have highlighted the diversity within their samples and emphasized the necessity of adopting an approach that considers this heterogeneity for informing future policy implications. This variation is attributed to the socio-demographics, geographical location, seasonality, and behavioral habits. Nevertheless, studies on the rapid effects of energy prices in the residential sector are lacking. Knowledge of the effect of energy prices on demand is crucial for developing price policy, regulating demand, and accepting the price by consumers and regulators.

The results obtained from the study conducted in 2019 using household panel data from Germany confirmed that households show a wide range of responses to price changes. The study estimated that electricity demand's short-term and long-term price elasticities were −0.44 and −0.66, respectively (Frondel et al., 2019). The most up-to-date study on residential electricity demand under the Increasing Block Tariff Rates was conducted in China in 2022. The findings indicate that residential electricity demand is inelastic, with values ranging from −0.95 to −0.87 in urban and rural areas. Nonetheless, the estimates vary from −0.41 to −0.64, depending on geographical location (Jia et al., 2021). Further analysis of the residential price of electricity demand comprising 103 studies worldwide confirmed that the short-term price elasticity can vary from −0.95 to 0.6, averaging at −0.23, and the long-term price elasticity spans from −4.2 to 0.6, with an average of −0.58 (Zhu et al., 2018). The latest comprehensive meta-analysis study on income and electricity price elasticities within the European Union indicates significant variability in price elasticity. This variability confirms that electricity demand tends to be inelastic (Pellini, 2021). The author observed notable variations in price elasticities across different studies. Short-run price elasticities ranged from −0.84 to −0.04, while long-run price elasticities spanned from −2.27 to −0.02. The comprehensive study conducted by Alberini et al. (2022), using data from the Georgia Household Budget Survey spanning from 2012 to 2019, revealed that the short-run marginal and average price elasticity of electricity demand are both equal to −0.3.

Our research outcomes align with the recent studies suggesting that the average price elasticity of electricity demand is around −0.3 in the short run.

The study on gas demand is getting more attention each year, especially considering factors like COVID-19 and war in Ukraine, which are expected to change the demand. This matter was discussed in a recent study by Erias and Iglesias (2022). The authors analyzed elasticities for natural gas demand from 2016 to 2020 using data from 15 European countries. They emphasized the importance of the seasonal effect in estimating the demand response. The results on the average gas price elasticity for the EU imply that in the short run, it varies between zero and −2.209, depending on the month. The long-price elasticity can range, depending on the season, from −0.935 to −4.416. We did not find a variation in the price elasticities between the seasons. Nevertheless, the values of −0.1472 for heating and −0.1411 for non-heating seasons lie between the average values estimated in the corresponding paper. In the recent findings from the study conducted in the USA, estimating elasticities at different consumer levels indicates that gas prices are inelastic. Using monthly meter reading data from 2001 to 2015, the author confirmed that the short-run price elasticity for the residential sector across 50 states is −0.5 (Joshi, 2021). The study's conclusions pointed out that consumers' responses to price changes have maintained almost identical patterns as in the past, even though there have been shifts in the natural gas sector over time and across locations. The research conducted in 2020, utilizing data from 19 OECD countries spanning the years 1980 to 2016, found that the natural gas price elasticity is negative in the long run (Jaouad et al., 2020). The study's findings underscored that environmental policy proves effective in achieving a long-term reduction in residential natural gas consumption. This discovery aligns with our results, which indicate a lower short-term price elasticity. Such a pattern suggests that households require a long period to adapt to policy modifications, such as a rise in gas prices. Additionally, the authors found that colder temperatures are associated with higher residential natural gas use. In the same year, a study examining panel data from 958 Swiss households between 2010 and 2014 unveiled that the gas demand exhibits a price elasticity of around −0.73 at the household level (Filippini and Kumar, 2020). The authors also confirmed the correlation of low temperatures with increased gas consumption in the residential sector. An earlier meta-analysis study by Labandeira et al. (2017) conducted for various fuels, including natural gas, suggested consistent negative gas price elasticities in European countries. In the short run, the average price elasticity for natural gas demand was −0.184, while in the long run, it was −0.568. This study suggests that, under unchanged conditions, pricing policies could reduce demand for these commodities proportionally less than the price change, both in the short and long term. In conclusion, this meta-analysis highlights variations in the price elasticities of energy demand between developing and developed countries, but these differences are primarily observed in the long term.

Our finding suggests that the short-run price elasticity of gas demand for the total sample is around −0.16 and significant at the 1% level. Households with income below the sample median tend to exhibit more pronounced price elasticity (−0.20), as do households who live in single-family homes (−0.22). The research findings on the price inelastic demand align consistently with the closely related literature within this field. However, it is important to interpret these findings in the context of the specific regions because they can exhibit varying levels of price elasticity due to consumer behavior, availability of substitutes, market dynamics, geographical locations, or temperature.

One might question why we are treating gas consumption separately from energy-efficient measures when estimating the price elasticity of gas demand. It is essential for several reasons: influence factors and response factors. Energy-efficient measures, such as improvements in insulation, more efficient appliances, and better heating systems, can directly impact gas consumption. Treating gas consumption separately from the EE effect allows us to focus specifically on price elasticity without confounding it with the impacts of energy-efficient measures. On the response side, energy-efficient measures can alter how consumers use energy. If households implement energy-efficient upgrades, they might reduce their overall gas consumption, even in the face of price changes. By treating gas consumption separately, we can analyze how consumers respond to changes in gas prices without the additional influence of the response in behavior due to the implementation of energy-efficient measures. Distinguishing these two effects can bring more accurate insights into how policy changes affect gas demand and how consumers respond to price changes. In addition, isolating gas consumption from energy-efficient measures allows for more meaningful comparisons over time or across different countries and regions. Including the effects of energy-efficient measures could obscure the actual changes in gas demand and make it harder to compare trends accurately. Moreover, incorporating energy-efficient measures in the analysis can increase the complexity of the model, making it challenging to disentangle the effects of price changes and efficiency improvements.

Lastly, Chapter 3 of the dissertation is motivated by the findings from the previous two chapters. The aim was to broaden the understanding of household behavior under rapid and repeated energy price pressure. The household choice to renovate can be driven by various reasons: social, economic, technical, and behavioral. The economic factor is most valuable because consumers can save energy and money. The majority of the existing governmental policies and programs target these benefits. While household decisiveness might be driven by the need to improve thermal comfort or reduce street noise, some want to reduce illness-related risk by blocking draughts or leakages or wish to increase property value by making structural improvements to the facade or interior of the building. However, it is crucial to recognize that combining these factors influences renovating decisions. For a more profound understanding, it is essential to approach the issue from a country-specific perspective, considering everyday life and existing barriers.

Chapter 3 assesses the changes in energy-efficient investments between 2008 and 2018, which includes the time before, during, and after the price increases in Ukraine. It aims to provide an answer to the question of what encourages households to make renovations to their homes. Additionally, it provides an overview of the energy-efficient measures adopted in Ukraine over ten years, focusing on their types, rates, and prices. The findings uncover novel information about the preferences of Ukrainian households since data gathering and monitoring have not yet been established on a governmental level. The acquired survey data proves that renovations require time. Households make energy-efficient upgrades with a step-by-step approach. They implement various upgrades on average over three years, choosing the priority measures with the highest energy-saving potential. In addition, I found that homeowners living in apartments in multi-family homes with more rooms are more inclined to make renovations. This effect becomes more pronounced for families that moved into their house a short time ago and if some household members worked abroad. Low-income and low-education households with a more significant number of family members and that have at least one child are more likely to invest in energy-efficient measures. The results obtained in this analysis contribute to the existing studies on determinants of energy-efficient upgrades and confirm the effect of social-demographic and dwelling characteristics. The analysis extends the general knowledge of these studies worldwide by adding a missing piece from Eastern Europe. Whether or not energy-efficient measures are important from an economic perspective remains a question for the academic community; see Allcott et al.(2012), Ameli and Brandt (2015), and Schleich (2019). This study provided essential information to extend understanding of the "energy efficiency gap" that can motivate future energy savings.

This article will be submitted for publication to the IES Working Paper Series soon and later to the academic journal.

Energy-efficient investments are influenced by various factors, with socio-demographic variables being among the most significant. Even though income is both the greatest benefit and a barrier simultaneously, it produces mixed results. My results suggest that low and mid-income households are more likely to do renovations, which sharply differs from findings that high income motivates EE investments (Poortinga et al., 2003, Nair et al., 2010, Achtnicht and Madlener, 2014). A contrasting finding was made by Gamtessa (2013), suggesting the negative effect of income. At the same time, a study Jakob (2007) confirmed that homeowners with high incomes and high levels of education do not engage in insulation activities more frequently. Numerous peer-reviewed papers indicate that a combination of economic and non-economic objectives influences homeowners decisions to participate in renovation projects. Hence, the existing incentives, which typically focus on the economic feasibility of these measures, have yielded limited success (Friege and Chappin, 2014).

While higher education is presumed to be associated with income, it also brings better information-gathering capabilities, leading to hesitancy in investments due to longer rates of returns. A positive correlation was found between education level and EE investment, but it relates to younger households (Nair et al., 2010). Individuals with primary education were more prone to change daily habits rather than invest in insulation than highly educated respondents. On the contrary, Ameli and Brandt (2015a) did not establish a significant role in education. The findings of my study indicate a positive correlation with renovation among low-income households. This could be attributed to the significant percentage of individuals working abroad and the prevalence of "grey" income in Ukraine.

The availability of the children is typically correlated with energy-efficient renovations and appliance installations. Mills and Schleich (2012), examining 5000 dwellings from 10 EU countries, highlighted that families with young kids are more likely to invest in energy-efficient upgrades. A similar positive correlation was estimated for installing attic insulation in single-family homes in Sweden (Azizi et al., 2020). The results of my study confirm a positive likelihood of investment by families with children in at least one renovation project or one with the highest energy-saving potential.

Nowadays, researchers dig deeper into understanding the motivations that drive households to undertake renovation projects. This behavior can vary based on socio-economic status and the type of EE measure due to differences in financial resources, awareness, access to incentives, and individual priorities. Recent studies suggest significant household differences in renovations (Mortensen et al., 2016). The authors have discovered that none of the estimated demographic factors play a predominant role, but instead, there is a tendency associated with the homeowner's current stage in life. They found that enhancements in comfort, indoor environmental quality, and architectural improvements can serve as motivating factors for EE upgrades. This finding mirrors the conclusion made by Azizi et al. (2020). They discovered that households experiencing at least one indoor environmental problem were more inclined to invest in EE upgrades. Authors suggested that families who recently moved into their houses are more inclined to express an interest in enhancing attic insulation. Households are prone to renovate if it is significant renovation. These results align with my estimations, confirming that the year of moving in is a significant factor driving renovations.

The renovation process is the complex interplay of factors influencing decisions about energy-efficient home improvements. The analysis of the Dutch homeowners revealed three stages in renovation decisions. Initially, external factors like environmental concerns and physical conditions spark interest. Then, as homeowners acquire knowledge and receive advice from their network or professionals, their decision-making process advances. Finally, financial and economic factors are pivotal in shaping homeowners' opinions to proceed with energy renovation measures (Broers et al., 2019). This finding aligns with my results that households take time to invest in energy-efficient measures and opt for a gradual, step-by-step approach to home renovation. On average, the timeframe for completion is approximately three years. During this period, homeowners select and implement one to five energy efficiency measures. This approach allows them to plan carefully and gather a budget for improvements, making sustainable home changes while spreading the costs and benefits over time.

Filippini and Kumar (2022), in a study of privately owned Swiss dwellings, shed light on the complex interplay of factors that drive homeowners' decisions to invest in energy-efficient retrofits. They highlighted the importance of not only the physical characteristics of the building but also the attitudes and motivations of decision-makers within households. A study finding implies a positive association between tax deduction policies and households' decisions to undertake energy-saving retrofits and the extent or intensity of those renovations. In the case of my research, the households' behavior is influenced by subsidies and benefits, and they are also salient as the tax deduction. Confirmation regarding whether receiving a subsidy or benefit influenced the likelihood of renovation has not been established, possibly because of the limitations imposed by a small sample size.

In conclusion, recognizing the potential significance of household behavior in achieving energy and environmental goals is essential. Policymakers should focus on better understanding the factors influencing these behaviors and use that knowledge to develop policies that promote energy efficiency and reduce CO_2 emissions more effectively and targeted. As stated in the study by Sunikka-Blank and Galvin (2012), non-technical (behavioral) measures demand greater attention because their effects are significantly larger than commonly assumed.

To summarize. The studies on energy demand presented in this dissertation thesis examine households' responses to changes in energy prices and consumption patterns, with a specific focus on price elasticity. The studies provide insights into how households adjust their energy consumption behaviors based on changes in energy costs. Additionally, all studies consider the influence of different factors, such as attentiveness to bills or consumption levels, and demographic characteristics on the responsiveness to price changes. Furthermore, the studies acknowledge the importance of understanding consumer behavior within the context of energy efficiency. The first study highlights the potential influence of factors beyond price elasticity, such as consumer attention and awareness, in shaping energy consumption patterns. The second study delves into how households adjust their natural gas consumption in response to price changes, even without structural energy-efficiency upgrades, indicating the potential for demand reduction through behavioral changes. The third study describes the types, rates, and prices of energy-efficiency measures implemented by households and what determines their choice to do such renovations. All three chapters pay attention to the role of consumer awareness and attentiveness, the influence of wealth and demographic characteristics, and the relationship between energy-efficient measures and consumption adjustments. All chapters provide insights into how different pricing strategies, government assistance, and energy-efficiency initiatives can impact household energy consumption behavior and overall energy demand.

Our analysis of electricity demand reveals a preliminary short-term price elasticity ranging from −0.2 to −0.5, averaging at −0.3. These values for gas price elasticity are weaker and average to −0.16 in the short run. We found that attentiveness to bills and quantity of electricity demonstrate a more pronounced elasticity value (–0.56). The price elasticity of electricity demand for quantity-attentive households has a lower value of −0.13 compared to quantity-attentive households for gas demand (−0.35). Households that are not quantity attentive have a comparable value of the price elasticities, ranging from −0.23 for electricity demand to −0.24 for gas demand.

It is essential to note that the price elasticities of gas and electricity demand differ because of the purpose for which it is used. Electricity is used mainly for appliances, with only 15% of households using electricity for heating purposes. In contrast, gas is used for water heating, cooking, and heating, thus taking a considerable portion of the monthly bill payment.

Comparing the responses of gas demand of the households of different income levels, we can state that families with income lower than the median appear to display a more noticeable level of price elasticity. (−0.20); similarly, as do dwellings that reside in single-family homes (−0.22). Conversely, families living in multi-family homes are less sensitive to price (−0.13)

For electricity demand, individuals who react to electricity price fluctuations primarily reside in apartments within multi-family dwellings, with an elasticity of −0.28 compared to households living in single-family houses (−0.09). The middle tercile of the income distribution in the sample shows a weaker response to the price elasticity (−0.18) compared to the first and third tercile with values of −0.35 and −0.39, respectively.

People might be accustomed to their current consumption patterns and may wait to adjust their behavior in response to price changes. It takes time for individuals to become aware of the price increase and then modify their habits accordingly. Estimations of electricity demand confirm that elasticity shows an increase of up to 50% in magnitude during the initial three months following price adjustments. We received significant estimates for the gas price elasticity when windows were constrained to three months before and three months after a price change and four months before and after a price change, without a substantial difference in the values. This evidence hints at the need for time to evaluate options and make informed decisions. For example, users might need to research energy-saving techniques, compare appliance efficiency, or plan when to use energy-intensive devices.

The outcomes of our study propose that in the case of electricity demand, households have managed to save electricity by being extra cautious with consumption. By consistently turning off lights, unplugging unused appliances, and using washing/drying machines at total capacity, families take actions that help them avoid excessive heating or cooling. Additional savings come from replacing traditional light bulbs with LED ones or purchasing more energy-efficient appliances, like new boilers.

The results obtained from the research indicate that gas consumption can be reduced if individuals do not adopt energy-saving technologies. These households have the most significant ability to reduce their consumption through behavioral changes. These skills can include changes in routine, avoiding keeping windows open while heating systems are in use, wearing warm clothes, performing simple repairs, managing thermostat settings, adjusting the thermoregulator, turning off the boiler during the night or during the day when not at home to maintain comfort without excessive energy use.

Comparing the results across three chapters proves that consumer responses to price changes or energy-saving initiatives may take time. When considering energy-efficient upgrades or renovations, consumers need time to evaluate options, gather financial resources, and plan for the implementation. This decision-making process can span months or years. When prices change, consumers often need time to become aware and adjust. Initial reactions might not reflect the final, sustained response. For instance, consumers might initially overlook minor price fluctuations until they become more pronounced over time. Recognizing that changes in behavior take time to develop and make decisions can help policymakers, researchers, and businesses design more effective energy-saving programs and strategies that consider the gradual nature of behavioral change.

All the chapters share a common insight that socio-demographic factors, including income, education, household size, and dwelling characteristics, are consistently identified as influential in shaping consumer decisions related to energy consumption and energy-efficient investments.

Even though higher-income households might have more financial flexibility to invest in energy-efficient appliances, renovations, or technologies, Chapter 3 confirmed an opposite statement, suggesting that low- and mid-income households tend to invest in energy-efficient measures. At the same time, households with first and top terciles income showed higher price-elasticity of gas demand, most likely due to their potentially heightened awareness of costs and a greater inclination to adjust consumption patterns based on price fluctuations.

Dwelling characteristics play a dual role: they impact price elasticity by affecting energy consumption patterns and responsiveness to price changes, and they influence the determinants of energy-efficient renovations by dictating the need for upgrades and the feasibility of implementing such measures. The relationship between these factors is complex and depends on dwelling type, number of rooms, and year when the family moved in, as was discovered in Chapter 3.

When contrasting the outcomes of studies focused on energy price elasticity with those that investigate the factors influencing energy-efficient retrofits, it is crucial to underscore the behavioral aspect. Despite all the suggestions provided by theoretical frameworks, this finding is essential and should receive adequate attention in future research.

Collectively, these three chapters contribute to understanding energy consumption patterns, price elasticity, and household behavior in Ukraine's energy sector. They offer insights into how extreme price changes, structural upgrades, and policy interventions influence households' decisions regarding energy consumption and efficiency. Each chapter has implications for energy policy in Ukraine, which can serve as a valuable basis for comparison with other countries.

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Chapter 1.

Response to extreme energy price changes: Evidence from Ukraine

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.

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.

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 perceived the block that their usage levels fell in).

Kahn and Wolak (2013) conduct an experiment where residential electricity customers in California receive an online 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 the face low marginal prices increase consumption. The overall effect is a 1.5–3% reduction in electricity usage.

In this chapter, we seek to estimate the price elasticity of residential energy demand in a set- ting 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 document 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

[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

generally smaller than in Western Europe or the 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 cut-offs.

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 who 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 chapter 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.[3] 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 1.1. displays the electricity tariffs for the Uzhhorod region from 2012 to 2016.[4] 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, consumers do not select supply plans as they might in the US or other countries, and the tariffs are exogenous to the single consumer.

[3] The exchange rate of the time of the survey 25.4 UAH to the USD.
[4] 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.

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.[5]

Table 1.1. 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 1.1., 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.[6]

Figure 1.1. 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 1.1. 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 1.2. 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

[5] 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.

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

April 2015, it was the second tier that was hit the most heavily (50% increase), whereas the first and third 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%.[7] Subsequent increases were by 25% (nominal) in the first and second tier, and 5% (nominal) in the third.

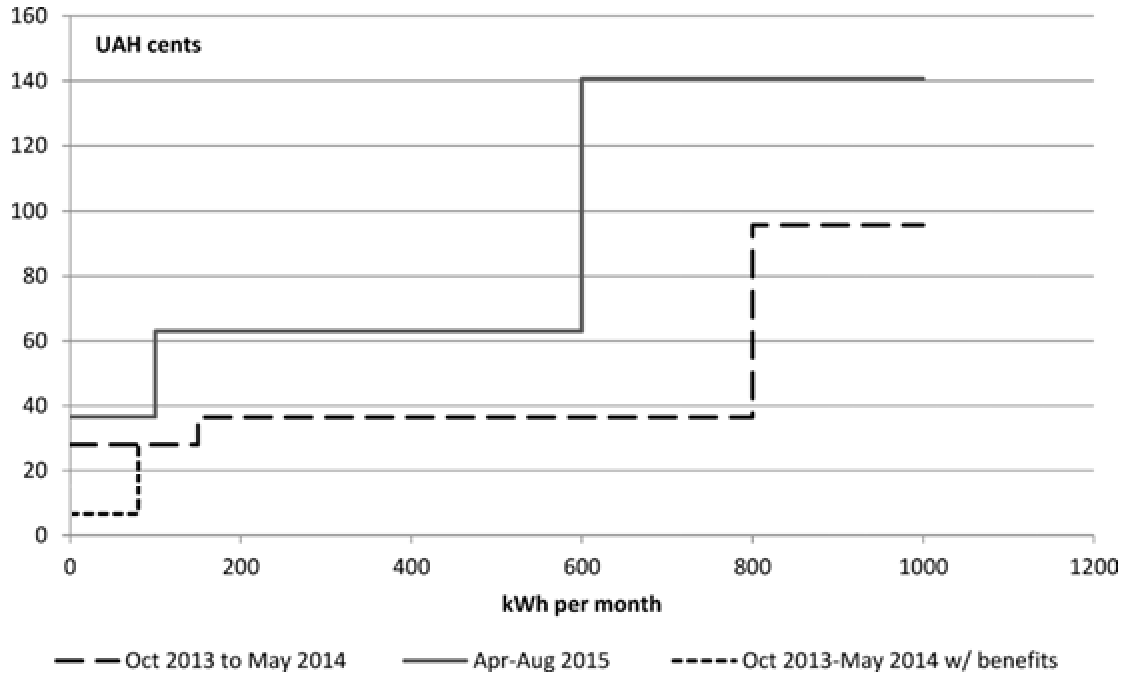
Table 1.1.: Electricity tariffs for urban households in the Uzhhorod region, 2012–2016.

	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

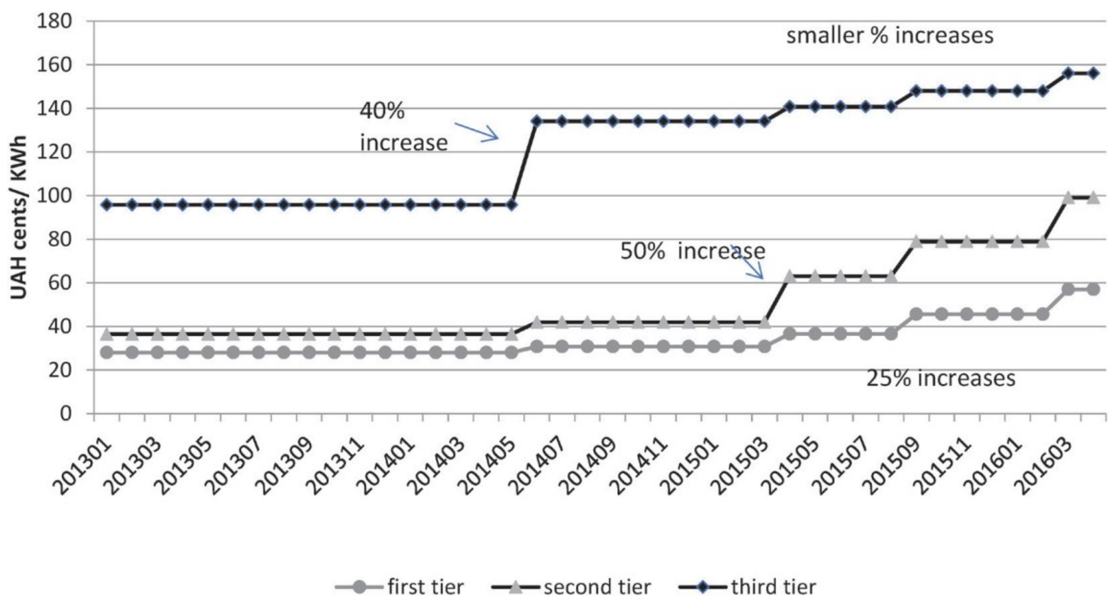
[7] Indeed, the CPI rose by 45% in Ukraine in 2015, with a disproportionate contribution to this increase coming from residential energy. Prior to that, there had been virtually no inflation in Ukraine in 2012 (annual inflation rate 0.6%) and 2013 (annual rate –0.3%), with noticeable price increases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

Figure 1.1.: 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.

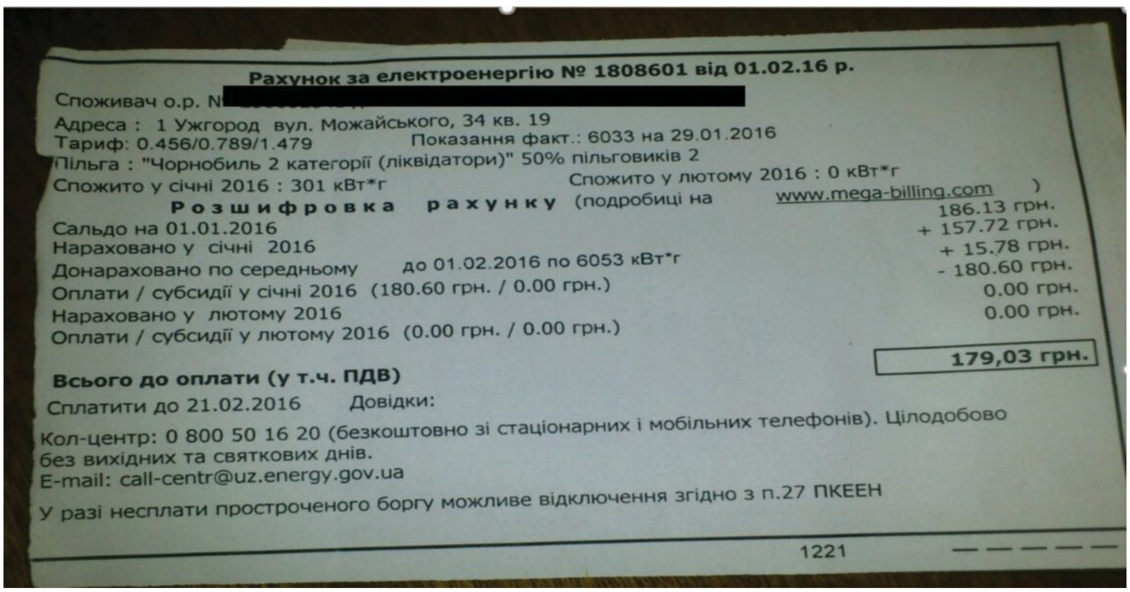
Figure 1.2.: Nominal tariffs by consumption tier.



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

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 1.3. for an example). This feature of the bill suggests that it is feasible for many households to inspect the bill carefully[8] and greatly simplified our data collection effort, which we describe in the next section.

Figure 1.3.: Sample electricity bill.



Рахунок за електроенергію № 1808601 від 01.02.16 р.
Споживач о.р. N[redacted]
Адреса : 1 Ужгород вул. Можайського, 34 кв. 19
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
У разі несплати простроченого боргу можливе відключення згідно з п.27 ПКЕЕН
1221

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.

[8] 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.

As residents of Uzhhorod, virtually all of the households covered by the survey use either natural gas orelectricity for heating, with only a small share using solid fuels (see Table 1.2.).

The enumerators were instructed to contact a predefined 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.[9]

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.

[9] 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.

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.

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 chapter, attention is restricted to electricity usage. We use these data to fit the regression equation:

$$lnE_{it} = \alpha_i + \beta \cdot ln\, P_{it}^{E} + \boldsymbol{W}_t\boldsymbol{\gamma} + \boldsymbol{X}_{it}\boldsymbol{\theta} + \tau_\tau + \varepsilon_{it}$$

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]), $\mathbf{W}$ a vector of weather variables,[10] $\mathbf{X}$ a vector of time-varying factors thought to affect demand, a α 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.[11]

[10] **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%.

[11] 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.

The model is a form of household electricity demand model based on the concept of energy services demand. The model aims to explain variations in electricity consumption by considering various factors likely influencing how households consume electricity. In this context, the model attempts to capture the raw amount of electricity households consume and the underlying reasons and determinants of that consumption. Some of the key aspects of the model that align with an energy services demand approach include factors influencing demand. The model includes various factors beyond just price and income that are known to impact electricity consumption. These factors include weather variables, time-varying factors, and household characteristics.

Including household fixed effects recognizes that different households have unique characteristics and preferences influencing their electricity consumption patterns. It aligns with the energy services demand concept, acknowledging that consumption behavior can be specific to each household's needs and habits. By incorporating month-by-year time fixed effects, the model accounts for seasonal and yearly trends that can affect the demand for specific energy services. This temporal dimension is vital for understanding how energy consumption patterns change over time. The model addresses the potential endogeneity of prices, a common concern in energy services demand analysis. Considering both marginal and average prices acknowledge the complexities of pricing structures and how they might affect consumption decisions. While income is unavailable for every month of the study period, the model attempts to account for its influence by interacting it with time-varying variables. This interaction recognizes that income can impact how households allocate resources to various energy services. The model adopts a comprehensive approach, considering a broad spectrum of factors that align with the energy services demand concept. Understanding energy services demand helps to analyze consumer behavior and preferences.

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)?

The average price represents the total cost of electricity divided by the total quantity consumed over a specific period, such as a month or a year. It captures the average overall price level that households face for their entire consumption. Estimating elasticities using average price is more straightforward and requires fewer assumptions than using marginal price. It is used when precise data on marginal prices are unavailable, as marginal prices can be complex to measure due to tiered pricing structures, demand fluctuations, and regulatory changes. Elasticities estimated using average price reflect the overall responsiveness of consumers to price changes across different consumption levels. This can be useful for understanding how consumers react to price changes, regardless of their consumption patterns. Using average price is limited since it assumes that consumers face a constant price for all units of consumption, which might not reflect reality if there are tiered pricing structures or time-of-use pricing. Additionally, it might not capture the behavior of consumers who adjust their consumption only when prices reach certain thresholds.

On the other hand, the marginal price represents the cost of the last unit of electricity consumed. It considers the pricing structure, which may involve different prices for different consumption levels due to block rates or time-varying rates. Marginal price is more appropriate when the pricing structure is complex or when consumers react differently to changes in price at different levels of consumption. Elasticities estimated using marginal price reflect the responsiveness of consumers to price changes, specifically at the margin, which can be particularly relevant for understanding how consumers adjust their consumption when facing higher prices. Estimating elasticities using marginal price requires accurate and detailed data on pricing structures, which might be challenging to obtain. It can also lead to endogeneity issues if prices are influenced by consumption behavior (Alberini and Filippini, 2011).

Researchers conducting studies on increasing block rate tariff schemes tend to favor the use of marginal prices over average prices. It relates to the correlation between the increase in energy demand and the increase in margin. Such association allows for concurrent determination of marginal price and electricity use. (Jia et al., 2021). The authors estimated price and income elasticity using data from the Chinese Residential Energy Consumption Survey 2014. Results prove that the residential electricity demand is price inelastic in the short-run. Deryugina et al. (2020) preferred marginal price to study residential electricity demand by exploiting 250 Illinois communities. The authors estimated that in the long run, the price elasticity of electricity demand changed from −0.09 in the first six months to −0.27 two years later. Filippini and Kumar (2020) used average price to estimate the price elasticity of gas demand. The reason for the choice was that marginal prices displayed minimal variation because of the sample specification. They found that gas demand is inelastic, averaging around −0.73. Lanot and Vesterberg (2021) drawing from data on Swedish households experiencing significant marginal price fluctuations, utilized the marginal price to estimate the price elasticity of electricity demand. They found that the response was relatively small despite the presence of substantial marginal incentives, ranging from −0.002 to −0.037. The study of a "wild" tariff scheme in Georgia found that marginal price and the average price per kWh are identical and it is −0.3 Alberini et al. (2022). When authors fitted an electricity demand function, the price elasticity become more pronounced (−0.5), suggesting that households respond to the current average price (that is the marginal price) rather than the expected price.

Both marginal and average prices 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 (Nieswiadomy and Molina, 1989, Mansur and Olmstead, 2012;). 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 3 prices faced by each respondent in or after April 2015 (and zero for the earlier periods).[12, 13] 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

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

[13] 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 perfect 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 perfect collinearity with the month-year effects.

benefits), andan interaction term between the two. (For households not on benefits, the allowance is zero and thepercent tariff reduction is likewise zero.)[14]

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 chapter, we simply choose to proxy it with house type-by-month and income-by- month effects, i.e., the **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-

[14] 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 wouldapply 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.

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 1.2., 1.3. and 1.4.

Table 1.2.: Characteristics of the Home.

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%

Briefly, Table 1.2. shows that 57% of the respondents live in multi-family buildings and 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. 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.

Table 1.3.: Energy Consumption statistics: Monthly electricity usage.

Description	Mean	Std Dev
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 1.4.: Respondent Socioeconomics.

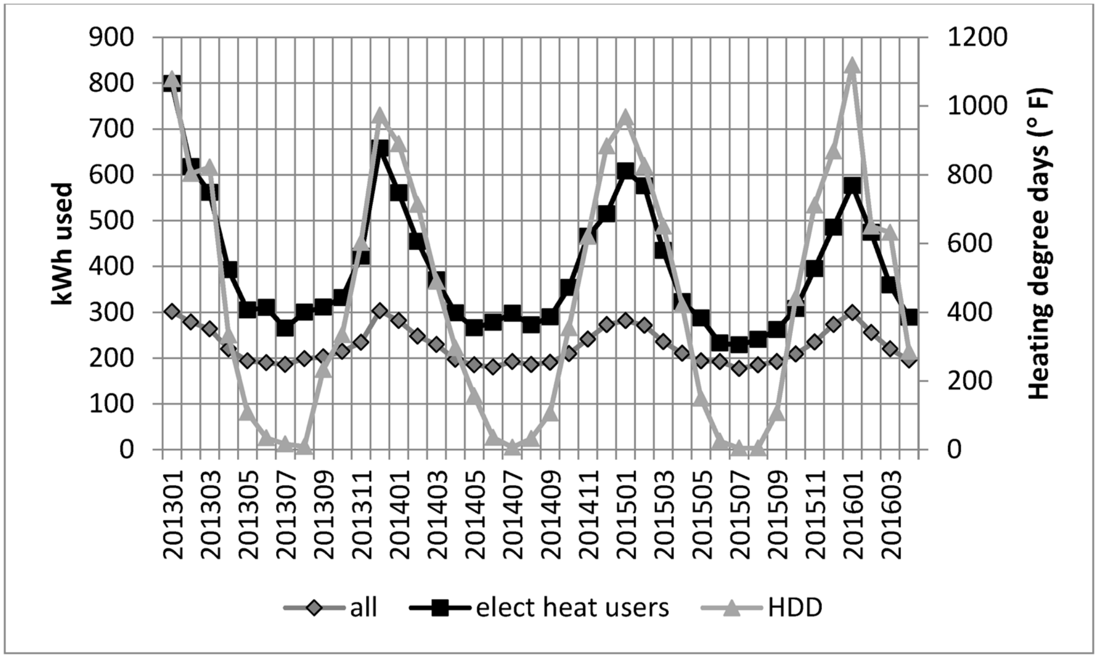
Variables	Average or percent of the sample (standard deviation in parentheses)
Household size	3.386 (1.4809)
Household monthly income (UAH)	5063.46 (2417.30)
Did not report information about income	6.4%
Education:	
Secondary	16.7%
Professional-technical	25.9%
High education (MSc, BSc, DiS)	56.0%
Other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

Table 1.4. 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 USD), our sample is thus similar to the Ukraine population average. The sample median income is 4250 UAH.

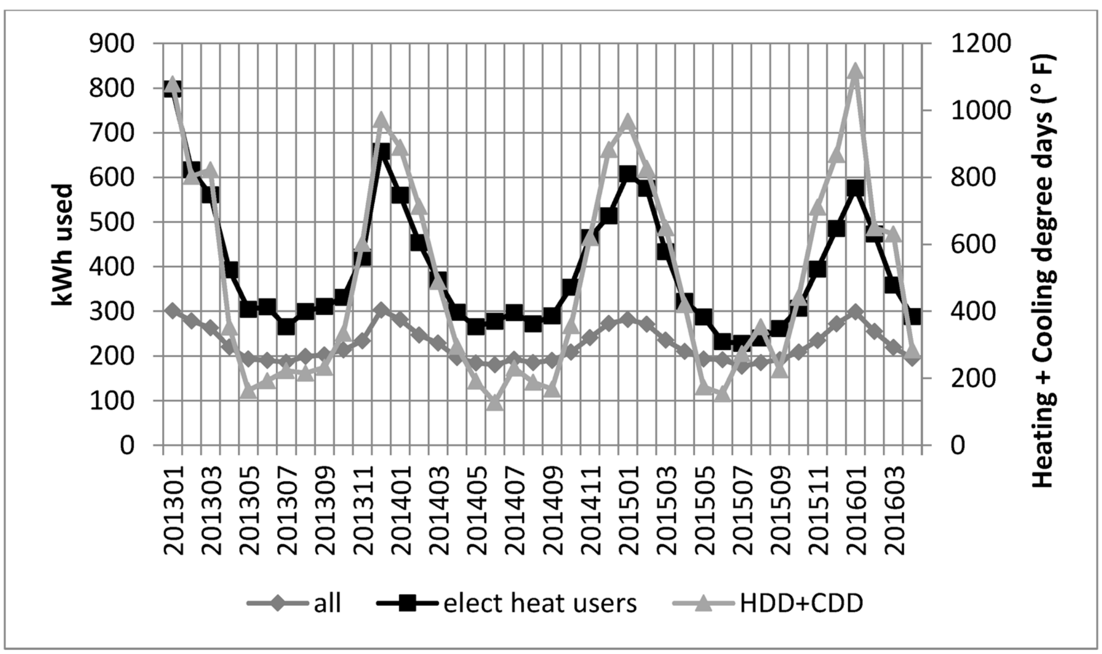
The two panels of Figure 1.4. shows that, as expected, electricity usage is highly seasonal, and that this seasonality is extremely pronounced for households who rely on electricity to heat their homes.

Figure 1.4.: Average monthly electricity consumption and weather.

(A)



(B)



The peaks are in the winter, as is consistent with a location with some 5300 Fahrenheit heating 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 1.4.

Figure 1.4. 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 1.5. 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.

Table 1.5.: 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

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 floors of the building (if the household lives in a multi-family building).

One key research question in this chapter 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.[15] They are however significantly less likely to be using electric heat, and, if quantity-attentive, they tend to use less electricity each month.[16]

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.

[15] 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.

[16] 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.

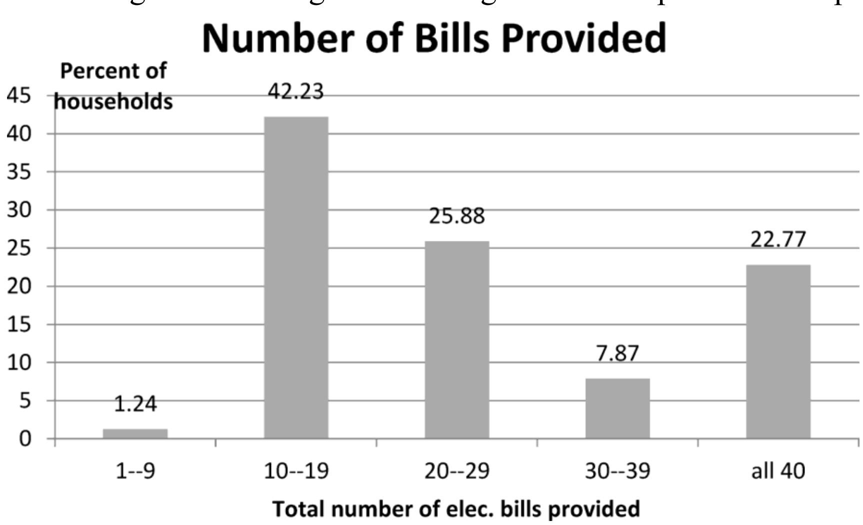
6. Results

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 ableto 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 ofthe 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 1.5. 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.

Figure 1.5.: Length of the longitudinal component of the panel.



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 than 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.

Including month and year variables (*i)* allows for capturing the temporal dynamics of the data. It is particularly crucial when analyzing panel or longitudinal data, where observations are collected over multiple periods. Including these variables makes it possible to account for any systematic changes or trends over time. If significant time-related patterns exist in the data, the model may provide better predictions and a more accurate representation of the underlying relationships when these variables are included.

The results are shown in Table 1.6. 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.

Table 1.6.: 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		

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 1.7., 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 conventional levels (Table 1.7., 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 1.7.: 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.

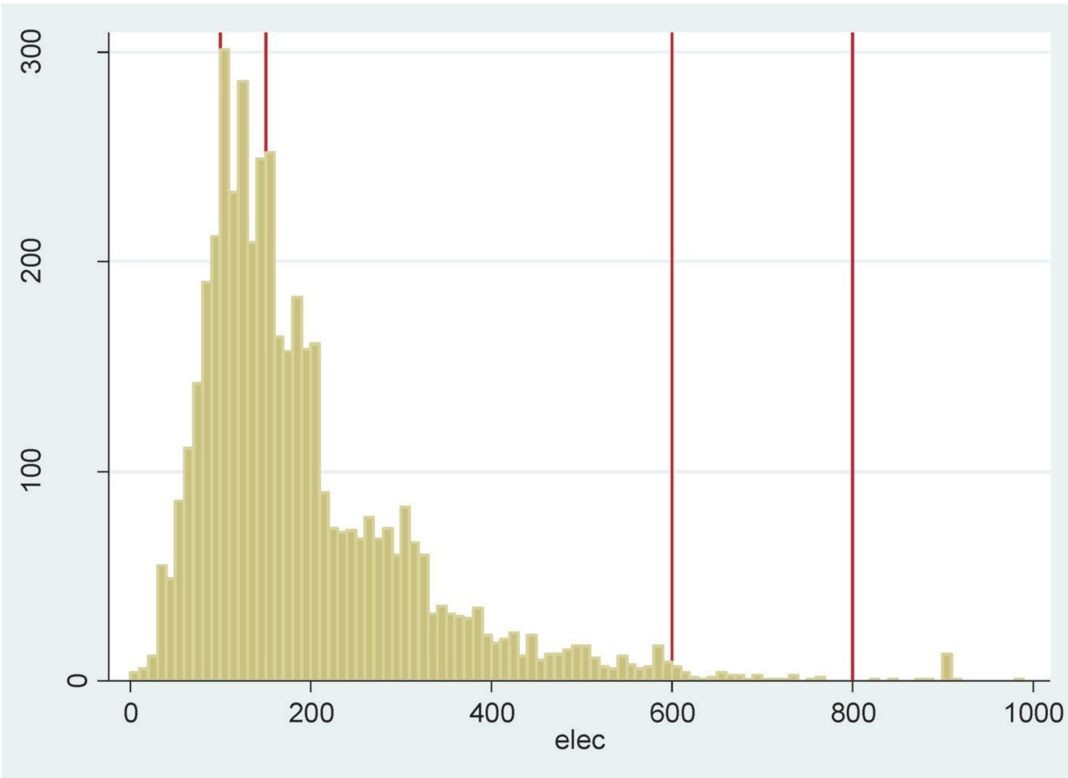
The corresponding histograms are striking although sometimes difficult to interpret. For example, the one in Figure 1.6. (earlier period, until March 2015) seems to suggest that there is bunching at 150 kWh/month, but also a much more pronounced spike in the frequency of the data at 100 kWh/month, even 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.[17]

There are also minor spikes in the distribution at various other consumption levels. They might suggest that consumers may respond to factors or influences beyond the explicit rate structure of utility bills. Consumers may exhibit inefficiency in adjusting their consumption behavior or lack information or awareness about the rate structure and how it affects their bills. Some may continue to consume energy at certain levels out of habit, regardless of rate changes. Additionally, the availability of subsidies can influence consumer behavior independently of rate changes because they can be present in one season and be absent in another.

[17] 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.

Still, consumers may opt for a stable consumption pattern even if it means paying slightly higher bills. Households can respond to the tariff incentives also by shifting consumption from peak hours to off-peak hours (Lanot and Vesterberg, 2021).

Figure 1.6.: Histogram of usage for households without electric heat and without benefits, January 2013–March 2015.



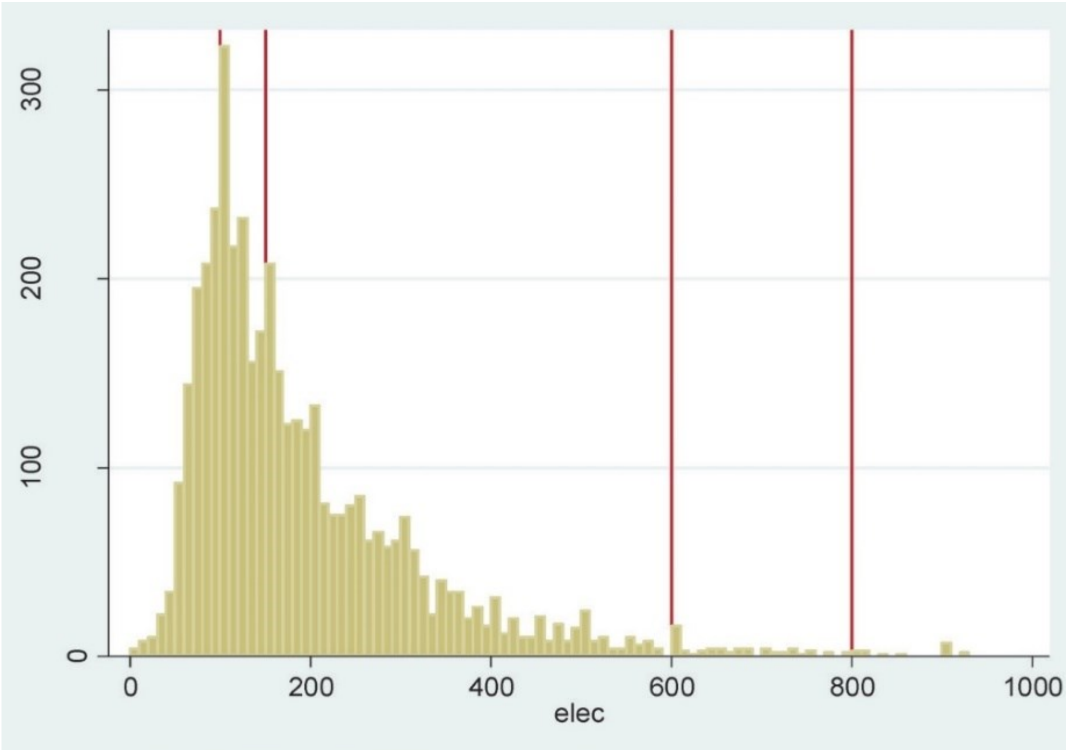
Notes: The block cutoffs are 150 and 800 kWh per month. Also shown are vertical lines at 100 and 600 kWh.

Figure 1.7. (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.[18] 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.[19]

[18] 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.

[19] When the histograms of Figures 1.6. and 1.7. are constructed for quantity-attentive respondents and all others, they display patterns like the ones in Figures 1.6. and 1.7.

Figure 1.7.: 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.

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.

Table 1.8. 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.

Table 1.8.: 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 (12.03)	1.4726 (12.07)
Log price in block 2 × before April 2015 dummy	–0.1570 (–6.50)	–0.1652 (–6.87)
Log price in block 3 × before April 2015 dummy	0.1748 (4.37)	0.1941 (4.78)
Log price in block 1 × on or after April 2015 dummy	3.4005 (31.77)	3.4108 (31.83)
Log price in block 2 × on or after April 2015 dummy	–0.9850 (–22.92)	–1.0059 (–23.11)
Log price in block 3 × on or after April 2015 dummy*	—	—
Allowance (monthly allowance in kWh)	–0.0013 (–4.32)	–0.0013 (–4.31)
Fraction of block 1 price paid (less than 1 only if household receives benefits)	0.0855 (0.98)	0.0905 (1.06)
Allowance × fraction of block 1 price paid	0.0016 (3.10)	0.0016 (1.06)
Nobs	11672	11672
Number of households	482	482
F test on excluded instruments	264.43 (p value < 0.00001)	243.44 (p value < 0.00001)
C test of the null that allowance and allowance × percent price paid are exogenous	0.943 (p value = 0.6242)	1.674 (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.

In both specifications shown in Table 1.8., 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 1.8., the C test fails to reject the null that those two excluded instruments are exogenous.[20]

Table 1.9. 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 1.6.–1.7.

[20] The outcomes of the F and C tests are similar when the sample is restricted to certain groups of people or residents incertain types of homes as shown in Table 1.9. See Baum et al. (2003) and Wooldridge (2010, p. 134–137).

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 1.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 –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.[21]

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 1.9.), 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)).

[21] 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 1.9. (and Appendix Table 1.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 1.9.: 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	119
(O) Income in the middle tercile of the distribution in the sample	–0.1797	–1.91	3612	151
(P) Income in the top tercile of the distribution in the sample	–0.3866	–3.37	3991	166
(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 1.9. 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.

Table 1.10.: 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.

In Table 1.10. 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 don't affect the estimated 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).[22]

Turning to the question of how quickly households adjust their electricity demand to price change, Table 1.11. 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

[22] 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 1.A.2. in Appendix 1.A.). Perhaps these respondents pay more attention to the bill amount, and hence to the average price, than to the marginal block prices.

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.[23]

Table 1.11.: Effects over time.

	(A) 1 month before + 1month after	(B) 1 month before + 2months after	(C) 2 months before + 2months after	(D) 3 months before + 3months 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.

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 1.B.). The elasticities are more pronounced when log average price is used (–0.27 and –0.52, respectively).

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

[23] Since the sample of column (D) in Table 1.11. 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.

in Ukraine is 0.5631 kg,[24] 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 permonth) gives a cost per ton of some 3341 UAH, or 131 USD.[25,26]

7. 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

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[24] 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.

[25] 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.

[26] 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 CO_2 (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.

homes with electric 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 USD.

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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Appendix 1.A. Estimation results using log average price

Table 1.A.1.: Electricity demand estimation: Log-log model with household fixed effects, month-by-year effects, log degree days. Log marginal price is instrumented for. T statistics based on standard errors clustered at the respondent level.

Description of the sample or specification	Coeff. on log average price	t statistic	Nobs
(A) All	−0.2895	−3.44	11673
(B) Single family homes	0.0149	0.08	4689
(C) Apartments in multi−family buildings	−0.2407	−2.70	6626
(D) Jan 2013−Mar 2015	−0.8622	−2.82	6101
(E) April 2015 and later	−0.2028	−2.42	5572
(F) No recipients of benefits	−0.4642	−4.47	10462
(G) Drop bottom and top 1%	−0.1997	−2.10	11442
(H) Add detailed weather controls	−0.2896	−3.44	11673
(I) Exclude families that have done energy-efficiency upgrades in the home in the last 3 years[a]	−0.2754	−3.16	8678
(J) Exclude families with electric heat that have done energy-efficiency upgrades in the last 3 years[a]	−0.2653	−3.12	11069
(K) Exclude families with electric heat that haven't done energy efficiency upgrades in the last 3 years[a]	−0.3644	−1.78	10467
(L) Add house type-by-month fixed effects and income interacted with month dummies[a]	−0.2327	−2.84	11673
(M) Income in the bottom tercile of the distribution in the samplea	−0.3852	−1.78	2844
(N) Income in the middle tercile of the distribution in the sample[a]	−0.1737	−1.63	3612
(O) Income in the top tercile of the distribution in the sample[a]	−0.3922	−2.76	3991

[a] Detailed weather controls are included in this equation.

Table 1.A.2.: Effect of attentiveness to consumption or expenditure levels. Models include detailed weather controls. T statistics based on standard errors clustered at the respondent level.

	Quantity-attentive respondents	Non quantity-attentive respondents	Bill-attentive respondents	Non bill-attentive respondents	Both quantity- and bill-attentive	No respondents who do not know current tariffs	Only respondents who do not know current tariffs
Coefficient on log average price	−0.3231	−0.2294	−0.1895	−0.2729	−0.5442	−0.2504	−0.6554
t statistic	−1.64	−3.04	−1.15	−3.02	−2.32	−3.17	−1.92
Nobs	4667	7006	3693	7980	1935	10113	1560

Table 1.A.3.: Effects over time. Log-log model with household fixed effects, month-by-year effects, log degree days. Log average 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.

	1 month before + 1 month after	1 month before + 2 months after	2 months before + 2 months after	3 months before + 3 months after
Coefficient on log average price	−0.1497	−0.1447	−0.2111	−0.2681
t statistic	−1.61	−1.93	−2.64	−3.11
Nobs	3592	4706	6471	8717

Appendix 1.B. Dynamic panel

We fit a dynamic panel model based on a partial adjustment assumption, namely that

$$\text{(B.1)} \qquad \left(\frac{E_t}{E_{t-1}}\right)=\left(\frac{E_t^*}{E_{t-1}}\right)^{\lambda},$$

where E* represents the desired long-run equilibrium consumption and λ is the speed of adjustment. On further positing that the long-run demand function is

$$\text{(B.2)} \qquad E^*=\exp(\mathbf{Wg})(P^E)^b I^c$$

Where **W** contains weather variables, *I* is income, taking logs and substituting into the log-transformed version of (B.1), we obtain the equation

$$\text{(B.3)} \qquad \ln E_{it}=\alpha_i^*+\rho\cdot\ln E_{it-1}+\beta^*\cdot\ln P_{it}^E+W_{it}\gamma^*+\tau_t^*+e_{it},$$

where ρ is (1-λ), β* is bλ, etc., and the τs are month-by-year dummies.[27] We estimate equation (B.3) after re-writing it in the first differences:

$$\text{(B.4)} \qquad \Delta\ln E_{it}=\rho\cdot\Delta\ln E_{it-1}+\beta^*\cdot\Delta\ln P_{it}^E+\Delta W_{it}\gamma^*+(\tau_t^*-\tau_{t-1}^*)+\Delta e_{it}.$$

In equation (B.4), both $\Delta\ln E_{it-1}$ and $\Delta\ln P_{it}^E$ are endogenous, and so we estimate this equation by 2SLS, with $\ln E_{it-2}$ the excluded instrument for $\Delta\ln E_{it-1}$ (Anderson and Hsiao, 1982) and the usual set of block prices plus exogenous benefit indicators the excluded instruments for $\Delta\ln P_{it}^E$. We prefer the simpler Anderson and Hsiao approach (1982) to the Arellano-Bond (1991) and Blundell-Bond (1996) approaches, which use a richer set of instruments, because the unbalanced nature of our panel limits the number of lagged observations that can be used to construct these instruments. The price elasticity in (B.2) is estimated as the coefficient on $\Delta\ln P_{it}^E$ divided by 1 minus the coefficient on $\Delta\ln E_{it-1}$. We develop standard errors around $\beta^*/(1-\rho)$ using the delta method.

[27] We omit income as we do not have income for each month of our study period.

Since we have monthly data, it is unclear whether b is correctly interpreted as a long-run elasticity. We prefer to interpret is a mid-run elasticity with respect to price.

Table 1.B.1.: Dynamic panel model estimation results. T statistics based on standard errors clustered at the respondent level.

	using log marginal price		using log average price	
	coeff.	t stat	coeff.	t stat
Short-run elasticity (=coefficient on log price)	−0.2114	−2.72	−0.2785	−2.62
coefficient on log elec (t−1)	0.4666	8.34	0.4669	8.29
long-run elasticity	−0.3964	−2.88	−0.5226	−2.78

Chapter 2.

Responsiveness to energy price changes when salience is high: Residential natural gas demand in Ukraine

Abstract

Despite its importance for policy purposes, evidence about the price elasticity of natural gas demand in the residential sector is very limited and based on inference from situations with modest variation in prices. We focus on a locale and time when price changes were extreme and salient to consumers, namely Ukraine between 2013 and 2017. We exploit the tariff reforms and detailed micro-level household consumption records to assess whether consumers adjust their consumption in response to the rate changes and estimate the price elasticity of the demand for natural gas. To isolate behavior, attention is restricted to those households that made no structural energy-efficiency upgrades to their homes, thus keeping the stock of gas-using capital fixed. We find that households *are* capable of reducing consumption, even without installing insulation or making any other structural modifications to their homes. The price elasticity is about −0.16. Wealthier households, people living in multi-family buildings, and heavy users have more inelastic demands. Households reduced consumption even when they received government assistance. This, and the fact the demand is inelastic, especially for wealthier households, bode well for tariffs or energy tax schemes where wealthier households subsidize the consumption of the poorer ones.

Keywords: residential gas demand; energy transition; short-run price elasticity; tariff reforms; salience.

1. Introduction

At an average content of 53.07 kilograms of carbon dioxide per million British Thermal Units (BTUs), natural gas is generally regarded as the cleanest-burning fossil fuel.[1] In the US alone, it currently ranks as the most widely used fuel for space heating (OECD/IEA 2018) and its use for power generation has been increasingly steadily over recent years, just as coal-fired generation has been declining, due to a combination of market forces, technological innovation in extraction, and environmental concerns. At this time, gas-fired plants account for about one-third of power generation in the US,[2] and, depending on the area, for a much larger share during peak load times.

Similar trends have been observed in the European Union, which remains a net importer of natural gas.[3] The geopolitics of natural gas are complicated, as natural gas exporting countries have often been politically unstable or involved in conflicts, and delivering natural gas involves the construction of pipelines, sometimes from or through such nations. Reducing dependence on natural gas is thus part of a smooth transition to low-carbon, secure sources of energy.[4]

In this chapter, we focus on residential demand for natural gas (for space and water heating, and cooking). In Ukraine, our study site, such demand accounts for 36% of total consumption (OECD/IEA 2018).[5] We are interested in its responsiveness to price. Traditionally, this information is summarized into the (own) price elasticity of demand, a key parameter for predicting how demand would change if a tax on each unit of natural gas was introduced (or revised) to correct for the externalities associated with gas usage (such as a carbon tax), computing the loss of welfare associated with disruptions in supply, and understanding the extent of the rebound effect (Sorrell et al., 2009) following improvements in the energy efficiency (EE) of buildings.

Surprisingly, evidence about the price elasticity of natural gas demand from the residential sector is limited. Auffhammer and Rubin (2018) identify a total of nine studies from the US, the UK and Germany, uncovering demand functions ranging from almost inelastic (price

[1] See https://www.eia.gov/environment/emissions/co2_vol_mass.php.
[2] See https://www.eia.gov/todayinenergy/detail.php?id=34612.
[3] See https://ec.europa.eu/eurostat/statistics-explained/pdfscache/46126.pdf.
[4] See https://energytransition.org/.
[5] In 2016, 59% of the heat in Ukraine was produced from burning gas, while only 6% of the total consumption is for generating electricity (OECD/IEA 2018). In Ukraine combined heat and power, heat, and the electric power sector account for 33% of the total consumption of natural gas, the industrial sector for 10%, the residential sector for 36%, transportation for 5.5%, and the commercial, non-energy sector, own use and losses for the remaining 12%.

elasticity −0.08; Metcalf and Hassett, 1999) to almost perfectly elastic (price elasticity −0.71; Metcalf and Hassett, 1999). Auffhammer and Rubin (2018) use a large panel from California and find that the price elasticity falls in the range from −0.23 to −0.17 and varies across seasons and with household income.

Burke and Yang (2016) rely on a panel of national-level data from several countries, and find that while gas consumption as a whole is responsive to price, the demand for gas from the residential sector is inelastic in the short run. The estimated short-run price elasticity is −0.13, but this coefficient is statistically insignificant at the conventional levels. Burns (2017) examines aggregate data from the US and concludes that the demand is price-inelastic and getting more so over time.

The identification of the price elasticity of demand does, of course, depend crucially on the variation in prices over time and across the units of observation. Auffhammer and Rubin (2018) appear to rely on price fluctuations well within 50% of the lowest price observed over 2010-2016; baseline prices (price in the first tier of consumption) and marginal prices generally exhibit coefficients of variation no greater than 0.20 (Auffhammer and Rubin, 2018, Table 2.3.).

Employing the Chinese Residential Energy Consumption Survey data, Zeng et al. (2018) analyzed the gas price elasticity of Chinese households. His findings suggest a more responsive demand for changes in price, as indicated by an overall price elasticity coefficient of approximately −0.898.

Jaouad et al. (2020) conducted a comprehensive study from 1980 to 2016 using data from 19 OECD countries. Their estimations emphasized that the natural gas price elasticity is negative in the long run. Environmental policies have demonstrated their effectiveness in reducing residential natural gas use in the long term.

A study of panel data from 958 Swiss households between 2010 and 2014 by Filippini and Kumar (2020) stated that the gas demand exhibits a price elasticity of around −0.73 at the household level. The authors also confirmed the connection between lower temperatures and higher gas consumption in the residential sector.

The most up-to-date study examined the elasticities related to natural gas demand in 15 EU countries from 2016 to 2020. They underscored the significance of accounting for seasonal influences when assessing the demand response. The outcomes concerning the average gas price elasticity for the European Union indicate that it fluctuates in the short-run from zero to -2.209

and in the long-run from −0.935 to −4.416, contingent on the specific month under consideration. (Erias and Iglesias, 2022)

The comprehensive study of the gas price elasticities conducted in the USA among 50 states indicates that gas prices are inelastic. The author estimated that the short-run price elasticity for the residential sector is −0.5. The study's conclusions highlighted that even though there have been shifts in the natural gas sector over time and across various locations, consumers almost did not change their response to the prices as in the past. (Joshi, 2021)

When price changes are small, one wonders whether they are salient to people (Deryugina et al., 2019; Alberini et al., 2011). Salience refers to economic agents' ability to fully observe, retain and process the price of a good, or changes in the price of a good. Salience may be compromised by price labels that fail to report a portion of the price of the item, such as the sales tax eventually imposed on it (Chetty et al., 2009), by automatic billing schemes where charges go unnoticed (Finkelstein, 2009; Sexton, 2015), or when the utilities are folded in the dwelling's rent, as was often the case in transition countries during the Soviet era (Dodonov et al., 2004).

In this chapter, we focus on a locale and time when price changes were extreme and salient to consumers, namely Ukraine between 2013 and 2017. From one month to the next (March 2015 to April 2015), the tariffs tripled, and by the subsequent month (May 2015), they were *seven times* as high as in March. The tariff hikes were accompanied by a restructuring of the tier system, and later (April 2016) by the complete removal of the block system. Extreme tariff changes are sometimes observed in markets that undergo sudden structural transformation, such as the removal of subsidies (e.g., in other former Soviet republics, see McRae and Meeks, 2016, or, more recently, Argentina, where residential gas tariffs increased by 500% since 2015), or where deregulation triggered undesirable consequences (as in California during the Enron crisis, which doubled the electricity rates for residential customers in the SDGandE service territory). Ukraine's actual seven-fold increase in gas prices dwarfs the tariffs increases examined or computed as necessary to cover costs in earlier analyses (e.g., Dodonov et al., 2004).

We take advantage of the tariff scheme structure and reform, and the associated tariff shocks, to examine the responsiveness to price changes and identify the short-run elasticity of residential gas demand in city of Uzhhorod in western Ukraine. Unlike other parts of Ukraine, where district heating may still be important,[6] the region around Uzhhorod, Transcarpathia, began to disconnect homes from district heating in 2005 and completed this process by 2012. By the beginning of our study period (January 2013), every dwelling had its own separate heating system, even in multi-family buildings, and was responsible for paying for its own consumption. Most people chose natural gas as their main heating fuel, taking advantage of existing infrastructure and low, and highly subsidized, residential natural gas prices.

We ask three research questions. First, faced with massive tariff hikes, are people capable of reducing gas consumption? Second, does the responsiveness to price vary across households? Third, does government assistance in the form of lump-sum transfers offset the effect of price increases on demand? These questions have important implications for consumer welfare as well as for utility revenue purposes.

We argue that the tariff hikes were salient to consumers for at least eight reasons. First, people own and run their own heating system and are responsible for their own consumption. Second, the sheer magnitude of the tariff hikes, and the subsequent escalation of government energy assistance programs, suggest that the tariff reforms did not possibly go unnoticed. Third, each family receives the gas bill every month, with clear information about consumption for that month and the tariff(s). Fourth, Ukraine relies on one-part tariffs, which make the relationship between usage and the bill very clear. Fifth, the gas bill is not combined with other utilities (e.g., electricity or water). Sixth, the published rates are inclusive of taxes. Seventh, most households at our study locale save their bills and even maintain their own "utility book" where they manually record the same information that appears on the bill. Last but not least, direct debit payment is uncommon: Most people bring their bills to the post office or to the bank to pay them, suggesting that the effect documented in Sexton (2015) is absent here. [7]

In our study area gas meters are usually placed inside a dwelling. This means that attentiveness (Sallee, 2014) and usage monitoring are possible with a relatively low effort on the part of the consumer. These and the abovementioned circumstances are in sharp contrast with

[6] Some 30-40% of the households in Ukraine are served by district heating (Nithin Umapathi, World Bank, personal communication, 8 March 2019; Emerson and Shimkin, 2015).

[7] The study by Sexton suggests that introducing automatic billing decreases consumers' salience. By enrolling in the automatic billing program, households do not inspect their bills, thus ignoring the consumption. The findings indicate that automatic billing program enrollment results in a 4.0% rise in residential electricity consumption and an increase of up to 8.1% in commercial electricity consumption. Additionally, participation in programs aimed at smoothing out the seasonal fluctuations in monthly utility bills for low-income customers leads to a 6.7% increase in electricity usage.

earlier descriptions of energy-related habits in Soviet times, when the utilities were often folded into the rent and the rates were extremely low, and even right after the breakup of the Soviet Union, when authorities were reluctant to raise the tariffs (Dodonov et al., 2004; Fankhauser et al., 2008).

We assembled a panel dataset documenting monthly consumption from January 2013 to April 2017 for a sample of households in the Uzhhorod metropolitan area and use it to examine the price elasticity. We wish to isolate changes in consumption due to behaviors, holding the structural characteristics of the dwelling and gas-using capital stock fixed, and based on this notion, in our empirical work we restrict attention to those households that did not do any energy efficiency upgrades to their homes during our study period. (In other words, these households did not install insulation, or changed windows, put in a new boiler, switched to a different heating fuel, etc. between January 2013 and April 2017.) To identify cleanly the short-run elasticity, we further limit the analyses to a few months before and after the tariff changes.

Unlike in Auffhammer and Rubin (2018), in Ukraine tariffs are not adjusted monthly to reflect the higher or low cost of acquiring natural gas for the utility: They are simply set exogenously by the regulator for a period of about one year at a time.[8] Because for part of our study period there was an increasing block tariff scheme, we are concerned with endogeneity of prices and quantity consumed at the consumer level, which we address with instrumental variable estimation. During our study period a number of households received "subsidies," namely lump-sum government assistance to help pay the gas bills. We wish to see whether the subsidies offset the incentive to reduce consumption.

We find that the demand is not completely inelastic: Even without structural modifications to their homes, consumers were able to reduce usage meaningfully as tariffs were raised. When price doubles, consumption is cut, all else the same, by 7-22%. The reduction is however disproportionately small compared with the extent of the price hike and implies a short-run price elasticity of −0.16, which falls in the low end of the range from earlier studies and provides empirical evidence for the assumptions in Fankhauser and Tepic (2007), who examine the affordability of utility bills in transition countries under various cost-recovery pricing scenarios. Wealthier households and people living in multi-family buildings have less elastic

[8] Gas prices were regulated by the National Commission for State Regulation of Energy (NERC) from October 23, 2011, to October 1, 2015. The Ukrainian Cabinet of Ministers has been regulating the price of gas as an "energy carrier" ever since, while NERC retains the authority to set prices for gas distribution and transportation.

demand functions. People seem to respond to current prices and not to future prices. We find modest evidence that households likely to hold different levels of "salience" have different price elasticities, but this effect may partly overlap with that of income and/or baseline consumption.

The offsetting effect of the subsidies is very modest. If both prices and subsidies were to double, consumption would still be reduced by about 10%, and consumption would still be reduced even if the proportional increase in the subsidies was greater, as long as it does not exceed a five-fold hike. This has important implications for the design of schemes that help low-income families. In our sample, the tax revenue from the gas sales to the wealthiest households in the sample would be sufficient to cover the subsidies to the poorest households in the sample.

Researchers and policymakers have been struggling for decades with understanding incentives to conservation and why energy efficient technologies are only slowly adopted by households (Jaffe and Stavins, 1994; Allcott and Greenstone, 2012). Some of our results hint at the possibility that those who do not adopt such technologies might be the ones who by necessity or skills are the most capable of reducing consumptions through behaviors.

The remainder of the chapter is organized as follows. We present background information in section 2. Section 3 presents the data, and section 4 lays out the model and estimation techniques. Section 5 presents the results and section 6 concludes.

2. Background

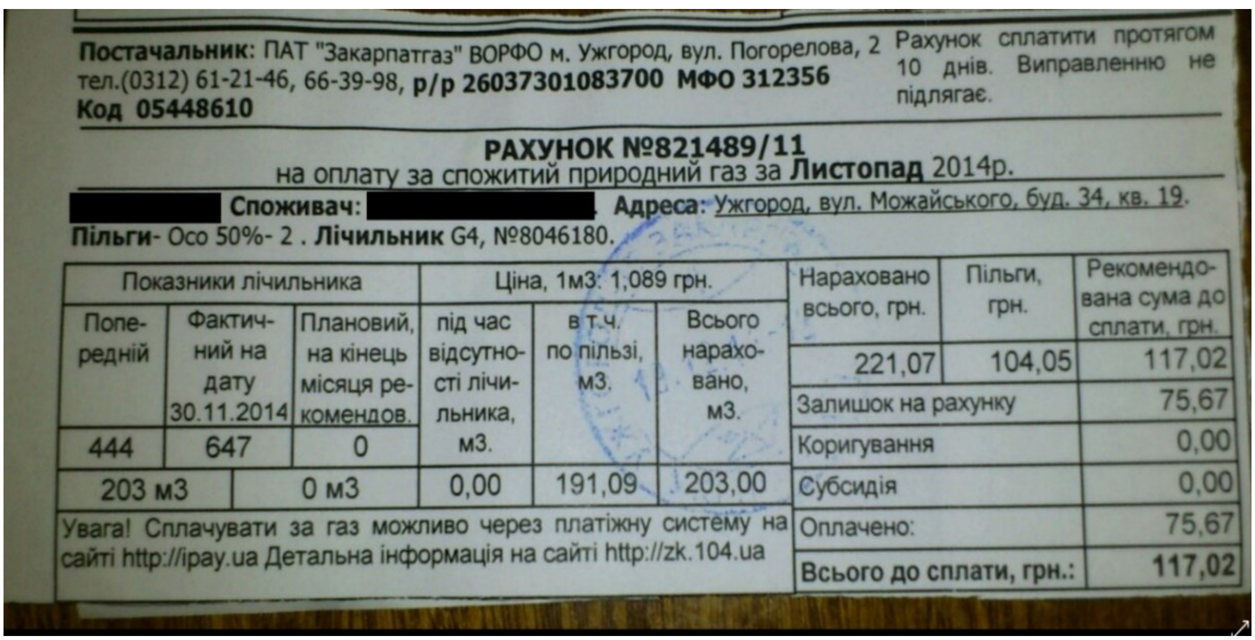
In May-June 2016, and then again in May-July 2017, we collected data about natural gas and electricity use by households in Uzhhorod, a city with some 113,000 residents in western Ukraine.[9] Unlike other parts of Ukraine, where district heating still serves a large share of the homes, Transcarpathia, the administrative region where Uzhhorod is located, started disconnecting dwellings from district heating in 2005 as part of a pilot project. The process was completed by 2012, which means that by the beginning of our study period (January 2013), everyone had installed and had been using their own separate heating systems, even in multi-

[9] Ukraine is a former Soviet republic with per capita GDP of $8,800 (2017 PPP dollars) in 2017, only 17% that of Germany and 15% that of the United States (CIA Factbook, see https://www.cia.gov/library/publications/the-world-factbook/, last accessed 21 March 2019). Internal political turmoil and conflict with Russia affected the country in 2014, and resulted in a negative growth in 2015 (real GDP growth -9.8%), followed by 2.5% growth in 2016 and 2017.

family buildings. The majority of the homes in the Uzhhorod metropolitan area are heated by gas boilers (and radiators), and natural gas is supplied by PJSC Zakarpatgaz, a state-owned utility.[10]

People receive their gas bills every month, and charges are based on actual (not estimated or presumptive) consumption for that month, as per the monthly meter reading conducted by a representative of the utility. The bills (see Figure 2.1.) display clearly the meter reading at the end of the current and previous billing periods, consumption as the difference between them, the tariffs, and any applicable "benefits" or "subsidies" (described below). There is no fixed monthly charge: In other words, Transcarpathians pay a one-part tariff. Most households keep their gas bills and even maintain their own "utility book," where they manually record the same information that appears on the bill. It certainly helps that gas meters are most often *inside* the homes.[11]

Figure 2.1.: Sample Gas Bill.



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Пільги- Осо 50%- 2 . **Лічильник** G4, №8046180.

Показники лічильника			Ціна, 1м3: 1,089 грн.		
Попередній	Фактичний на дату 30.11.2014	Плановий, на кінець місяця рекомендов.	під час відсутності лічильника, м3.	в т.ч. по пільзі, м3.	Всього нараховано, м3.
444	647	0			
203 м3		0 м3	0,00	191,09	203,00

Нараховано всього, грн.	Пільги, грн.	Рекомендована сума до сплати, грн.
221,07	104,05	117,02
Залишок на рахунку		75,67
Коригування		0,00
Субсидія		0,00
Оплачено:		75,67
Всього до сплати, грн.:		**117,02**

Увага! Сплачувати за газ можливо через платіжну систему на сайті http://ipay.ua Детальна інформація на сайті http://zk.104.ua

The tariffs are set exogenously by the regulator and generally remain unchanged for about a year: Unlike in the US, they do not adjust monthly to mirror the higher or lower cost at which the utility has acquired natural gas (Auffhammer and Rubin, 2018). As shown in Table 2.1. and

[10] Starting in 2015, PJSC Zakarpatgaz was made responsible for the distribution of natural gas, while the provision of gas itself was assigned to Zakarpatgaz zbut Ltd.
[11] Gas meters are located inside each unit of a multi-family building, and inside single-family and semi-detached homes built before 2004. Gas meters were placed outside single-family and semi-detached homes built in 2004 and later.

Figures 2.2. and 2.3., over the course of three years (from 2013 to 2016) gas prices to residential customers increased dramatically by over 700% in nominal terms in part because of the deteriorating relationship, and eventual conflict, with Russia, which cancelled deliveries to Ukraine, and in part to help the gas utility, which had until then been selling natural gas for industrial and residential use at highly subsidized rates, recover costs.[12] Until March 2015 consumers faced a fairly complicated increasing block rate tariff scheme based on annual consumption with a mid-year assessment.[13] This scheme was replaced in April 2015 by a two-block system during the heating season, with the block cutoff set at 200 m^3 per month, and uniform pricing the rest of the year, and dramatically higher rates per m^3. Figure 2.2. displays the rate per m^3 charged over our study period to a consumer whose usage falls in the first block. In Figure 2.3. we display the tariffs for a consumer in the first block and one in the second block to highlight the different percentage increases. A consumer who used exactly 200 m^3 would have paid $(1.089\times200) = 217.80$ UAH in March 2015, but $(200\times3.6) = 720$ UAH in April 2015. A consumer using 400 m^3 would have paid $(200\times1.089+200\times1.788) = 575.40$ UAH in March 2015, but $(200\times3.6+200\times7.188) = 2{,}517.60$ UAH in April 2015.

In April 2016, the block system was dropped, and a uniform pricing scheme introduced.[14] The rate was set at 6.879 UAH/m^3, seven times as much as what our 200-m^3/month customer would have paid only 13 months earlier.[15] Electricity tariffs likewise rose during the same four-year period, but at a much lower rate (no more than 50% from one tariff regime to the next) and more frequently (Alberini et al., 2019).

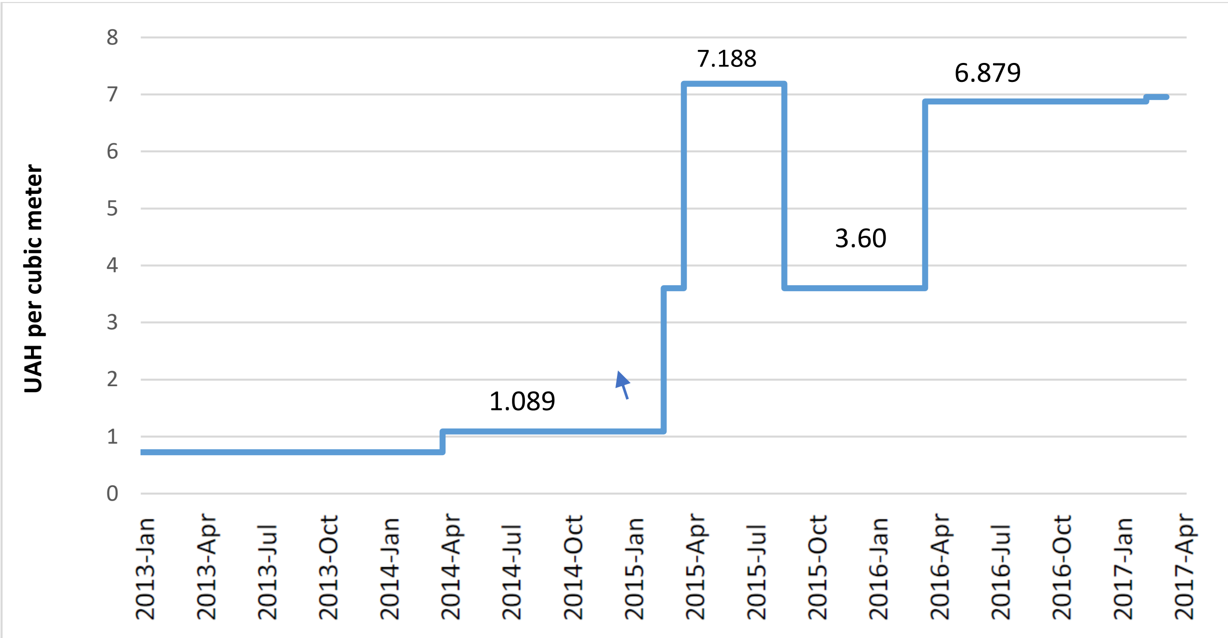
[12] Prior to the 2015 tariff reforms, Ukraine had the lowest household gas prices in the industrialized world and its economy an extremely high energy-intensity, comparable to that of Russia, but “without the latter’s natural resource endowment” (Emerson and Shimkin, 2015, p. 3). Calculations by Fankhauser and Tepic (2007) based on pre 2006 data show that Ukrainian households were, on average, able to pay their utility bills “without problems,” and that affordability would have remained very good even if tariffs had been raised to ensure cost recovery in 2007.

[13] To illustrate, initially there were a total of four blocks from zero to 2500 m^3/year, from 2500 to 6000 m^3/year, from 6000 to 12000 m^3/year, and more than 12000 m^3/year. Suppose that a household in one year used 2000 m^3. At the beginning of the next year, the household would be charged the first-block rate for each m^3 consumed in each month. At the end of June, the utility would re-evaluate this household. If the household had used less than 60% of the block cutoff (namely, $0.60\times2500=1500$ m^3), it would continue to be charged the first-block rates. If it had exceeded that cutoff (having consumed, for example, 1850 m^3), it would be bumped up to the second-block rate. At the end of the year, if the consumer had managed to stay below 2500 m^3, it would be assigned the first-block rate starting the next January, while if it had consumed between 2500 and 6000 m^3 over the year, it would be assigned the second block rate. This scheme was slightly simplified, and rates raised somewhat, in May 2014, when the regulator did away with the upper block, as can be seen in Table 2.1. In April 2015, the scheme was replaced by a two-block system. The cutoff between the first and second block was set at 200 m^3 *per month*. The block system was dropped entirely in April 2016.

[14] In Figure 2.3., this is shown by the fact that the tariffs for the first and second block overlap after April 2016.

[15] The exchange rate was 28.77 UAH per euro on April 15, 2016. (see https://freecurrencyrates.com/en/exchange-rate-history/EUR-UAH/2016/nbk).

Figure 2.2.: Gas Tariff (price per cubic meter) charged to a consumer in the first block (up to 200 m3/month) from January 2013 to April 2017.



Note: the first consumption block was 1500 m^3 for January through June, and 2500 m^3 for the full year, until March 2015; 200 m^3/month from April 2015 to April 2016. The block system was dropped in May 2016.

Figure 2.3.: Gas Tariffs (price per cubic meter) charged to a consumer in the first block (up to 200 m3/month) and to one in the second block from January 2013 to April 2017.

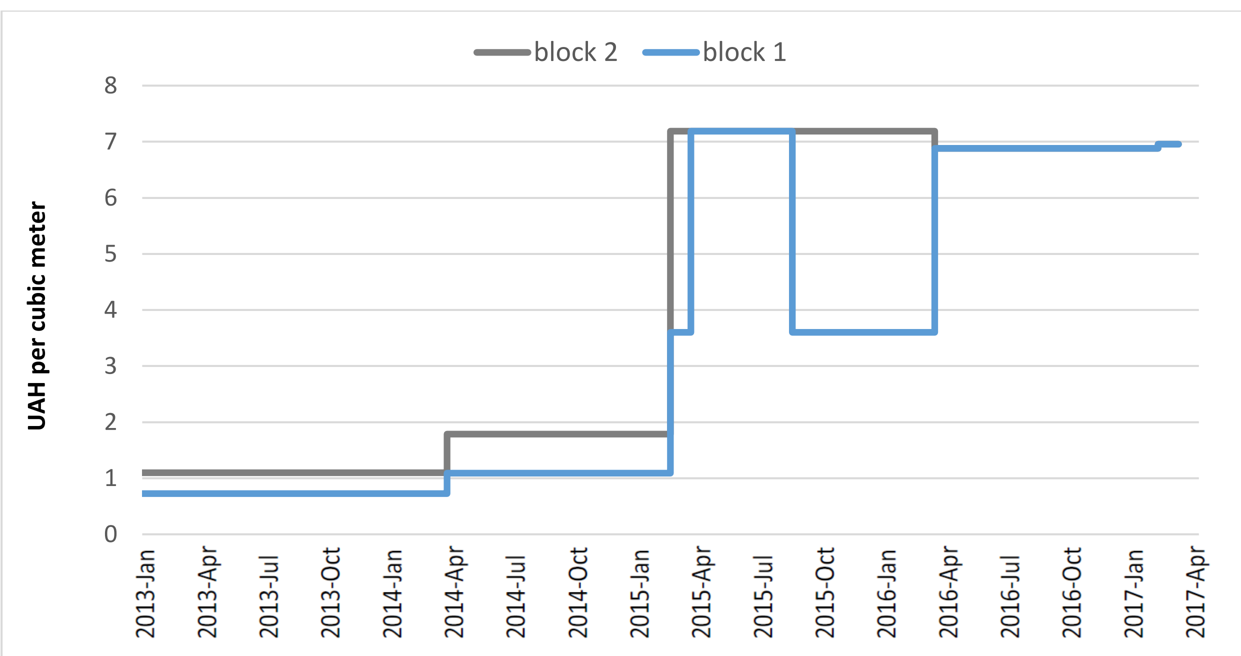


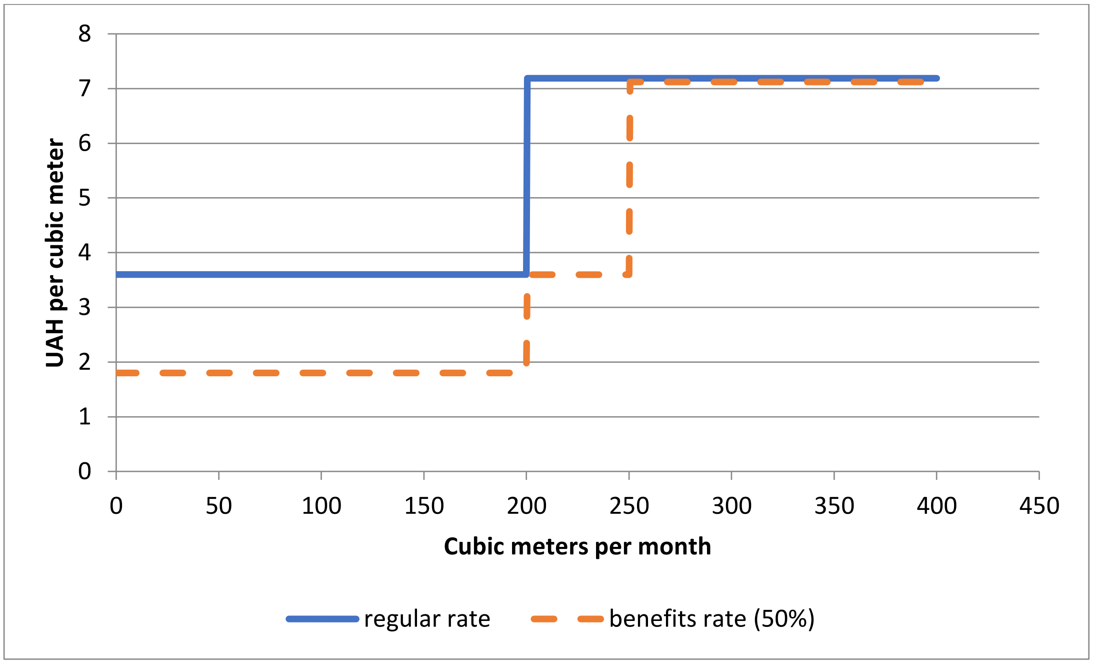
Table 2.1.: Natural gas tariffs for residential customers in Ukraine.

	Unit	2010 Aug 1 to 2014 Apr 30	2014 May 1 to 2015 Mar 31	2015 Apr 1 to 2016 Apr 30	2016 May 1 to 2017 Mar 31	from 2017 April 1
upper bound of block 1	m^3	2,500/year	2,500/year	200/month	NA	NA
upper bound of block 2	m^3	6,000/year	6,000/year	NA	NA	NA
upper bound of block 3	m^3	12,000/year	NA	NA	NA	NA
variable cost 1 with meter	UAH per m^3	0.7254	1.089			
variable cost 2 with meter	UAH per m^3	1.0980	1.788			
variable cost 3 with meter	UAH per m^3	2.2482	3.645			
variable cost 4 with meter	UAH per m^3	2.6856				
use gas for cooking and/or water heating in *multi-family* buildings, with meter	UAH per m^3		1.182			
variable cost 1 without meter	UAH per m^3	0.7980	1.197			
variable cost 2 without meter	UAH per m^3	1.2078	1.965			
variable cost 3 without meter	UAH per m^3	2.4732	4.011			
variable cost 4 without meter	UAH per m^3	2.9541				
use gas for cooking and/or water heating in *multi-family* buildings, without meter	UAH per m^3		1.299			
use gas for individual heating or cooking and/or water heating (May 1 – Sept. 30), households without gas heating (whole year)	UAH per m^3			7.188		
variable cost 1 - use gas for individual heating or cooking and/or water heating (Oct. 1 – Apr. 30)	UAH per m^3			3.600		
variable cost 2 - use gas for individual heating or cooking and/or water heating (Oct. 1 – Apr. 30)	UAH per m^3			7.188		
gas for all residential users (unit price for all households users, regardless of quantity used and/or conditions of consumption)	UAH per m^3				6.879	6.958

Note: Tariffs include VAT.

What we have described above are the rates for regular residential customers. In practice, in Ukraine persons in certain professions (e.g., civil servants, the military, retirees, veterans, Chernobyl decontamination workers) receive so-called “benefits,” namely discounted tariffs for the portion of their consumption that falls below a specified "allowance." The allowance is calculated by the government following a precise formula that takes into account family size, dwelling size, the number of stories of the building, whether gas is used for heating, cooking and/or hot water, and is seasonally adjusted. The allowances thus create additional tiers and the discounts with respect to the regular tariffs bring additional variation in rates (see Figure 2.4).[16]

Figure 2.4.: Benefits rates v. regular tariff with two-block tariffs.



Note: heating season: April 2015; October 2015-March 2016). The hypothetical household on benefits rate receives a 50% discount off the regular rate when consumption is within the allowance (here assumed to be 250 m^3/month).

The sharp increases in natural gas rates for residential customers in April 2015 and a year later triggered massive increases in prices and were a major cause of distress among the population. Government assistance however was, and still is, available, as families that struggle to pay their utility bills may be entitled to "subsidies." The subsidies vary across eligible households and are lump-sum transfers meant to help cover the utilities. The gas subsidies thus do not change the marginal price of gas. Households do not actually receive cash: The subsidy amount is simply subtracted from the utility bill, thus reducing the balance due. The subsidy is thus a transfer of revenue from the government to the utility. The subsidy amount is clearly indicated on the bill.

[16] Eligible households are enrolled automatically for benefits on the basis of professional status, services rendered to the government, date of birth, or family status. There is no issue of self-selection into the benefits program. Within the allowance, the tariff is reduced by 20% to 75%, depending on professional or personal status.

The subsidy (usually referred to as Housing and Utility Subsidy, or HUS) is calculated following a non-linear formula that depends on (i) a means-tested eligibility threshold, (ii) the maximum amount of energy covered by the subsidy (i.e., normative consumption), and (iii) adjustment coefficients that vary across regions and seasons.[17] Since the subsidies are based on normative (not actual) consumption, which depends on size of the home, household size and heating fuel, households cannot influence the provision of subsidies through strategically increasing consumption, and thus have no incentive to do so. Subsidies do depend on income, but the authorities require exhaustive documentation of all sources of income, including recently liquidated assets. During our study period, the share of the population that received subsidies in Ukraine increased from 9.9% to 46.5%, with a sharp increase in September-October 2016.[18] The figures for Transcarpathia mirrored the national ones. Despite the financial pressure created by the new tariffs and the subsidy eligibility changes during out study period, observers generally point out that families kept up their payment compliance (Laderchi and Umapathi, 2017).[19]

We ask three broad questions. First, residential gas demand is generally held to be relatively inelastic. But faced with such massive tariff hikes, are people capable of reducing consumption? Second, does the responsiveness to price vary across households? Third, if assistance in the form of lump-sum transfers increases consumption, how strong is this effect? These questions have important implications for consumer welfare as well as for utility revenue purposes.

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[17] HUS beneficiaries are those households whose total housing and utility normative bill is above a threshold defined as (Y/SUBS)×br×k, where Y is total household income per household member, SUBS is subsistence level per household member (set by the government) as of the date when the subsidy is granted, br (=0.5) is base income ratio for the subsidy, and k (=.15) is the base rate for housing and utilities services. For instance, for a household with income that is just the same as the subsistence level, the threshold is 7.5%, which gets multiplied by total household income. Normative consumption is household-specific, and depends on the size of the home, on household size and on the type of equipment and heating fuel. For example, for a home that uses gas heat for the period after September 2014, the normative gas consumption was set as 23.6×hhsize + 11×min(21×hhsize, home area in m^2). The HUS payment is calculated as the difference between the total cost of normative consumption (i.e. the normative consumption for each type of utility, times the relevant tariff) and the maximum expenditure on normative consumption given household income ((Y/SUBS)×br×k)×income). If the latter exceeds the former, as might be the case for a relatively high-income household, the household is not eligible for HUS support.

[18] Fankhauser and Tepic (2007) and Fankhauser et al. (2008) examine earlier government assistance programs in Ukraine.

[19] There appears to be much heterogeneity in the collection rates and arrears in the transition economies, both across countries and over time. Anex (2002, p. 404) reports that in 1997 collection rates for electricity were only 50% in the Russian federation and Kazakhstan, about 70% in Armenia, and about 80% in Ukraine, but these figures appear to commingle industrial and residential customers. Dodonov et al. (2004) consider non-payment widespread and cite official estimates that households pay for only 70%-80% of the electricity they consume. Fankhauser et al. (2008) examine the “stock” and “flow” of arrears for all utilities in the various regions of Ukraine in 2003 and 2004. Based on their tables 11 and 12 (p. 4174), at that time Transcarpathia, the region where Uzhhorod is located, appears to be roughly in the middle of the distribution for both the stock (cumulated month of arrears) and the flow (change in the stock, which indicates time to repayment). Fankhauser and Tepic (2007) report that “payment discipline” among residential customers has improved over recent years, and that “many countries now have collection rates close to 100%.”

3. The Data

3.1. Data Collection

We use a panel dataset that documents monthly natural gas consumption in a sample of Uzhhorod homes from January 2013 to April 2017. We collected this information directly from households in the course of interviews conducted in person by trained local enumerators. The enumerators were instructed to ask each respondent to produce as many electricity and natural gas bills as possible, going back to January 2013, and to transcribe the exact consumption during each billing period, the tariffs as shown on the bill, and any "benefits" or subsidies information.

The enumerator also recorded information about the type and size of the dwelling, energy efficiency renovations[20] that were done since January 2013, the home heating system type and fuel, major electric appliances, and the mode of payment of the utility bills. Each respondent (a person in the household who was familiar with the utility bills) was also asked about expected future tariffs and any switch to a different heating system or newer equipment motivated by the tariff changes. The questionnaire ended with sociodemographic questions.

The questionnaire was administered to the occupants of 500 residences selected to be representative of the housing stock in Uzhhorod in May-June 2016 (wave 1), and then again to 500 more households in May-July 2017 (wave 2). In wave 2, 250 interviews were conducted at homes selected to be representative of the housing stock,[21] and the remaining 250 were conducted at homes that we knew had at some point been thermally insulated, because such renovations

[20] The renovations we inquired about are cavity wall insulation, attic insulation, double-glazed or triple-glazed windows, replacing the boiler, insulating the basement, and placing jackets around hot water pipes. These are simple technologies that are much needed in the housing stock of Ukraine, where 45% of the population lives in multi-family buildings, 70% of which date back to the Soviet period (Emerson and Shimkin, 2015).

[21] We instructed our survey firm to collect 500 completed questionnaires in wave 1 and 250 in wave 2 using the following sampling frame. The samples were 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. The homeownership rate in Ukraine is 93.7% (United Nations Economic Commission for Europe, 2013). 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). For example, in wave 1 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. These figures were halved in wave 2. The samples were 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, and so the enumerators elicited that information at the very beginning, and terminated the interview if a prospective respondent was a renter. 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.

were visible from the outside. The outside walls of individual units in multi-family buildings where insulation was recently installed, for example, tend to be of different color and appear to be thicker than the adjacent ones. We instructed the enumerators to scout for dwellings exhibiting such signs in the same neighborhoods as the remainder of the sample. Table 2.2. summarizes the sampling frame.

Table 2.2.: Sampling frame.

2016 Survey	2017 Survey
• N=500 households • Sample was representative of the stock of housing • Energy bills from Jan 2013 to Apr 2016 • Max T=40	• N=500 households • N=250 Choice-based sampling - wall insulation visible from the outside • N=250 representative of the stock of housing • Energy bills from Jan 2013 to Apr 2017 • Max T=52

Table 2.3.: Survey Response Rates.

	Wave 1	Wave 2
total contact attempts	959	802
address not found	16	20
unable to access building	77	11
no response at door	182	94
ineligible (renters)	53	42
total invalid or failed contacts	328	167
Valid contacts made	631	635
declined to participate	108	117
completed questionnaires	500	500
bad questionnaires	23	18
Response rate out of valid contacts	79.24%	78.74%

The questionnaire was administered only to households who owned their dwelling (the majority of the population of Transcarpathia and Ukraine as a whole). The two waves of surveys resulted in a response rate (out of valid contacts) of about 79% (see Table 2.3.).

3.2. The Data

We merged the monthly natural gas consumption, “benefits” and subsidy data with weather records and tariffs and created a panel dataset where the cross-sectional unit of observation is the family/dwelling. The panel is unbalanced, since not everyone was able to find all of his or her monthly gas bills going back to January 2013, and the maximum longitudinal size is T=40 for wave 1 and T=52 for wave 2.

Table 2.4., panel A, summarizes the structural characteristics of the dwelling by wave of the survey. The two waves are similar in terms of dwelling type, size, vintage, and prevalence of natural gas as the primary heating fuel (72%). Wave 2 has a somewhat higher household income in nominal terms, but this is likely due in part to changes in the national wage rates that occurred between the two waves of the survey.[22]

Table 2.4., panel B, examines the EE renovations concerning space heating since January 2013. The most popular are window replacement and wall or attic insulation. The prevalence of these EE measures is higher in wave 2, as is to be expected due to the nature of the sampling and the fact that more time had elapsed since January 2013. Virtually everyone used their own savings to finance these upgrades.[23] We also asked respondents whether they had switched from one heating fuel to another since January 2013, and found that only one respondent had switched to solid fuels, and no one had gone from using natural gas to using electric heat, or vice versa. This is in sharp contrast with Krauss (2016), who finds that between 2009 and 2011 some 8% of the households in Armenia shifted away from natural gas after the gas tariffs were increased by 40%.

Finally, Table 2.4., panel C, presents summary information about gas usage and about the share of the respondents in each wave of surveys who receive benefits. Benefits recipients account for 7% and 5% of the sample in wave 1 and 2, respectively. For these persons, the allowance can be quite substantial and the discount off the regular tariffs (for the cubic meters within the allowance) averages 35% and 46%, respectively. No one reported subsidies in wave 1, whereas 27.8% of the households in wave 2 received subsidies.[24]

[22] Statistics Ukraine reports that between 2016 and 2017 the average nominal salary in Transcarpathia increased by about 47% (www.uz.ukrstat.gov/ua/statinfo/vitrat/2018/struct resurs 1999-2017.pdf).

[23] In wave 1, 174 families out of 181 who had done EE upgrades financed them exclusively with their own money. The remaining 7 used a combination of own and government-program funding. In wave 2,351 of the 386 households who had done EE renovations financed them entirely on their own; 33 financed them in part from government programs, including government loans and "Warm Loans," and the remaining 2 availed themselves exclusively of "Warm loans." "Warm loans" are a government-approved program in partnership with private banks. This program has been criticized because of the high interest rates (up to 27% per annum) on these loans.

[24] The subsidies as listed on the bills were cross-checked with an on-line searchable database set up by the Ukrainian government ("Ioc Minsocpolityky Ukrainy," Information on the status of the subsidy in the household according to the data of the Unified State Register of Subsidy Recipients of the Ministry of Social Policy of Ukraine, https://subsidii.ioc.gov.ua/, last accessed 18 November 2018).

The average subsidy for the latter was 64.83 UAH/month, which is close to the average for the Transcarpathia region since November 2011 (961.89 UAH/month).[25]

Table 2.4.: Descriptive Statistics by Wave. Mean or percentage of the sample.

	Wave 1	Wave 2
A. Dwelling and Household		
Type of home		
Single family home	39.8%	35.2%
Apartment in multi-family building	56.8%	61.4%
Rowhome	3.4%	3.2%
Size of the home (**m^2**)	79.95	78.34
Year built	1976	1978
Main heating fuel		
Natural gas	73.0%	72.0%
Electricity	15.8%	21.2%
Solid fuels	8.8%	6.0%
Monthly household income (UAH)	5,063	6,457
B. Energy Efficiency Upgrades Related to Space Heating Done in the Last 3 Years		
Cavity wall or attic insulation	10.6%	36.8%
Double-glazed windows	19.6%	30.5%
Triple-glazed windows	2.2%	3.8%
Basement	n/a	2.2%
Hot water pipes	1.6%	1.2%
Boiler replacement	5.1%	9.2%
Any of the above	31.0%	54.6%
C. Monthly Energy Statistics		
Gas consumption (m^3)	139.60	142.77
Gas benefits – percentage of the sample	7.50%	5.04%
– allowance (m^3/month)	280.7	159.6
Gas subsidies – percentage of the sample	0%	27.8%

[25] See https://galinfo.com.ua/news/v_2017_rotsi_za_zhytlovymy_subsydiyamy_zvernulos_ponad_8_mln_gromadyan_279786.html.

In sum, overall, the two waves appear reasonably similar in terms of dwelling characteristics and type of heating equipment. In the remainder of this chapter, we focus on the subset of households/dwellings from combined waves 1 and 2 where *no* EE upgrades were done since January 2013. There were a total of 572 such dwellings.[26] Our first order of business is thus to compare these dwellings/families (henceforth dubbed the "non-renovators") with the 428 from combined waves 1 and 2 that did do renovations since January 2013 (the "renovators").[27]

Table 2.5. shows that non-renovators and renovators are similar in terms of size of the home, prevalence of multi-family or single-family homes, and natural gas as their main heating fuel.

Table 2.5.: Non-renovators v. Renovators: Characteristics of the dwelling and natural gas consumption and price. Mean or percent of the sample (standard deviation in parentheses).

	No space-heating EE upgrades since January 2013	Did space-heating EE upgrades since January 2013	T test of the null that the means are the same[a]
A. Dwelling Characteristics			
Size of the home in square meters	78.00 (51.76)	80.68 (49.51)	−0.83
Dwelling is a unit in a multi-family building	59.61%	58.41%	0.38
Dwelling is a single-family home	36.19%	39.25%	−0.99
Year built	1977.32	1977.38	−0.04
Gas heat	74.12%	68.86%	1.48
Electric heat	15.38%	22.66%	−2.88***
B. Natural Gas Consumption and Prices			
Monthly usage (cubic meters)	139.69 (46.56)	143.52 (170.91)	−1.78*
Monthly usage during the heating season (Oct.-Apr.) (cubic meters)	178.10 (157.20)	186.97 (192.23)	−2.99***
Monthly usage during the non-heating season (May-Sept.) (cubic meters)	69.21 (88.75)	65.41 (72.99)	2.11**
Marginal price (April 2016 UAH)	4.13 (2.58)	4.59 (2.53)	−7.26***
Receives benefits for at least part of the sample period	10.14%	8.64%	0.73
Receives subsidies for at least part of the sample period	11.01%	16.12%	−3.00***

*, **, and *** denote statistical significance at the 10%, 5% and 1% level, respectively.
[a] The test assumes unequal variances.

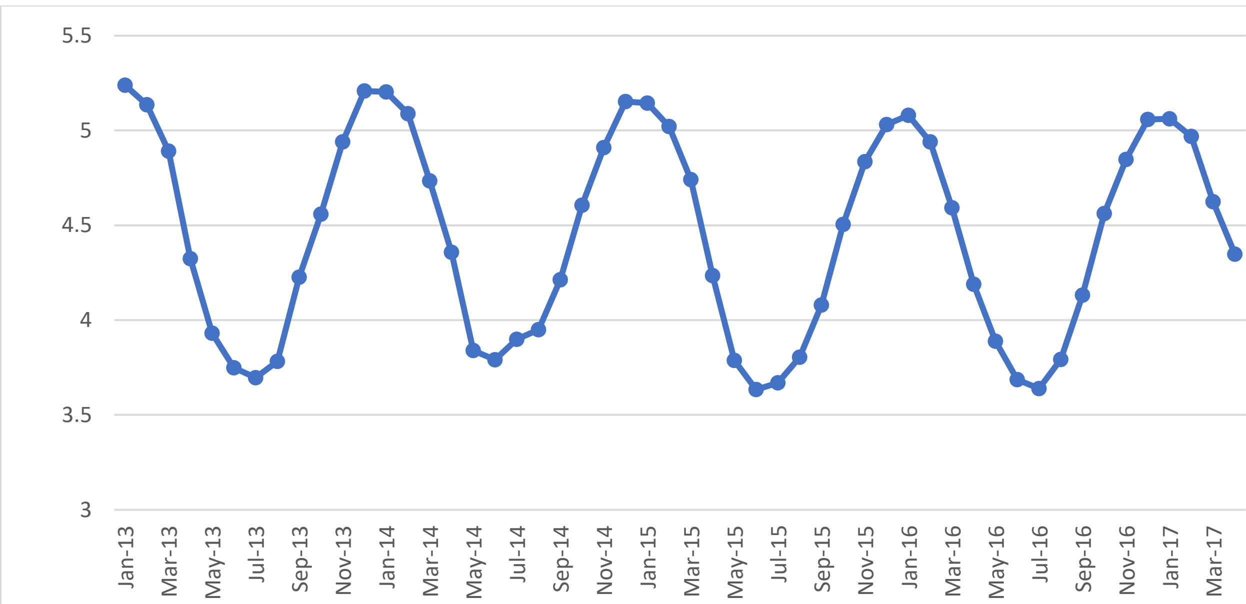
[26] We examine the effects of EE upgrades in the homes in wave 2 in another paper (Alberini et al., 2019).
[27] We wish to emphasize that in this paper we define as non-renovators simply those households that had done no energy efficiency renovations from January 2013 to the time of the survey. A number of people that did not do any upgrades after January 2013 had done energy efficiency upgrades including insulation, new windows, new heating equipment, etc. before January 2013. Of the 345 non-renovators from wave 1,256 had done one or more of these upgrades 4-10 prior to the time of the survey. Out of the 227 non-renovators from wave 2,139 had done upgrades in the 5-10 years before the time of the wave 2 survey.

Homes with electric heat are, however, more heavily represented among the renovators. The two groups do not differ significantly in terms of benefits, but the non-renovators are less likely to receive subsidies.

The second panel of Table 2.5. shows that the non-renovators use less natural gas in the winter but a little more in the summer and are faced with lower marginal prices. The difference in marginal gas prices paid is statistically significant at the conventional levels (t stat= −13.58).

Out of the 572 households that did not do any energy efficiency upgrades since January 2013, 514 use natural gas for space heating, cooking or water heating purposes. A total of 305 come from wave 1, and 209 from wave 2. Their gas usage follows a seasonal pattern, as is shown in Figure 2.5., which also shows that (log) gas consumption appears to decline over time.

Figure 2.5.: Average log monthly gas consumption by month for households that did no EE upgrades after January 2013.



Summary statistics for the weather are displayed in Table 2.6. The annual heating degree days (base: 65° F) are typically 5,400-5,700. Our questionnaire further asked respondents how they pay their gas bills. Most of them pay in person at the post office (34.35%) or at their bank (49.02%), 15.97% pay online, and only 0.66% uses automatic debit. This suggests that it is extremely unlikely that tariff changes will go unnoticed as in Sexton (2015). The gas meter is inside the home for 93% of the dwellings in our sample.

Table 2.6.: Descriptive Statistics: Weather.

	No. obs.	Mean	Standard Deviation	Min	Max
Share of the time during the billing period with no wind	25,604	0.275	0.228	0	0.75
Share of the time with no clouds	25,604	0.145	0.208	0	0.875
Share of the days during the billing period with humidity between 25% and 75%	25,604	0.527	0.499	0	1
Share of the days during the billing period with humidity above 75% but less than 92%	25,604	0.353	0.478	0	1
Share of the days during the billing period with humidity above 92%	25,604	0.121	0.326	0	1
Number of days during the billing period with outdoor temperature of 30° C or more	25,604	2.737	5.351	0	20
Number of days during the billing period with outdoor temperature of 0° C or less	25,604	8.332	9.432	0	31
Heating degree days during the billing period	25,604	449.45	364.082	1	1,374

It is important to stress that we use "non-renovators" for certain reasons. Energy-efficient measures can influence how consumers use energy. When households invest in such upgrades, they become more conscious of energy conservation. Such investments can reduce gas consumption, even when gas prices fluctuate. To better understand the influence of price elasticity on gas consumption, it is essential to separate gas consumption from the effects of energy-efficient measures. This isolation helps us study how changes in gas prices affect consumer behavior without the added complexity of energy-saving upgrades.

Isolating gas consumption from energy-efficient measures provides more accurate insights into how policy changes affect gas demand in the short-run. Energy programs and subsidies can be targeted based on actual consumption patterns rather than combining them with the effects of energy-efficient measures. Separating gas consumption allows meaningful comparisons over time or across different regions and countries. It allows the study of consumer awareness and decision-making in response to energy-efficient technologies versus price changes. Also, it can provide behavioral insights into how consumers respond to different incentives and disincentives, shedding light on the psychology of energy consumption.

On the disadvantage side, separation assumes that consumers distinguish between responding to price changes and implementing energy-efficient measures. Consumers behavior can be influenced by a combination of factors and separating them may not accurately reflect real-world decision-making. Over time, the cumulative impact of energy-efficient renovations on gas consumption becomes more significant. Hence, combining the two factors in long-term analyses proves more effective in capturing this synergy and evaluating the extent to which renovations contribute to sustained energy savings.

4. Methodology

Attention in this chapter is restricted to the 514 households from both waves that use natural gas and did not do any EE renovations between January 2013 and April 2017. The stock of gas-using capital is therefore held constant, and any reductions in use, all else the same, are attributed to behaviors.

We estimate the regression equation

$$lnG_{it} = \alpha_i + \tau_t + \mathbf{W}_{it}\boldsymbol{\beta} + \gamma_1 \cdot \ln P_{it} + \gamma_2 \cdot \ln S_{it} + \gamma_3 \cdot D_{it} + \varepsilon_{it} \quad (1)$$

where i denotes the household, t the month and year, G is monthly natural gas consumption, P is the marginal price faced by the household,[28] S is the subsidy amount and D is a dummy denoting that the household receives subsidies, but the exact amounts are not available, interacted with a heating season (October through April) indicator. (S is coded to zero when subsidies were received but their exact amount is unknown.) We interpret coefficient γ_1 as the short-run or behavior-only price elasticity of demand. Vector $\mathbf{W}_{it}$ includes weather variables, plus i) vintage of the building interacted with a dummy denoting the heating season, ii) income above the sample median-by-month effects, and iii) single-family (SF) home-by-month effects. The purpose of these covariates is to account as much as possible for the different extent of seasonal fluctuations in consumption across households. Since we have household income at the time of the survey, but not month by month over our sample period, item ii) above and the subsidies, S, are our best way to account for the budget available for gas expenditure in any given month.

Equation (1) includes household-specific effects and time fixed effects. The former account for unobserved heterogeneity among households, capture the effect of any pre-existing insulation measures, and are the appropriate way to handle our sampling frame (which entails

[28] Ito (2014) has conjectured, and found empirical evidence in support of, the notion that in the presence of block pricing residential consumption responds to the average price, rather than the marginal price. Ito (2014) shows that when this is the case, households consume more than that if they had responded to marginal price, thus defeating the purpose of increasing block pricing, which is to encourage conservation. Based the histograms in Figures 7a and 7b, we believe that it is reasonable to assume that people were responding to the marginal price.

some choice-based sampling), since the analysis is conditional on the fixed effects. The latter control for economy-wide events that could have affected consumption (e.g., the state of the economy; the exchange rate with the dollar or the euro; conflict with Russia) or seasonal effects that might explain natural gas consumption in any given month (e.g., the number of days in that month; holidays or other events where people spend more/less time at home, thus demanding more/less heat, etc.). Our time fixed effects are month dummies plus "tariff regime" dummies.[29]

Table 2.7.: Percent increase in tariff per cubic meter in the first three blocks of natural gas consumption.

	Proportional increase in the price per cubic meter		
Date of the tariff change	1st block	2nd block	3rd block
from April to May 2014	+3.36%	+62.84%	+62.13%
from March to April 2015	+230.58%	+302.01%	−1.23%
from April to May 2015	+99.66%	0.00%	0.00%
from September to October 2015	−49.92%	0.00%	0.00%
from March to April 2016	+91.08%	−4.30%	−4.30%
from April to May 2016	+1.11%	+1.11%	+1.11%

Tariff remained stable during the months after the dates indicated above, until the next tariff increase. In April 2015, the second and third block became the same. In April 2016, the block scheme was dropped and replaced by a uniform price per cubic meter.

Estimation of equation (1) is complicated by the fact that, in the presence of (increasing) block pricing the marginal price is endogenous (and positively correlated) with consumption, as the consumer chooses jointly the desired level of consumption and the price that accompanies it. Unless properly addressed, the positive correlation may result in the appearance of a positively sloped demand function. To circumvent this problem, we instrument for log price. Our excluded instruments are the log tariffs in each block (Nieswiadomy and Molina, 1989; Mansur and Olmstead, 2012), which, as shown in Figure 2.3. and in Table 2.7., changed at a different rate over time, plus the log allowance and log discount off the regular tariff if the household receives benefits.[30] The latter two are exogenous, alter the rates and hence the marginal price faced by that household, and should not directly influence consumption.

[29] Our tariff regimes (or tariff periods) are January 2013-April 2014, May 2014-March 2015, April 2015-April 2016, May 2016 to March 2017, and from April 2017.
[30] The log gas allowance and log discount off the regular tariff are coded to zero for those households who do not receive benefits.

We estimate the model in the first differences:

(2) $$\Delta lnG_{it} = \tau_t^* + \Delta\mathbf{W}_{it}\boldsymbol{\beta} + \gamma_1 \cdot \Delta\ln P_{it} + \gamma_2 \cdot \Delta\ln S_{it} + \gamma_3 \cdot \Delta\, D_{it} + e_{it}.$$

The first stage is

(3) $$\Delta lnP_{it} = \theta_t + \Delta\mathbf{W}_{it}\boldsymbol{\lambda}_1 + \lambda_2 \cdot \Delta\ln S_{it} + \lambda_3 \cdot \Delta D_{it} + \Delta\ln \boldsymbol{TARIFF}_{it}\boldsymbol{\delta} + \\ + \Delta\boldsymbol{BENEFITS}_{it}\boldsymbol{\pi} + u_{it},$$

where lnTARIFF is a vector of five variables containing the log rates per m^3 in block 1 through 3 until March 2015 and in blocks 1 and 2 from April 2015 respectively, and BENEFITS includes the log gas allowance and the log discount off the regular tariff when consumption falls within the monthly allowance. The standard errors are clustered at the household level.

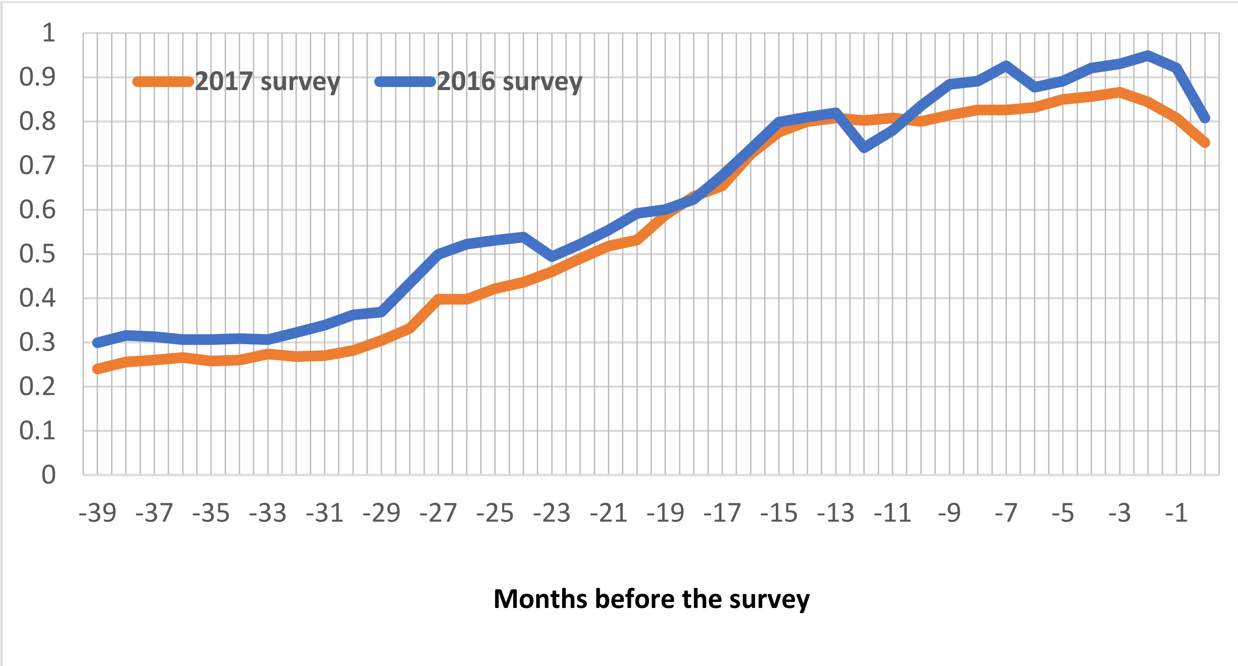
One might question if benefit is a plausible instrument for explaining variations in natural gas consumption. Benefits eligibility is defined by government policies or regulations, which are neutral concerning income or consumption levels. Ukrainian households can enjoy reduced utility payments if they meet specific "benefits" criteria. The degree of discount, ranging from 25% to 100%, and varies depending on the nature of the "benefit" classification. This classification includes individuals with disabilities, veterans, families affected by the loss of a breadwinner, among others. Eligibility for these benefits is not income-based, which is exogenous to an individual's current economic situation. This exogeneity ensures that the instrument is valid. Entitlement status criteria are stable over time. This stability ensures that the instrument remains relevant and reliable for econometric analysis over an extended period. Benefits eligibility is an additional variable in the model, capturing relevant information that might otherwise be omitted.

5. Results

5.1. Checking for Sample Selection Bias

We first examine the availability of the gas usage data and make sure that there is no sample selection bias. In Figure 2.A. we plot the percentage of bills produced by the respondents in each month of the study, starting from the most recent bill (May 2016 for wave 1 and May 2017 for wave 2) and going back in time.

Figure 2.A.: Share of gas bills available each month of the study period.



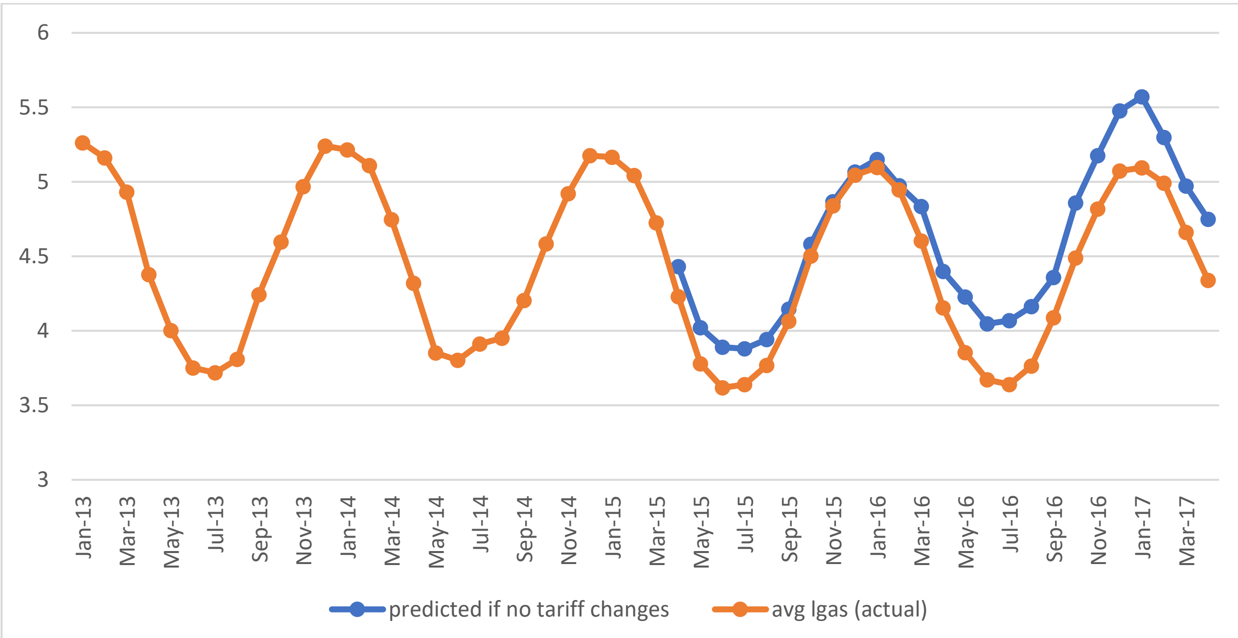
It is clear that the share of bills available declines the further back in time from the time of the survey: Presumably people tend to keep the most recent bills and discard the older ones. The rate at which they do so is roughly the same for both wave 1 and wave 2. Of the 514 people who use natural gas and did not do any EE upgrades to their homes during our study period, 116 produced 40 or more bills (22.56%), 34 (6.61%) 30 to 39 bills, 162 (31.52%) 20 to 29 bills, 200 (38.91%) 10 to 19, and only 2 (less than 1%) between 1 and 9.

To check for possible systematic attrition, we specify a regression where the dependent variable is log gas usage in year and month t. The regression includes respondent-specific fixed effects, month-by-year fixed effects, covariates $\mathbf{W}_{it}$, the benefits information, and a dummy denoting whether the bill (and hence information on gas usage) was available in the previous month. An insignificant coefficient on this dummy is interpreted to mean that the presence or absence of a bill is not systematically related to consumption levels, and that there is no evidence of systematic attrition (Wooldridge, 2010, p. 823-4). The coefficient on this variable (−0.0381; t stat. −1.76) is indeed insignificant at the 5% and 1% levels. Based on this, we proceed to our main analyses.

5.2. Do Tariffs Really Matter?

Figure 2.5. shows that consumption has generally declined over time, but does not tell us for sure whether that is because of milder winters and summers, or as a result of the tariff changes. The winter of 2017 was actually colder than that of 2016, which in turn was colder than that of 2015, and yet consumption seems to be less.

Figure 2.6.: Average actual ln gas consumption (in orange) and average predicted ln gas consumption (in blue) if the patterns before April 2015 had continued.



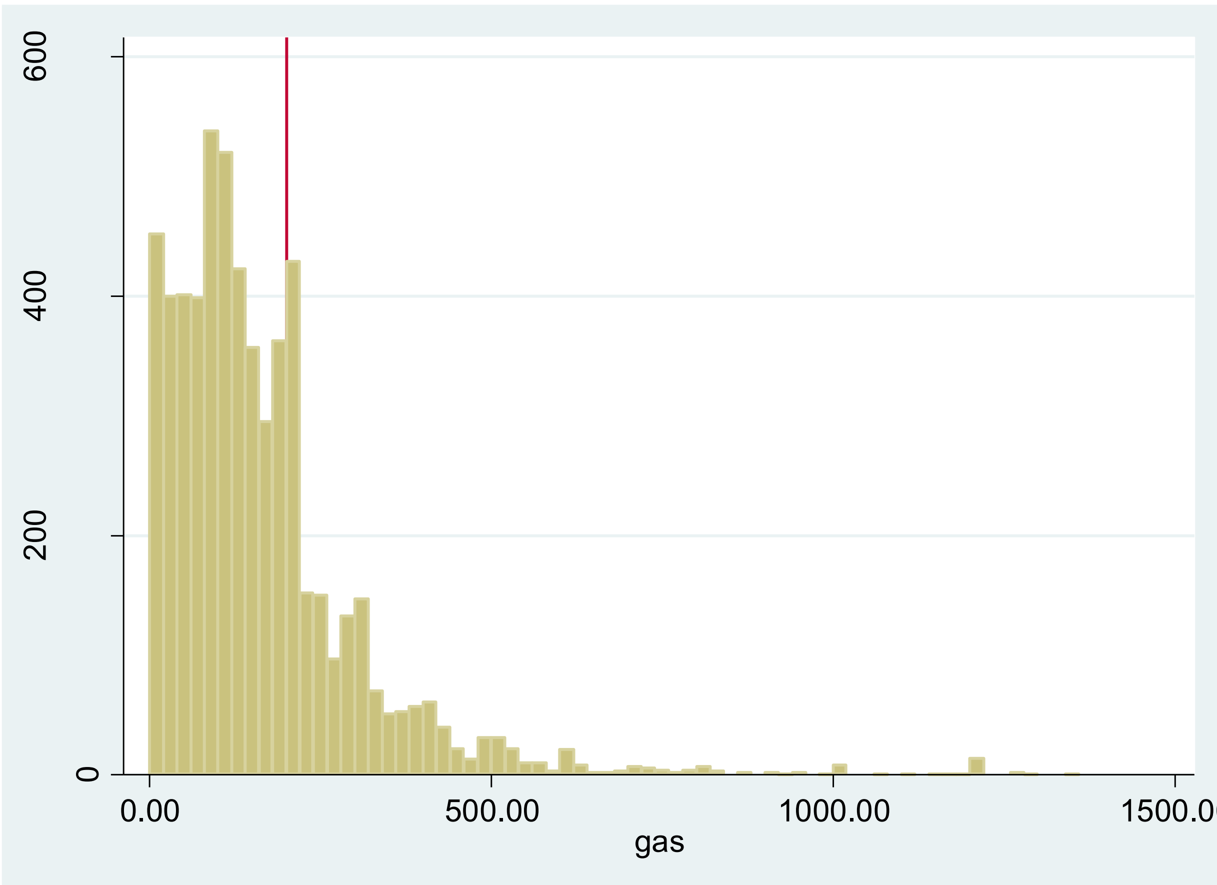
Note: Predictions for April 2015 and later months were formed by first regressing log gas consumption on household-specific fixed effect, tariff period fixed effects and weather, and then forming predictions for April 2015 and the subsequent months at the actual weather, using the coefficient on the dummy for the tariff period in force before April 2015.

Figure 2.6. is constructed after running a regression similar to that of equation (1), limited to the data before April 2015 and excluding prices, and using the coefficients from that regression, plus actual weather since April 2015, to predict what consumption would have been from April 2015. The figure shows clearly that based on pre-April 2015 consumption patterns, one would predict higher usage levels than the ones actually observed in and after April 2015. In other words, people appear to have cut consumption after the tariff reform of April 2015.

This still does not prove unambiguously that people were responding to the gas tariff changes rather than to something else. We do not have a control group in our sample: Everyone was subject to the tariff changes, but we take advantage of the different intensity with which people experienced them, depending on their consumption levels (see Table 2.7.) and "benefits" status.

For additional evidence, Figures 2.7a. and 2.7b. are histograms of consumption between April 2015 and March 2016, and from April 2016.

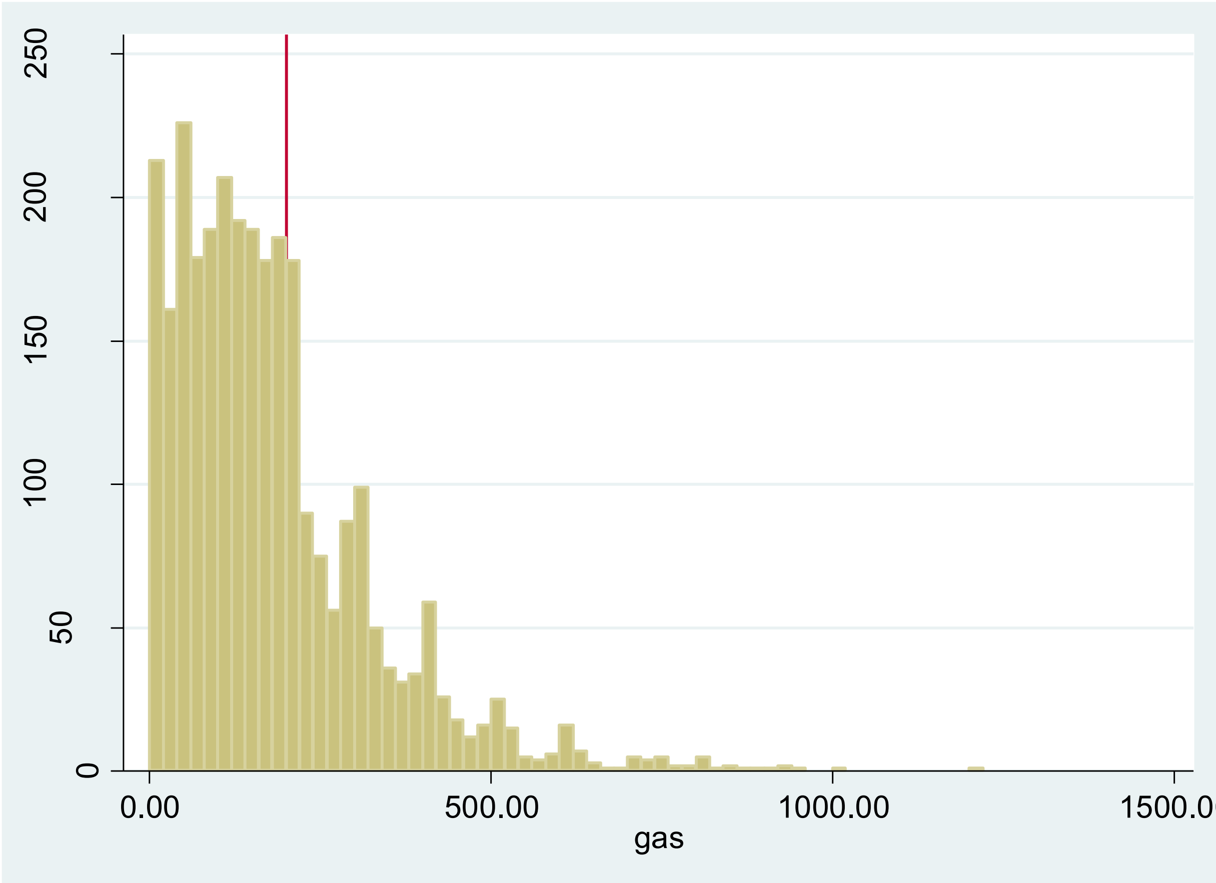
Figure 2.7a.: Histogram of monthly consumption from April 2015 to April 2016.



Note: The vertical line is placed at 200 cubic meters per month, which was the block cutoff during the heating season.

Figure 2.7a shows evidence of bunching around 200 m^3 in the former period, when this was the block cutoff during the heating season. The histogram in Figure 2.7b. is much smoother around 200 m^3, displaying no evidence of "bunching" around that level, which is exactly what we would expect, since the block system had been by then eliminated. These histograms suggest to us that people were aware of the tariff reforms and responded to them.

Figure 2.7b.: Histogram of monthly consumption from May 2016 to April 2017.



Note: The vertical line is placed at 200 cubic meters per month, which was by then the obsolete block cutoff.

5.3. Short-run Responsiveness to the Tariffs

We begin with estimating equation (2) by ordinary least squares, without instrumenting for the change in log marginal price. The results from this regression are reported in Table 2.8. Unsurprisingly, due to the presence of an increasing block pricing scheme for at least part of the time, the coefficient on Δlog price is positive (but significant only at the 10% level). The subsidy elasticity is 0.02 and insignificant.

The short-run elasticities from IV estimation of equation (3) are displayed in Tables 2.9.-2.12. for different subsets of the data. In general, the first stage performed very well, producing R-squares of around 0.74. The log tariffs in each block and the log benefits were significant predictors of the log marginal price of natural gas. We follow Andrews et al. (2018) and use the effective F (Montiel Olea and Pflueger, 2013) as our diagnostic of the strength of the instruments.[31] The effective F statistics are large and all exceed 23.11, the rule-of-thumb 5% critical limit critical limit that is asymptotically valid for the 2SLS estimator, indicating that the bias of the 2SLS estimator is small compared to the worst-case bias.

Table 2.8.: Results from OLS regression of Δln gas demand on controls and Δln marginal price.

	Coefficient (t stat.)
Δln marginal price	0.0460 (1.77)
Δln subsidy	0.0200 (1.28)
Received subsidy but exact amount n/a (dummy) × heating season (dummy)	0.1184 (0.52)
Number of observations	12,763
Number of households	512

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

The coefficients on log subsidy and the subsidy dummy were insignificant at the conventional levels in the first stage, which confirms our reasoning that they, as a lump sum transfer, should have no effect on the marginal price.

The short-run or behavior-only price elasticity for the full sample is around −0.16 and significant at the 1% level. Households with income below the sample median tend to exhibit more pronounced price elasticity (−0.20), as do households who live in single-family homes (−0.22). By contrast, households living in units in multi-family buildings are less sensitive to price.[32]

The subsidies - an income transfer have a negligible effect on consumption. The elasticity of demand with respect to the subsidy is positive, as expected, and around 0.02 but statistically insignificant. The dummy denoting that subsidies are received but their exact amount is

[31] When the instruments are weak (i.e., they have low correlation with the endogenous regressor), the 2SLS estimates tend towards the OLS estimates, are just as heavily or even more heavily biased, and have a non-standard distribution. Staiger and Stock (1997) recommend using the F statistic of the null hypothesis that the coefficients on the excluded instruments in the first stage are equal to zero, and consider the instrument strong if the F is at least 10.

[32] In four out of the five 2SLS regressions displayed in table 2.9. the Hansen J test fail to reject the null that the instruments are valid at the 1% level. (The software was unable to calculate the test in the remaining one case.) We also checked whether the BENEFITS variables are valid excluded instruments using the difference-in-Sargan test. For large samples and under the null, this statistic (also dubbed C statistic) is distributed as a chi square with three degrees of freedom (see Baum et al., 2003, and Wooldridge, 2010, p. 134-137). The test did not reject the null in the three 2SLS regressions for which it was possible to calculate this statistic.

unavailable, interacted with the heating season dummy, is likewise an insignificant determinant of consumption. The magnitude of the subsidy elasticity (0.02) indicates that it would take an 800% increase in the subsidy to offset completely the effect of a doubling in marginal price, like the ones from April to May 2015 or April to May 2016. Dropping the respondents who received subsidies from the sample has little effect on the price elasticity, which is equal to −0.1593 (t statistic −5.17).[33] The households living in single-family homes are the ones with the strongest responsiveness to both price and subsidies.

Table 2.10. reports results from separating our sample into two groups - namely those who had, and those who had not, done some EE improvements 1-7 years before the study period. The latter exhibit a stronger elasticity (−0.2330) than the former (−0.1458). Although these coefficients are not significantly different from one another (Wald statistic 1.6380, p value 0.75), the results do hint at the possibility that those with the least EE uptake might be those by necessity or skills are more adept at attaining consumption reductions through behaviors. It is interesting that these subjects are twice as sensitive to subsidies.

Table 2.10.: Short-run elasticities: Subsamples based on whether EE renovations were done before the beginning of the study period. Results from 2SLS estimation of Δln gas demand.

	(A) no EE upgrades since January 2013, but some done 1-7 years before January 2013 (in 2006-2012)	(B) no EE upgrades since January 2013, and no EE upgrades 1-7 years before January 2013 (in 2006-2012)
SR price elasticity (t statistic)	−0.1458 (-4.30)	−0.2330 (-3.94)
Log subsidy	0.0163 (0.79)	0.0380 (1.73)
Received subsidy but exact amount n/a × heating season	0.1100 (0.51)	--
Number of observations	8930	3796
Number of households	357	155

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The excluded instruments are the log tariffs in each block, log gas allowance, and log percent discount on the regular (the discount is received only if the respondent receives "benefits"). The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

[33] This is regression is not reported in Table 2.8. It is based on 11,163 observations from 455 households.

5.4. Different Time Periods

Table 2.11. reports the price elasticities for specific periods of time. The responsiveness to price seems to be stable across the heating and non-heating seasons, and when we restrict the sample to a relatively narrow window around the time when the tariff changes take place.

Table 2.11.: Short-run elasticities. Results from 2SLS estimation of Δln gas demand, by season and time window.

	Heating season only	Non-heating season only	Jan 2014 to Sept 2016	3 months before + 3 months after the tariff changes	4 months before + 4 months after the tariff changes
SR price elasticity (t statistic)	−0.1472 (-4.16)	−0.1411 (-1.11)	−0.2135 (-4.87)	−0.1470 (-2.19)	−0.1513 (-3.54)
Log subsidy	0.0242 (1.48)	0.0101 (0.52)	0.0444 (1.44)	0.0417 (1.37)	0.0512 (1.64)
Received subsidy but exact amount n/a × heating season	0.0238 (1.48)	0.2785 (1.43)	0.1233 (0.52)	0.1007 (0.38)	0.1051 (0.40)
Number of observations	8,147	4,579	9,872	5,198	6,920
Number of households	512	511	512	512	512

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The excluded instruments are the log tariffs in each block, log gas allowance, and log percent discount on the regular (the discount is received only if the respondent receives "benefits"). The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

Table 2.11. also presents the results of a regression where we limit the sample to after January 2014 (as the bills from 2013 are sparse) but before October 2016, when the number of recipients of subsidies soared in Transcarpathia and in the rest of the country. The results suggest that when people are fully responsible for paying their bill, they tend to be more responsive to price. The price elasticity is −0.21. The subsidy elasticity is still 0.02 and still statistically insignificant.

All in all, our results suggest that in the face of extreme tariff changes, households were able to reduce their natural gas consumption, even without installing (new) insulation or making any other energy efficiency investments. All else the same, a price change of the magnitude that was observed between March and April 2015 (230% for a 200 m^3 customer), would have resulted, all else the same, in a reduction in consumption by 18-37%, based on the range of estimates reported in Tables 2.9.-2.11. A 100% increase in tariff or marginal price (e.g., April to May 2016) would have reduced consumption by 7.88% to 22%, if no changes in subsidies were experienced. If subsidies were doubled, the model predicts a 4-14% decline in consumption. If the price elasticity is −0.1643 (Table 2.9., column (A)), the subsidies would have to be more than quintupled (a 460% increase) for consumption to remain unchanged.

Table 2.9.: Short-run elasticities. Results from 2SLS estimation of Δln gas demand.

	(A) All	(B) Above median income	(C) Below median income	(D) Multi-family building	(E) Single-family or semi-detached home
SR price elasticity (t statistic)	−0.1643 (-5.56)	−0.0788 (-1.76)	−0.2044 (-4.32)	−0.1294 (-3.46)	−0.2247 (-4.67)
Log subsidy	0.0208 (1.31)	0.0284 (1.58)	−0.0057 (−0.18)	0.0177 (0.70)	0.0417 (1.39)
Received subsidy but exact amount n/a × heating season	0.1363 (0.62)	−0.0109 (−0.04)	0.2682 (0.90)	0.5380 (10.17)	−0.1803 (−0.54)
Effective F statistic	257.85	n/a	n/a	154.55	n/a
Number of observations	12,726	5,944	5,667	7,533	5,193
Number of households	512	237	231	305	207

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The excluded instruments are the log tariffs in each block, log gas allowance, and log percent discount on the regular (the discount is received only if the respondent receives "benefits"). The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

5.5. Additional Checks

Since natural gas prices are posted for the present and for future tariff periods on a dedicated web page of the National Commission for State Regulation of Energy and Public Utilities (NERC), one wonders whether the earlier results might be biased by possible anticipation of future price increases. To test for this, we enter future tariffs (specifically, the tariffs in block 1 through 3 for the next month, which become identical to one another when the tier system is abolished) in the right-hand side of the regression, but, as shown in Table 2.12., the coefficients on these future tariffs are statistically insignificant both individually and jointly.

Table 2.12.: Placebo test. Results from 2SLS estimation of Δln gas demand.

	Estimate
SR price elasticity	−0.1407 (-4.81)
log tariff for 1st block in the next period	0.00055 (−0.24)
log tariff for 2nd block in the next period	0.0495 (0.97)
log tariff for 3rd block in the next period	0.0246 (0.94)
Wald test that the coefficients on the three future log tariffs are all zero (p value)	5.75 (0.1243)
Number of observations	12,214
Number of households	512

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The excluded instruments are the log tariffs in each block, log gas allowance, and log percent discount on the regular (the discount is received only if the respondent receives "benefits"). The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

We have argued that the large rate increases experienced over our study period should be "salient" to people, because of their magnitude and impacts on household budgets, and for a number of other reasons. But were they really salient to the individual households in our sample? The most natural way to check would be to ask survey respondents to report the current and past rates and compare their reports with the true rates (or ask them for a direct assessment of the salience of the rate changes). This proved impractical in the course of our survey, but we were able to elicit the respondents' own estimates of their average bills and consumption levels for winter and summer.

Since the surveys took place just after the end of the heating season, we expect the respondent to recall the bills and usage for the most recent heating season best. We calculated average bills and consumption for the most recent heating season (October 2015-April 2016 for wave 1 respondents, and October 2016-April 2017 for wave 2 respondents), and compared their own assessments with the true winter-time averages. Respondents can be classified into one of four groups: i) those who are fundamentally correct (their estimates bracket the true average), ii) those who overestimate the true average, iii) those who underestimate it, and iv) those who simply didn't know.

Out of the 509 households for whom we were able to calculate the average monthly consumption for the most recent heating season, 203 (39.88%) were in the ballpark, 265

(52.06%) overestimated consumption, 27 (5.30%) underestimated it, and 12 didn't know. As shown in Table 2.13., those who correctly estimate their consumption are less sensitive to price, while the price elasticity is stronger among those who overstated their usage. This is consistent with interpreting an overstated usage level as a hint that the tariff changes were meaningful and salient to the respondent, but also with the possibility that the price elasticity is higher because the respondent was in fact trying to reduce usage.

Table 2.13.: Short-run elasticities: The effect of Salience and Attentiveness Potential. Results from 2SLS estimation of Δln gas demand.

	Correctly estimate winter usage	Overstate winter usage	Heavy users (>224 m^3 a month)	Light users (<224 m^3 a month)	Pay bills in person at the bank or post office	Gas meters inside the home	SF home and gas meter is inside
SR price elasticity	−0.1297 (−3.55)	−0.2315 (−5.05)	−0.1995 (−3.21)	−0.1573 (−4.86)	−0.1615 (−5.21)	−0.1566 (−5.17)	−0.1739 (−3.43)
Log subsidy	0.0445 (1.60)	0.0043 (0.22)	0.0079 (0.39)	0.0265 (1.28)	0.0187 (1.08)	0.0218 (1.31)	0.0087 (0.57)
Received subsidy but exact amount n/a × heating season	−0.2664 (−3.13)	0.1620 (0.77)	0.0690 (0.26)	0.2599 (0.96)	0.2041 (0.88)	0.2675 (1.26)	0.1750 (0.69)
Number of observations	4,863	6,908	3,362	9,364	11,517	11,667	3,845
Number of households	204	264	124	388	463	463	146

Note: The regressions include household fixed effects, period fixed effects, month fixed effects, weather variables, vintage of the dwelling-by-heating season, above median income-by-month effects, SF home-by-month effects. The excluded instruments are the log tariffs in each block, log gas allowance, and log percent discount on the regular (the discount is received only if the respondent receives "benefits"). The model is estimated in the first differences. T statistics in parentheses. The t statistics are based on standard errors clustered at the household level. The sample includes only those households in both wave 1 and wave 2 that did not do EE upgrades during the study period.

Presumably salience is especially pronounced for light users, who in this context experienced a starker proportional increase. "Heavy users" (those with average monthly usage greater than 224 cubic meters a month, or the top 25% of the distribution) do exhibit have an elasticity that is some 27% stronger than that of "light users" (everyone else; −0.1995 v. −0.1573, respectively). However, a Wald test does not find these two elasticities to be significantly different from one another (Wald statistic 0.3628, p value 0.4530).

In the fifth regression of Table 2.13. we exclude from the sample those who pay their gas bills online or through automatic debit. Those who pay their bills in person at the bank or the post office and can be presumed to be aware of prices and consumptions exhibit a price elasticity of −0.16 similar to that of the sample as a whole.

Finally, we wish to test whether easy access to the gas meter, which has the potential to counter inattention, makes a difference. When the sample includes only dwellings with indoor gas meters, the price elasticity is −0.1566, and it is further limited to single-family homes with indoor gas meters, the price elasticity is −0.1739.

5.6. Revenue and Equity

Concerns have been expressed that energy taxes or tariff schemes might be regressive, in that the tax or energy bill burden might fall disproportionately on low-income persons. Borenstein and Davis (2012) examine the residential natural gas tariff schemes in the United States, which generally entail a (low) fixed fee and a price per unit above marginal cost, concluding that, since natural gas consumption is only weakly correlated with income, the schemes are mildly progressive. Levinson and Silva (2019) arrive at a similar conclusion using a nationwide sample of electric utility prices.

Ideally, in a poor country, tariffs and subsidies would be designed so as to generate sufficient revenue to cover the cost of gas and infrastructure while protecting lower-income households (McRae, 2015; Coady et al., 2018). In Ukraine the gas subsidies are covered from general revenue and are paid by the government to the utility (consumers get a reduced bill, but no cash). We ask whether the tax collected through the gas bills is sufficient to cover the subsidies, keeping in mind that the gas tariff includes a 20% value-added tax, and that consumption fell as the tariffs were increased during our study period, but is relatively insensitive to the subsidies. Attention is restricted to May 2016 and later months, when the tariff finally more than covered the import price of natural gas, plus transmission and distribution costs (Rozwalka and Tordengren, 2016).

We group our sample into income terciles. As expected, the tax component of the gas bill increases, as does gas consumption,[34] as we move from the first to the third tercile. Expressed as a share of monthly income, however, the tax paid however decreases (from 3.97% in the first tercile to 2.31% in the top tercile). The average monthly subsidy (average across actual recipients and those who receive nothing) is 187.62 UAH is in the first tercile, 168.06 UAH in the second,

[34] Gas bills increase weakly with household income in our sample from May 2016 to April 2017. On average, gas bills are 757 UAH, 1,007 UAH, and 1,281 UAH a month, respectively, in each tercile. These figures represent 23.8%, 17.8%, and 13.9% of household income, respectively.

and 154.46 in the third, which represent 5.9%, 2.97% and 2.31% of total monthly household income, respectively.

The VAT revenue from customers in the lowest tercile is on average 126.2 UAH every month; each household in this group receives on average a monthly subsidies of 187.7 UAH. In the second tercile, the tax revenue just about equals the subsidies received (167.9 UAH v. 168.1 UAH/month, respectively). In the top tercile, the monthly tax revenue per household is 213.5 UAH, which exceeds the average subsidies received by the households in this group (154.4 UAH) and generates some 59 UAH of surplus per household in the third tercile. These are more than adequate to cover the government disbursement for the households in the first tercile. While our sample appears to have been revenue-neutral or even capable of generating a small tax revenue surplus, it is not however clear whether we would arrive at the same conclusion for the general population of the region or the country, which on the one hand experiences a higher incidence of subsidies and on the other hand includes households that made energy efficiency upgrades to their dwelling (and thus presumably saved on gas and tax).

6. Conclusions and Policy Implications

We have taken advantage of the recent and abrupt natural gas tariff reforms in Ukraine to estimate the price elasticity of residential gas demand. We have monthly usage records from individual households, restrict attention to households who did not change their heating equipment, installed insulation or otherwise improved the thermal integrity of their home during our sample period, and interpret our estimates as behavior-only, short-term price elasticities. We also estimate models based on shorter windows around the times when the tariffs were changed.

We find that consumers are capable of reducing consumption when the price of gas increases, even without making structural modifications to their homes. The price elasticity is however low, as expected when opportunities for substitution are limited. We find that wealthier households have an even less elastic demand, along the lines of Krauss (2016) for households in Armenia, another former Soviet republic where people were faced with gas tariff reforms (albeit much more modest than in Ukraine) and demonstrated a willingness to substitute towards other heating fuels. Our results hint at the possibility that those with the least EE uptake might be those who by necessity or through skills are most capable of reducing usage through behaviors alone. These abilities may involve alterations in daily routines, such as refraining from keeping windows open while heating systems are active, effectively managing thermostat settings, fine-tuning the thermoregulator, and turning off the boiler when not at home or during the night to maintain comfort without unnecessary energy consumption, wearing warm clothing or making minor repairs to keep the house warm.

Earlier research has raised the issue of whether small tariff changes lack salience (Deryugina et al., 2019), which may explain apparent low-price elasticities. We have selected a locale where the sheer magnitude of the tariff hikes and a variety of other factors (including the fact that households are responsible for their own heating expenses, the format of the bill, and a history of compliance and attention to utilities) "should" imply salience, and have for good measure also examined whether the elasticity is different for groups of people with different knowledge of their consumption levels (which may signal the strength of salience) or for whom the tariffs hikes had a different proportional impact (which presumably affects salience).

We have found some evidence consistent with the notion that the stronger the salience, the stronger the responsiveness to price, although this effect is modest and may partly overlap with that of income and/or baseline consumption levels. We have also checked whether people might be responding to announcements about future prices but have found that once the current price is included in the model, future tariffs do not influence consumption.

Importantly, our models control for the subsidies, the lump-sum assistance provided by the government, and find a very small and insignificant subsidy elasticity of demand. Were we take this elasticity at face value, it would imply that when the marginal price of gas doubled, even households that received subsidies reduced consumption, as long as the subsidies did not increase by more than 460%. If both prices and subsidies doubled (as happened between April and May 2015, or April and May 2016, for prices), consumption is still predicted to decrease by about 4-14%. This is somewhat reassuring in view of the statements by government and utility officials that the subsidies had failed to deliver significant reductions in natural gas usage (primarily because they had not stimulated sufficient energy efficiency improvements).[35] Back-of-the-envelope calculations suggest that the tax revenue from the gas bills paid by the wealthiest

[35] See, for example, https://www.president.gov.ua/en/news/sistema-subsidij-maye-stvoryuvati-motivaciyu-dlya-ekonomiyi-42534, http://annualreport2016.naftogaz.com/en/jak-mi-pracjujemo/energoefektivnist, https://voxukraine.org/en/9-facts-about-the-system-of-subsidies-in-ukraine-and-the-real-gas-prices-for-the-population (in English); https://www.kmu.gov.ua/ua/news/gennadij-zubko-zmenshiti-vitrati-domogospodarstv-mozhna-tilki-za-rahunok-znizhennya-energospozhivannya, https://expres.online/archive/digest/2017/03/18/233410-navishcho-ekonomyty-pidrahovano-vidriznyayetsya-spozhyvannya-gazu-budynkah, https://dt.ua/ECONOMICS/diyucha-sistema-subsidiy-niyak-ne-motivuye-naselennya-ekonomiti-na-spozhivanni-gazu-213192.html; http://uacrisis.org/ua/43443-mehanizm-subsidij (in Ukrainian) (last accessed on March 20th, 2019).

households in our sample is sufficient to cover the subsidies for the poorest households. The fact that the elasticity is low and that wealthiest households have a comparatively more inelastic demand suggests that if in the future further (and hopefully more moderate) tariff adjustments were made, it should still be possible to redistribute revenue from the wealthier households to the poorer ones.

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Chapter 3.

Drivers of energy-efficiency renovations in Ukraine: A case study of the city of Uzhhorod

Abstract

Enhancing the energy efficiency of buildings holds significant importance for Ukraine, given its implications for energy independence, security, and climate change. Using data collected in the city of Uzhhorod in western Ukraine, I describe the types, rates, and prices of various energy-efficiency measures implemented by households between 2008 and 2018 in Ukraine, a period of strong fluctuations in energy prices and geopolitical changes. Families follow a step-by-step approach and spread energy-efficiency renovations out over an average of three years, with ten years at most between the first and the last energy-efficiency investment, choosing to implement up to five measures. The average price of one energy-efficient project is 261 EUR, and the most expensive installment is cavity-wall insulation, with 516 EUR for a project. I explore the role of socio-demographics and dwelling characteristics, finding that homeowners with lower educational attainment and income, larger household size, and at least one child living in units in multi-family buildings and with a more significant number of rooms are more likely to invest in energy-efficient measures. It also appears that energy-efficiency renovations are more likely among households that recently moved into their dwelling and where one or more household members work abroad.

Keywords: Energy-efficiency investment measures; renovation; household behavior; homeowners; discrete choice model.

1. Introduction

Energy-efficient renovations are widely recognized for delivering energy savings, enhancing home comfort, and reducing energy costs. The residential sector of Ukraine, with over 15 million households, can feasibly contribute to achieving these targets. It is the second largest consumer of energy. The households themselves are the primary users of gas (8.7 Mtoe in 2018), from the total of the residential sector (16.7 Mtoe).[1] The housing stock of Ukraine is old and in a bad state of repair. Energy-efficient renovations can deliver significant, cost-effective carbon dioxide emission cuts.[2] The Ukrainian government is setting targets to decrease through improved energy efficiency and conservation initiatives, aiming to reduce total CO_2 emissions by 60% by 2030 and 50% by 2035, using 1990 as a baseline (Cabinet of Ministers Ukraine, 2017). Furthermore, the Ukrainian government has formulated the "Energy Strategy of Ukraine 2030" as a key policy framework highlighting the importance of implementing energy-efficient and energy-saving measures to safeguard the environment. Subsequently, in 2017, an updated version known as the "Energy Strategy of Ukraine 2035" was introduced to address the economic, political, and energy-related challenges associated with the conflict with Russia (San-Akca et al., 2020). This initiative led to implementing government programs, such as the "Warm loans," which provide financial assistance for energy-efficient investments.[3] Additionally, the Ukrainian government sought financial support from international donors, including the European Union, the European Bank for Reconstruction and Development (EBRD), the Global Climate Partnership Fund, the World Bank, the Global Climate Partnership Fund, and the Nordic Environment Finance Corporation (NEFCO) projects, which also hindered the adoption of energy-efficient renovations in Ukraine.[4,5]

Due to the significant gap in monitoring energy-efficient investments and the lack of corresponding statistical information, there is room for improvement in conducting rigorous analyses to inform future policy adaptations. Gaining a better understanding of the investment preferences of households that motivate Ukrainian families to pursue energy efficiency is crucial in this regard. This study contributes to both points by providing valuable information on rates,

[1] https://iea.blob.core.windows.net/assets/ac51678f-5069-4495-9551-87040cb0c99d/UkraineEnergyProfile.pdf
[2] https://iea.blob.core.windows.net/assets/63aaa8a4-d16d-4ff4-84a8-387f440304be/IDR_EasternEuropeCaucasus_2015.pdf
[3] https://saee.gov.ua/uk/consumers/tepli-kredyty
[4] https://ebrdgeff.com/projects/iq-energy-the-launch-of-a-new-financing-facility-for-ukraine/
[5] https://www.nefco.int/

types, and costs of energy-efficiency measures implemented in Ukraine over ten years coinciding with sharp energy price jumps, drawing attention to whether: (i) gas price increase affects the frequency and type of EE measures; (ii) households follow a step-by-step or a single-step approach in renovations and (iii) average investment costs per specific type of EE measure changed over time.

Importantly, this chapter analyzes the determinants of EE measures in Ukraine from 2008-2018, before and during deep economic and geopolitical transformations. The research results contribute to answering the following questions: (iv) Which households are more likely to invest in at least one EE measure? (v) Which households are more likely to invest in the most energy-effective measures, such as thermal insulation of walls and attics and double-glazed or triple-glazed windows?

Although the literature on determinants is extensive, to the best of the author's knowledge, there is currently no existing research on the determinants of energy-efficient measures in the household sector of Ukraine. To explain a household's choice of the uptake of EE measures, scientists have been considering various factors: economic, technical, and social. The complexity and interrelation of these factors have been a recurring theme among researchers, underscoring the imperative for further analysis (Liu et al., 2022). Other authors suggest that investments should be studied repeatedly for identical dwellings and, over a long period, to understand the "household-retrofit decision" relation (Trotta, 2018a).

This study adds to the literature on determinants of EE measures from Ukraine, a developing country in Eastern Europe. A country with a population of 41.9 million (2018), it represents one of 'Europe's biggest energy markets. It remains the most significant country for the transit of natural gas globally.[6] This study offers comprehensive insights into consumers' choices regarding implemented energy-efficient upgrades. It seeks to understand how these choices vary across different household segments, examine the approaches employed for renovations, and investigate the association between these approaches and the determinants that influence their implementation.

There is substantial diversity in consumer preferences when adopting energy-efficient measures, and this diversity needs to be adequately understood. The results of this study have the potential to make a meaningful contribution to developing a unified approach to assess the

[6] https://www.iea.org/reports/ukraine-energy-profile

magnitude of the energy efficiency gap, taking into account the adoption of energy-efficient technologies and green investments across all sectors (Vasylieva et al., 2021; Lyulyov et al., 2021). Determinants of EE investments are heterogeneous and region/country specific. This chapter will bring the missing puzzle piece to the European picture by examining the energy-efficient renovations implemented in Ukraine. Furthermore, the information obtained can assist policymakers in developing future policies adapted to the needs and preferences of residential consumers.

The results of this chapter show that low-income and low-education households demonstrate a greater level of determination in implementing energy-efficient renovations. At the same time, the probability of investing increases if one of the members has worked abroad. Families that have a child are more likely to implement energy-efficient measures. Living in a multi-family apartment with more rooms and a larger household size increases the probability of adopting any of the listed EE measures. This statement also holds for the most cost- and energy-efficient measures, such as the thermal insulation of walls, attics, and double-glazed or triple-glazed windows. Such probability increases for families that have recently moved into a house. The results did not confirm that the availability of a subsidy or benefit influenced the likelihood of renovation, but rather the presence of a person who stays home during the heating season in the daytime. Risk aversion or the intention to sell a house/apartment is not a good determinant of the residents' choice to implement energy-efficient measures.

Notably, the results confirm that families renovate their homes following a step-by-step approach and complete the renovations relatively quickly, reducing the period with each new investment. Most residents have implemented EE measures within three years. Families that implemented two measures completed renovations in less than two years, and households only took a year and a half to implement a third upgrade. This study builds a profile of the households that should be provided with targeted government initiatives and financial support, to ensure the transition to an energy-efficient future while addressing equity and welfare considerations.

2. Literature review

The interest in this research comes from the findings from the previously co-authored papers. In the collaborative research, we studied extreme energy prices in Ukraine as a factor to which households would respond by decreasing energy consumption (Alberini et al., 2019). Under high price changes, families can reduce gas consumption without implementing EE insulation or making other significant home changes. The most productive at reducing energy use were consumers with the lowest rate of EE improvements, driven by necessity or through skills and behaviors (Alberini et al., 2020).

In the current research, attention is restricted to the determinants of energy-efficient measures, which are based on social-demographical characteristics (e.g., household type, number of household members, education, the existence of children of different ages, financial status), a 'building's characteristics (e.g., building type, building age, dwelling size, year moved into the house, staying at home most of the day), financial subsidies and benefits received from the government, as well as change behavior (being risk-averse, intention to sell a house).

The ability of a household to control energy consumption and expenditures can impact behavior change and motivate the implementation of EE measures. According to the 2016 survey conducted in Ukraine by the SG "REITINH," 72% of the respondents expressed their intention to actively pursue "efficient energy savings" to decrease gas consumption.[7] However, are household decisions to implement EE measures driven only by rational thoughts of energy-saving? The interrelation between a building's energy use and the behavior of its residents is very tight and hard to distinguish. The Energy in Buildings and Communities (EBC) report from the International Energy Agency (IEA) underscores the importance of considering a combination of factors when assessing a building's energy consumption. These factors encompass climate, building envelope, services, maintenance, energy systems, occupant activities, behavior, and indoor environmental quality (Yoshino et al., 2017).

A recent publication by Liu et al. (2022) analyzed the literature on homeowners' decision-making in implementing energy renovations. The authors identified 689 factors. Among those prevailing, a third is a group of decision-maker characteristics – demographic characteristics, environmental concerns, and family fluctuations; a further 30% are beliefs about energy

[7] http://www.iri.org/resource/ukraine-poll-continued-dissatisfaction-government-and-economic-situation

renovations consequences, comprised of social, financial, and technical benefits; following 12% accounts for dwelling characteristics; less than 5% are social norms and perceptions of energy-efficient measures. The remaining share is distributed among various factors with lower importance.

Given the limited research from developing countries, specifically Ukraine, adopting a multi-country approach can offer a more in-depth grasp of the elements influencing households' decisions to undertake renovations. This approach is beneficial due to demographic, geopolitical, economic, and social similarities. Moreover, it can provide valuable insights into future developments in this field, as the energy consumption of developing countries tends to increase in line with economic growth and improvements in household lifestyles. The original survey by Urban and Scasny (2012) provides a valuable opportunity to gain deep insights into residential decisions regarding energy investments and energy-saving measures among nine OECD countries while differentiating them from the perspective of electricity consumption growth. Their results suggest a positive effect on implementing energy-efficient investments for owner-occupied, wealthier households, households with children, and older people. Deeper environmental concerns are associated with a higher likelihood of investing in energy-efficiency retrofits. However, education does not play a significant role, as the survey findings indicate. Later, Ameli and Brandt (2015b) analyzed a rich data set from eleven countries based on the OECD Survey on Household Environmental Behavior and Attitudes. Owners are more likely to invest in stationary investments such as windows and thermal insulation; households are also more inclined to invest in energy measures when they first move into their homes. Income increases for low-income households also advance the probability of making such investments.

When examining the findings from the country-specific analysis, it is crucial to consider energy-efficient investments from multiple perspectives, particularly the similarity of climate conditions among different countries. Ukraine is a country with cold winters and hot summers. Like many other countries with similar weather conditions, climate affects the probability of adopting thermal insulation and other energy-efficient measures. A study of 3,000 detached houses in Sweden by Nair et al. (2010) provided proof of the important role of thermal comfort and socio-demographic characteristics for residents. The probability of investing in energy-efficient measures exhibits a positive correlation with factors such as an increase in thermal discomfort, the age of the house, previous energy-efficiency experience, and high energy costs. It is also positive concerning higher levels of education and the income of households.

Achtnicht and Madlener (2014), evaluating German house owners' preferences for energy retrofits, found several factors encouraging the decisions of households to renovate. These factors include financial affordability, possible energy cost savings perception, the payback period, and recommendations on retrofit measures from an independent energy expert. The interest of households in retrofit investment decreases with the house age for houses built after 1990.

Jakob (2007) provided a deeper insight into Swiss households' decisions. Using survey data, the author estimated Factors that motivate or impede the decision-making process for retrofitting single-family houses by house owners. The data demonstrate that energy-efficient renovations are more frequently motivated by the age and technical condition of a building rather than factors such as income, age, professional occupation, or education. Furthermore, households are primarily motivated to renovate by environmental concerns and the expectation of energy savings rather than monetary benefits.

Gamtessa (2013) conducted a comprehensive analysis of a substantial sample of households in Canada. The author examines energy-efficient investments in response to the "EnerGuide for Houses" program. He observed the importance of social demographics: household size, income, education, and the age composition of the household. Larger and wealthier households had a lower likelihood of energy retrofit investments. Similarly, the costs of retrofits lowered the probability of insulating. At the same time, households lacking high school education exhibited a positive correlation with renovations. The author highlights the significance of government financial incentives, which positively impact increasing the number of renovations, particularly for low-income households.

Trotta (2018b) highlighted dwelling characteristics in interpreting residents' choices in search of determinants of energy-efficient retrofits of households in the UK. Investments in detached houses built before 1990 are more likely to be done by families with independent children, assuming they have lived in the house for more than one year. Contradictorily, residents living in apartments have less incentive to invest. Ownership positively affects investments for households with mortgages. The author's earlier analysis (Trotta, 2018a), based on the data from the UK Survey of Public Attitudes and Behaviors towards the Environment, brings up high-income households and older age groups of residents as more likely to invest in energy-efficient retrofits. Living in a multi-family house has a negative correlation with such investments.

Fischbacher et al. (2020) looked at the heterogeneity of homeowner's choices concerning energy investments and consumption from a different perspective, suggesting a positive relationship between homeowner's investments and risk-taking. Additionally, households with pro-environmental inclination social preferences and those who value time and future preferences are positively related to energy-efficient investments.

Looking at findings from countries with a milder climate Hrovatin and Zorić (2018) provided an analysis of Slovenian households living in single-family homes based on retrofits performed between 1995–2009. They indicated the importance of informal advice provided to homeowners as a driving force for partial retrofit measures. At the same time, when applying an integrated approach to renovating, determining factors are energy-saving potential, household income, and professional advice. In the following paper, Dolšak et al. (2020) the authors examined data from 2006 to 2014. Estimated results indicated that financial status, energy expenditures, and the building's age, type, location, and past retrofit activity prompted investment in energy-efficient retrofits

The importance of energy-efficiency for Ukraine has been underlined in several studies.[8] Redko et al. (2021) highlighted the need to optimize the performance of Ukrainian district heat supply systems and lessen heat losses. In addition, the authors implied a relationship between the future development of energy efficiency and the systematic data collection of buildings based on the energy use category. Rozwalka and Tordengren (2016) pointed out the potential for gas savings from energy-efficiency measures in Ukraine through infrastructure investment. Similarly, Goncharuk and Lo Storto (2016) suggested that optimizing the gas industry and gas market can bring valuable input to improving energy efficiency in Ukraine. Recent studies point to the great potential of Ukraine to develop into an energy-efficient country through the maximization of green energy investments and improvements in the economic and political sectors (Lyulyov et al., 2021). The contribution of energy-saving investments in the residential sector can bring valuable input, not only from a decrease in energy use but also in the recovery of the country's economy (Emerson and Shimkin, 2015).

[8] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-27447.pdf

Considering previous findings, this research builds upon the main variety of EE measures also studied in other countries, the implementation of which can bring a reduction in energy use, energy independence, and the improvement of a country's economy.

3. Background and data

This study is based on information from an original household survey conducted in Uzhhorod, the capital of the Zakarpattia region of Ukraine. It is a city with a population of 113,000 inhabitants. The housing stock of the city consists of 60% single-family and 40% multi-family homes, which is similar to the share throughout Ukraine (Emerson and Shimkin, 2015). The majority of houses in Uzhhorod are privately owned. In general, Ukraine is among the countries with the highest homeownership rate, which is 93.7%.[9] House ownership is one of the socio-demographic variables found to be positively correlated with the implementation of energy-efficient and energy-saving measures (Urban and Scasny, 2012; Achtnicht and Madlener, 2014, Ameli and Brandt, 2015a, Milne and Boardman, 2000).

Explicit reasoning drove the selection of the location for the surveys. Zakarpattia is the only region in Ukraine with individual heating systems for all users. From 2005-2013, as part of a Ukrainian pilot energy-saving project, the region with 1.2 million inhabitants was disconnected from the district heating. Household owners installed gas and electricity meters in each dwelling. Most families use natural gas for heating, water heating, and cooking, corresponding to 95%, and the remaining 5% use electricity or solid fuel.[10] District heating systems are prevalent in most cities of Ukraine, where they serve as the primary means for heating and water heating. Due to old infrastructure and poor technical conditions of the infrastructure, heat losses reach over 60%.[11] Other regions in Ukraine have also initiated a process of partial disconnection from district heating, following the lead of the Zakarpattia region.[12] The region's unique characteristics provide a valuable opportunity to analyze households' energy conservation and efficiency behavior, yielding insights that hold broader implications for the entire country.

[9] https://unece.org/fileadmin/DAM/hlm/documents/Publications/CP_Ukraine_ECE.HPB.176.en.pdf
[10] https://www.nerc.gov.ua/
[11] https://geospatialworldforum.org/2014/presentation/lis/Nataalya%20Oliinyk.pdf
[12] https://gazeta.ua/articles/kiev-life/_kiyani-pochali-masovo-vidmovlyatisya-vid-centralizovanogo-opalennya/739074, https://tsn.ua/groshi/mista-masovo-vidmovlyayutsya-vid-centralnogo-opalennya-chomu-tak-stayetsya-i-yak-griyutsya-meshkanci-kvartir-1731430.html

Data collection occurred over three survey waves in 2016, 2017, and 2019. wave 3, conducted between June and September 2019, encompassed households previously surveyed during wave 1 in May-June 2016 and wave 2 in May-June 2017. Table 3.1. describes the sampling frame. The entire sample of wave 3 consisted of 500 households: 250 households re-interviewed from the survey conducted in 2016, and 250 dwellings re-interviewed from the survey conducted in 2017. The 2016 sample is representative of the housing stock in the city of Uzhhorod, with the number of interviewed households being 500. Only a part of the 2017 sample, with a total of 500 dwellings interviewed, represents the housing stock in Uzhhorod (250 households). The remaining 250 households were sampled based on wall insulation visible from the outside (i.e., choice-based sampling).

The 250 dwellings from wave 1 and 250 from wave 2 were re-interviewed in 2019. Each wave 1 and wave 2 sample consists of homeowners potentially in charge of household management, aware of the utility payments, consumption, home equipment, and energy-efficient measures. The selected households are only gas users and utilize it for heating, water heating, and cooking. All dwellings use gas with an independent heating system and fully control their energy bills and consumption. The 500 dwellings sampled for the study from wave 3 were mainly single-family and multi-family homes, with a small share of semi-detached homes.

Table 3.1.: Sampling frame, n=500.

2019 survey (Wave 3) n=500 households (A+B)	
2016 survey (Wave 1) (A)	2017 survey (Wave 2) (B)
• n=250 households • representative of the housing stock of Uzhhorod • gas users • gas bills from May 2016 to May 2019 • energy-efficient measures 2008-2018	• n=250 households: • n=130 choice-based sampling (renovations visible from the outside) • n=120 representative of the housing stock of Uzhhorod • gas users • gas bills from May 2016 to May 2019 • energy-efficient measures 2008-2018

The aim of wave 3 was to collect additional data on gas bills to get consumption throughout 2013-2019. In addition, an extensive questionnaire encompassed a comprehensive range of questions, yielding detailed information regarding energy efficiency measures implemented from 2008 to 2018. These measures included cavity wall, attic, and basement insulation; installation of double-/triple-glazed windows; utilization of thermoregulators and thermostats; boiler replacement; and installation of electric heaters, among other measures. Moreover, respondents could include any supplementary energy efficiency measures they had personally implemented.

The survey data includes information on dwelling characteristics and socio-demographics. Additionally, it includes details about financial benefits and subsidies provided by the government, as well as information related to changes in habits, expectations, and attentiveness. Behavioral patterns hold significant importance as they have the potential to drive changes in everyday life, foster skills for energy conservation, and motivate energy-efficient investments.

This chapter targets two outcomes. First and foremost, this study aims to offer a comprehensive and detailed description of the rates, types, and costs of energy efficiency measures implemented in Uzhhorod, Ukraine, over ten years. For this purpose, the study utilizes the entire sample of 500 households from wave 3. The description of the sample is provided in Section 4 in Table 3.2.

Secondly, this research seeks to determine the factors influencing the choice of energy-efficient measures. For this analysis, the study utilizes a subset of the sample. This subset consists of 370 households, selected based on the housing stock in Uzhhorod. In order to avoid potential bias, the research excluded 130 dwellings sampled based on visible insulations from the outside. The analysis is provided in Section 5. The descriptive statistics for this sample are outlined in Table 3.5.

4. Rates and types of energy-efficient measures

Detailed descriptive statistics on the entire sample of 500 households provided in Table 3.2., including households that invested in at least one energy-efficient measure and that did not carry out any renovations. This study includes eleven types of EE measures: cavity wall, attic, and basement insulation; installation of double-/triple-glazed windows; thermoregulator and thermostat; replacement of a boiler; installation of an electric heater; and other measures (which the respondent could add).

Table 3.2.: Descriptive statistics, sample n=500.

Variables	Description of variables	Mean, %				
		Full sample	At least one EE measure done	No EE measures done	T test of the null that the means are the same	
		N=500	N=346	N=154		
		A=B+C	B	C	B vs C	
Socio-demographics						
income (UAH)	total monthly family income (after tax)	7,197.1	7,158.9	7,282.8	0.388	
workabroad	dummy if one of family members works abroad	40%	42%	34%	-1.841	**
loweduc	dummy for middle education (school)	14%	16%	8%	-2.539	*
profeduc	dummy for professional-technical education	24%	24%	24%	0.079	
higheduc	dummy for higher education (BSc, DiS, MSc)	60%	58%	66%	1.841	*
child	dummy for having a child	57%	61%	47%	-2.784	***
kids0_5	dummy for kids below 5 years	8%	10%	4%	-2.348	**
kids6_12	dummy for kids between 6-12 years	17%	20%	10%	-2.902	***
kids13_17	dummy for kids between 13-17 years	25%	26%	21%	-1.164	
kids18plus	dummy for kids older than 18 years	26%	27%	23%	−0.957	
elderly	dummy for person over 65 living in home	34%	35%	31%	−0.767	
homestay	dummy for person that stays at home during the day during heating season	47%	48%	44%	−0.984	
benefit	dummy for receiving benefit	8%	8%	6%	−0.726	
subsidy	dummy for receiving subsidies	16%	16%	16%	0.177	
Dwelling characteristics						
SFhome	dummy single family house	41%	43%	38%	−0.934	
multifamily	dummy multi-family building apartment	56%	55%	58%	0.673	
semi-detached	dummy semi-detached house	2%	2%	3%	0.824	
hhsize	household size (n)	3.3	3.4	3.0	-3.362	***
agehouse	age of the house (years)	36.2	36.6	35.5	−0.473	
agehousemiss	dummy missing values of age of the house	13%	11%	16%	1.534	
yearmovedin	year when family moved into the house	1992	1991	1991	−0.495	
squaremetres	size of the home (m^2)	83.7	87.1	76.0	-2.440	**
livrooms	number of rooms (excluding kitchen)	3.0	3.2	2.8	-3.340	***
dirtyarea	dummy for homes located in dirty/noisy areas	10%	10%	9%	−0.257	
leakinghome	dummy for homes with leaks from roof/dampness	18%	17%	21%	0.915	
sellintention	dummy if household planning to sell house	12%	11%	14%	1.048	
riskaverse	dummy for households that are not risk-takers	76%	76%	75%	−0.235	

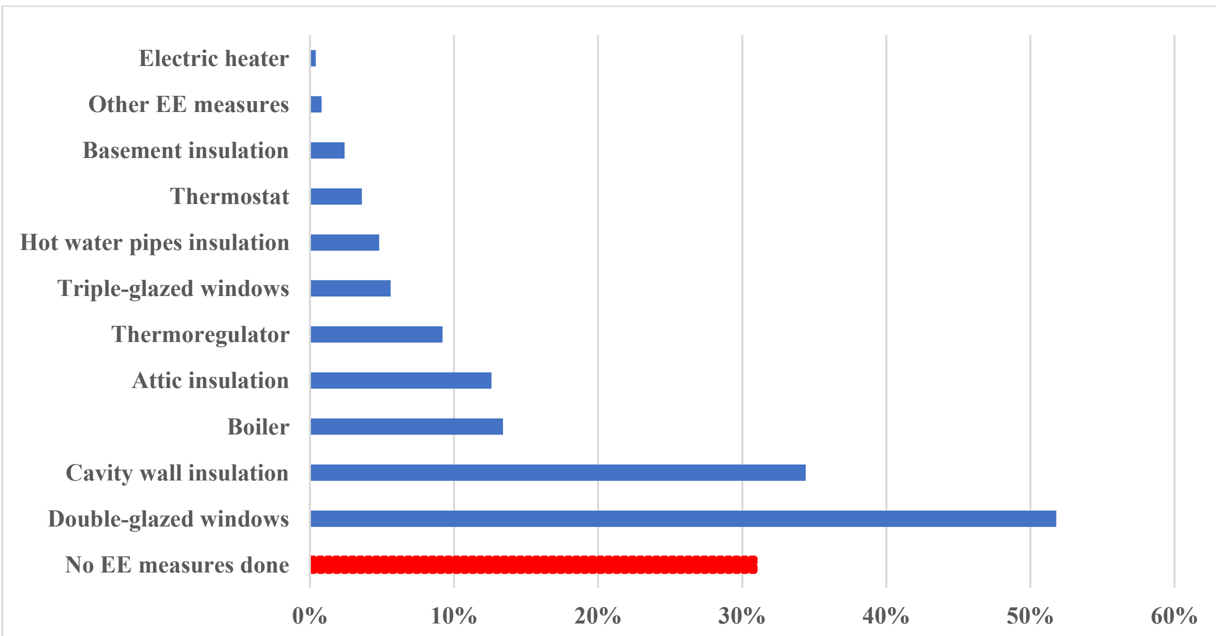
*, **, and *** denote statistical significance at the 10%, 5%, and 1% level, respectively.

The T test assumes unequal variances.

Given the study period between 2008 and 2018, which witnessed significant energy price fluctuations, particular attention was focused on three aspects: if (i) gas price increase affects the frequency and type of EE measures; (ii) households follow a step-by-step approach in renovations; (iii) average investment costs per specific type of EE measure changed over time.

Over the period of ten years, from the total sample of 500 households, 69% implemented at least one EE measure. (Figure 3.1.)

Figure 3.1.: Share of EE measures, sample n=500.

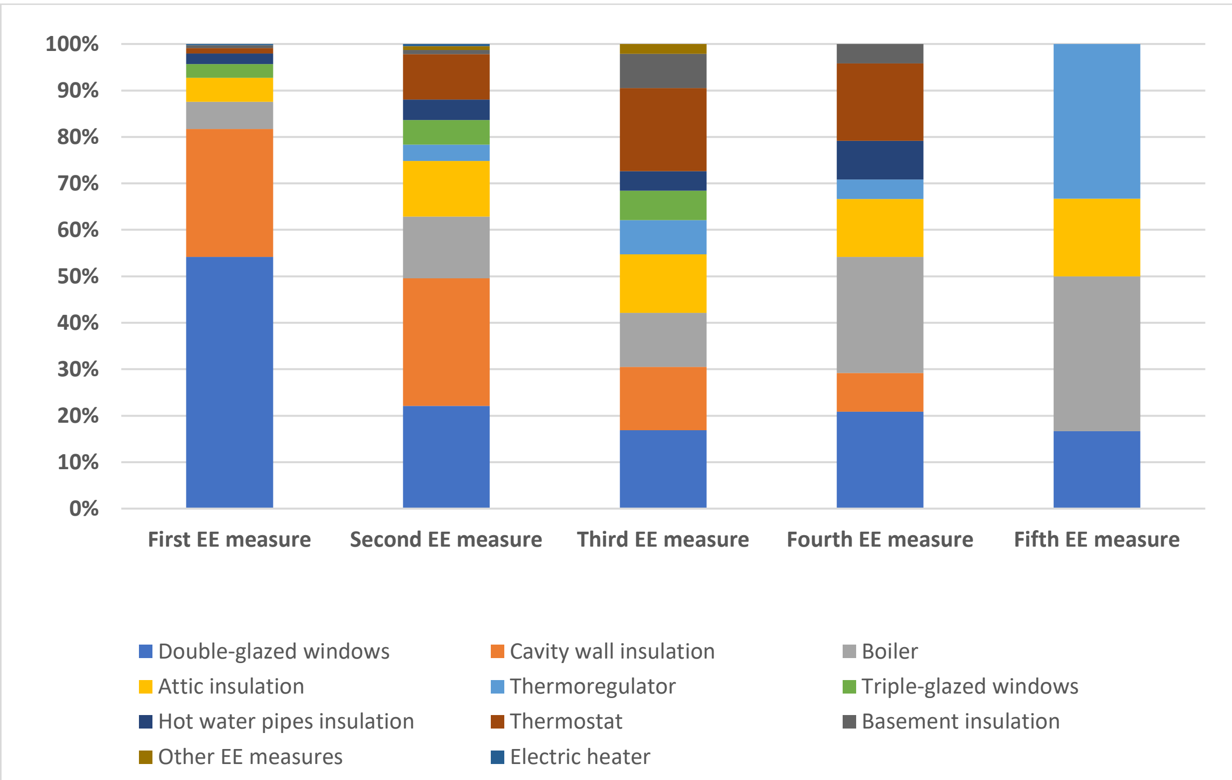


Most households, exceeding 50%, invested in double-glazed windows, while more than 30% opted for cavity wall insulation. Attic insulation and boiler replacement represent a share of 13% each. Thermoregulators were installed by 9% of households. Triple-glazed windows were preferred by 6% of residents and insulated hot water pipes by 5%. Thermostats comprise 4% of the sample, while only 2% of households chose basement insulation, and 1% chose other measures. Among the total sample, only 1% of households performed the highest number of energy-efficient upgrades, which is five. A relatively small portion of households (4%) made four energy-efficient upgrades. The majority of households chose to invest in two (26%), one (24%), or three (14%) energy-efficient measures.

Figure 3.2. displays the distribution of energy-efficient upgrades in the order of implementation, ranging from one to five measures per household. Double-glazed windows

emerged as the most prevalent first choice among EE measures, accounting for 54% of households. The second most common choice was cavity wall insulation, representing 27% of households. Families prioritized the installation of a thermostat as the third most popular EE measure, accounting for 18%. The fourth priority measure was installing a boiler, chosen by 25% of households. The combination of a thermoregulator with a boiler constituted the fifth measure, each having a proportion of 33%.

Figure 3.2.: Order of implemented EE measures, sample n=500.



Note: percentage share specified within each category (i.e., 100% for first EE measures, etc.).

Households followed a step-by-step approach by implementing one energy-efficient measure at a time. They prefer the most energy- and cost-effective measures, which can offer valuable savings and enhanced comfort in the home. These are double-glazed windows, cavity, and attic insulation. The degree of energy savings realized through different types of renovations varies significantly due to multiple factors. These include the climate, the quality of the equipment, the existing state of repair, the insulation materials used, and the overall energy efficiency of the building.

As a rough estimate, double-glazed windows can often lead to energy savings of 10% to 25%. Attic or cavity insulation can bring up to 30% of savings. On average, insulating a basement can result in energy savings of approximately 5% to 15%. Installation of a thermoregulator or thermostat can decrease consumption by 10%. Hot water pipes can offer around 3% of savings. General estimates for boilers are between 20-30% of the total energy used for heating. Still, engineering estimations often tend to overestimate savings compared to the actual data economic analysis (Fowlie et al., 2018). Nevertheless, Kadrić et al., (2021) that the most financially significant benefits are derived from improvements in external wall insulation, window glazing, and the replacement of the heating system. This relates to NPV value, energy savings and IRR.

The numbers and order of energy-efficient measures play an important role in a household's intention to renovate since previous experience can build skills for further investments. The data reinforce previous findings that households are more likely to replicate the renovation after completing at least one energy-efficient upgrade (Nair et al., 2010, Wilson et al., 2015; Dolšak et al., 2020).

Households that have implemented some retrofit continue investing in further measures after a moderately short time. This period becomes shorter with each new EE measure implemented. Eighty percent of the households implemented EE measures within three years, while 20% did it in the same year. (See Table 3.3.)

Table 3.3.: Average period in between implementation of EE measures, sample n=500.

The order of implementation of EE measures	Total number of households implemented EE measures from all n=500 [no. households]	Percentage of households who made the EE investment in the same year	The average length between two investments for all who did EE measures [years]	The average length between two investments, only if invested in different years [years]
1st and 2nd	131	24%	1.40	1.85
2nd and 3rd	71	41%	0.88	1.49
3rd and 4th	24	58%	0.75	1.80
4th and 5th	5	60%	0.40	1.00
1st and last	226	21%	2.35	2.97

The longest period between the first and the last EE upgrade is ten years. Almost one-third of families carried out two measures, and they completed them in less than two years; households implementing a third investment did so in a year and a half.

Households have financial limitations or funds for EE improvements. These constraints can arise from various factors, including income, savings, subsidies, or other financial obligations. The order of EE investments plays an essential role because it can affect how a household can make subsequent improvements. Households must consider their financial situation and prioritize EE investments strategically to ensure they can continue enhancing energy efficiency over time while managing their budget constraints effectively.

If a homeowner is particularly concerned about energy costs, they may prioritize measures that offer the quickest return on investment, such as cavity wall insulation and thermostat upgrades. Most households from the sample adopted a systematic step-by-step approach, introducing one EE measure at a time: prioritizing double-glazed windows, cavity wall insulation, and thermostat, followed by boiler and thermoregulator. With the average cost of double-glazed windows at UAH 8,435, an average family would have to allocate nearly one and a half times their monthly family income to cover this expense. For cavity-wall insulation, which costs UAH 16,731, households would need to give around two and a half times their monthly income to cover the costs. These expenses seem plausible considering that eighty percent of households installed energy efficiency measures within a span of three years.

Nearly one-third of households implemented two energy efficiency measures, incurring an average cost of UAH 17,571, and accomplished it within two years. Considering the reported average salary, these households would have to set aside approximately 11% of their monthly income to cover the costs.

The step-by-step approach to implementing EE measures reflects a pragmatic and budget-conscious strategy. It enables households to gradually reap the benefits of improved energy efficiency while managing their financial resources and addressing their specific needs and preferences. Families may prioritize more affordable upgrades first to manage their budgets effectively. The thermoregulator is one of the less favored types of upgrades with lower costs. Households can install it if they allocate 5% of their income toward savings each month during the year.

Homeowners may follow a timeline for home improvements, addressing one area of the home at a time. Some renovations can be prioritized not only due to energy saving potential. Window replacement can be done for aesthetics or to address issues like drafts, leakage, or damage (Dolšak, 2023). Furthermore, the expert recommendation or the neighbors' example can drive the choice and order of EE implementation (Bagaini et al., 2020).

While a new boiler can significantly improve energy efficiency and heating performance, its impact may be less noticeable than measures like double-glazed windows or thermostat upgrades. Moreover, for installing a new boiler, obtaining permission from regulatory authorities is a mandatory process. This process involves administrative procedures and can be time-consuming, which is the case in Ukraine.

Nevertheless, the decision to renovate is an investment with a risk perception, directly influencing further investments. Homeowners may initially prioritize concerns about the uncertainty of current expenses before considering the future cost savings resulting from improved energy efficiency (Fischbacher et al., 2021). The authors highlighted that homeowners consider the uncertainty about the future benefits of renovations as a crucial factor in their decision-making process. Such hesitation impacts both their choice to renovate and the scale of their renovation projects (Peñasco and Anadón, 2023).

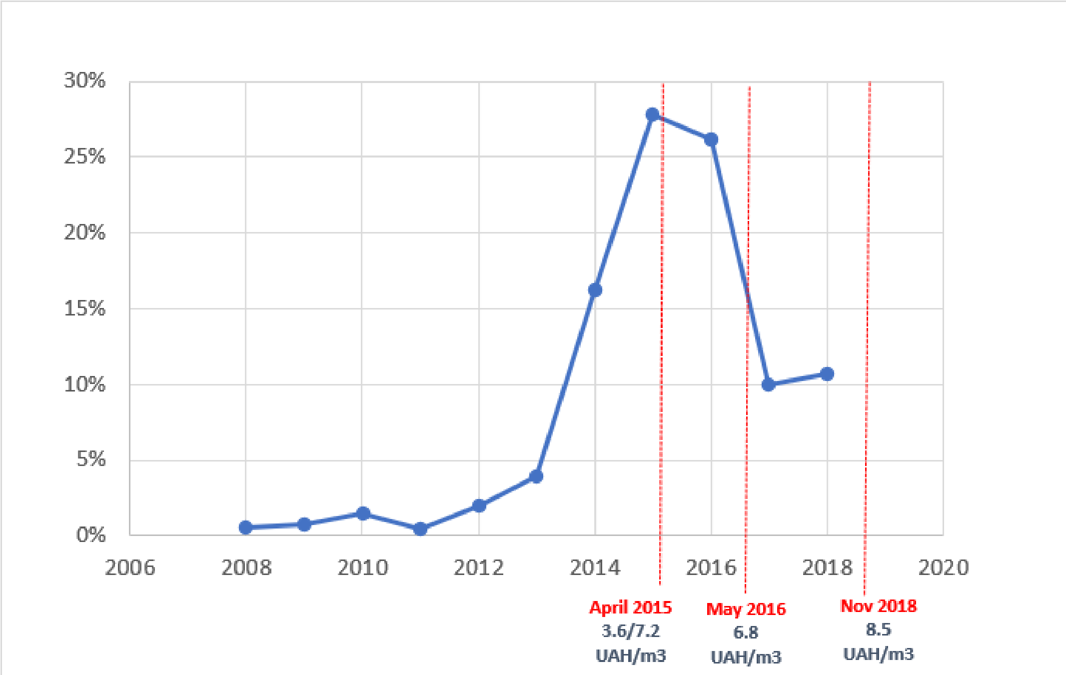
To determine whether households had intentions for future renovations, the survey instrument incorporated a question inquiring about the household's intentions for future renovations within the upcoming three years (2019-2021). Among the 346 households that have already implemented at least one energy-efficient measure, a significant majority of 80% have expressed their intentions to continue with further improvements. Surprisingly, even among the 154 households that have yet to engage in renovations, 85% are willing to undergo some form of upgrades. It is noteworthy that both groups of consumers show a preference for cavity wall insulation, boiler replacement, and the installation of a thermoregulator as their desired EE measures.

A study on Ukrainian firms by Hochman and Timilsina (2017) found that energy prices can trigger greater adoption of energy-efficient investments. Between 2013 and 2015, Ukraine experienced a significant seven-fold surge in gas prices.[13]

In Figure 3.3., the red dotted lines indicate the dates when gas prices increased and the corresponding tariffs. The blue line demonstrates an upward trend in implementing EE measures within the 10-year timeframe. The progress in the number of EE measures correlates with the sharp rise in gas prices.

[13] https://www.nerc.gov.ua/en

Figure 3.3.: Share of EE measures implemented by year, sample n=500.



Dwellings that implemented only one EE upgrade did so on average in 2015. A second measure, as well as a third and fourth, were implemented on average in 2016, with a fifth implemented in 2017. Investments in double-glazed windows were made on average in 2014, while cavity wall and attic insulation were typically carried out in 2015. Households have shown interest in replacing double-glazed windows since 2008. Implementing energy-efficient measures is frequently carried out in July, coinciding with favorable weather conditions for exterior work such as wall insulations and window replacements.

The reduction in rates of EE upgrades from 2016-2017 can be attributed to the difficult economic situation in Ukraine. The population's purchasing power was significantly diminished due to a substantial depreciation of the local currency resulting from the armed conflict with Russia. In 2016, the proportion of the country's population earning an income below the official poverty line was 58.4%. Furthermore, in July 2016, the Ukrainian government implemented biometric passports, enabling visa-free travel to neighbor European countries within the Schengen area. Such a change boosted working migration as well as remittances sent to Ukraine. These numbers correspond to USD 9.3 billion in 2017, compared with USD 7.5 billion in 2016 and USD 7 billion in 2015.[14] In this sample of 500 households, the share of family members working abroad corresponds to 40%. For residents who implemented at least one renovation, this rate is 43%, and for households without renovations, it is 34%.

The vast majority of households are financing renovations from their resources. From this sample, only one household has taken out a loan for basement insulation for 5,000 UAH. The weak involvement of households in governmental loans for energy-efficient renovations is conceivable due to high interest rates and limitations in types of materials. The interest rates for EE loans varied from 27% to 12-18%, depending on the bank and the year when the loan was taken.[15,16] Furthermore, the difference in the size of a loan depends on whether it is provided to a physical person or the homeowners association (HOA). For comparison, according to a survey by the State Agency of Energy Efficiency and Energy Saving in Ukraine (SAEE), the types of energy-efficient measures implemented using the WLP by homeowners associations and individual households are alike.[17] According to the 2019 report by the State Agency for Energy Efficiency and Energy Saving, among homeowners associations of multi-family houses that primarily use gas as their primary energy source, 75.4% of the loans are allocated for windows, 14% for insulation, and 35% for other measures. The majority of HOAs implemented two or more energy-efficient measures. From individual households living in single-family homes, 61.1% of loans were provided for window replacements, 25.3% for insulation, 8.8% for heating boilers, and 7.7% for other measures.

The decrease in energy efficiency enhancements can be linked to the exhaustion of feasible opportunities for implementing these measures. Household decisions regarding renovations can vary widely based on personal preferences, financial circumstances, and each household's specific goals and needs. Families may continue investing in renovations over time, while others may stop after a certain point. Some households faced budgetary constraints. Economic and behavioral barriers are the most valuable in implementing energy-efficient technologies (Bagaini et al., 2020).

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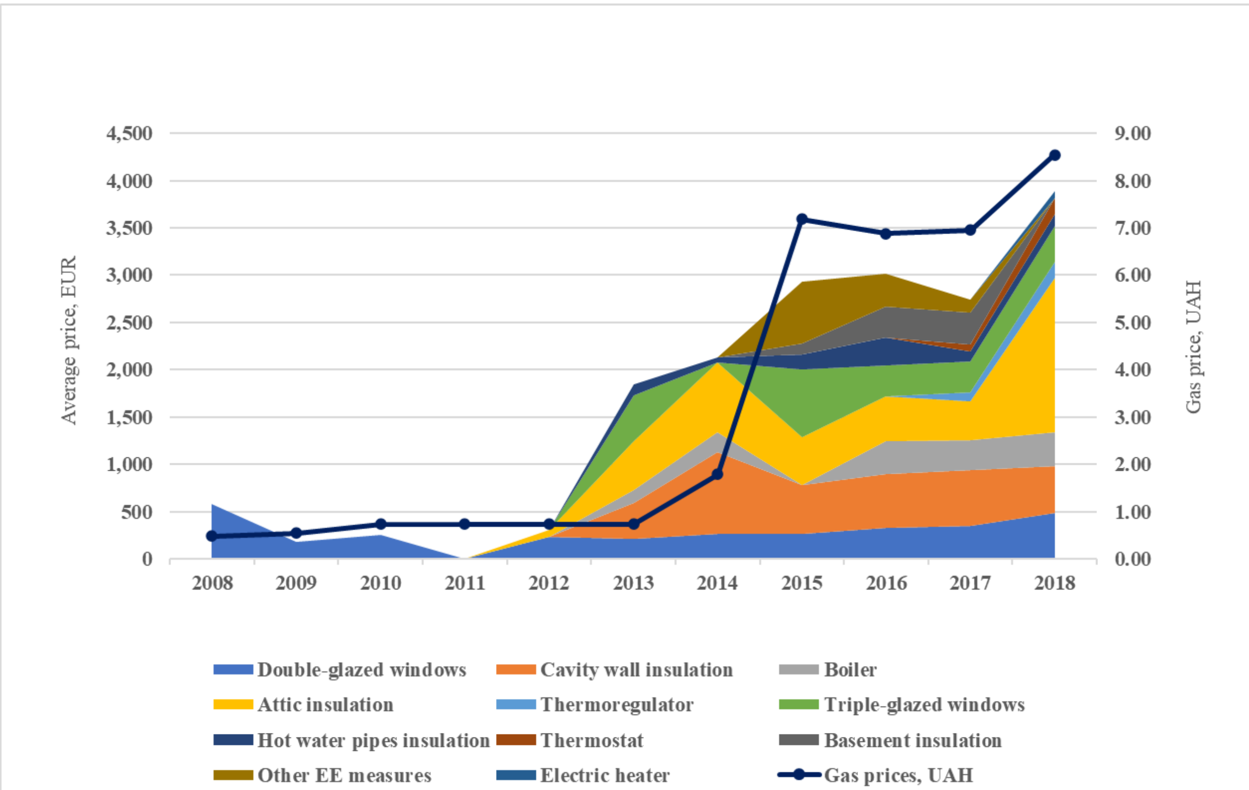
[14] https://www.reuters.com/article/us-ukraine-cenbank-remittances-idUSKBN1GX1WM
[15] https://i.factor.ua/ukr/journals/bn/2017/october/issue-43-44/article-31578.html
[16]https://finsee.com/%D1%82%D0%B5%D0%BF%D0%BB%D0%B0-%D0%BE%D1%81%D0%B5%D0%BB%D1%8F-%D0%BE%D1%89%D0%B0%D0%B4%D0%BD%D0%B8%D0%B9-%D0%B4%D1%96%D0%BC/
https://saee.gov.ua/uk/consumers/tepli-kredyty
[17] https://saee.gov.ua/uk/consumers/tepli-kredyty

Individuals who have already implemented some upgrades may believe that further improvements would not significantly increase energy efficiency or other desired outcomes (Fowlie et al., 2018; Peñasco and Anadón, 2023). Additionally, consumers may be content with the current state and see no immediate need for additional changes. Homeowners might hesitate to tackle additional projects if they involve substantial inconvenience, technical challenges, or lack of professional advice (Bagaini et al., 2020).

The average investment costs of EE measures implemented by Uzhhorod follow an upward trend towards 2018. (See Figure 3.4.)

Figure 3.4.: Price of EE measures by year (UAH), sample n=500.



The second economic crisis in Ukraine, which began at the end of 2014, accelerated the prices of materials and installation work. A significant increase was observed in 2016 and 2017 for nearly all measures, except for double-glazed windows, cavity wall insulation, and boilers, which experienced a slight price rise. These changes in prices are closely linked to currency fluctuations. The local currency, the hryvnia, faced triple depreciation in the Euro equivalent from 2013 to 2016; the hryvnia then remained at generally the same rate during the next few years. For example, in 2014, one Euro was worth 16.05 hryvnias; in 2016, it went to 27.96 hryvnias in 2016 and to 29.14 hryvnias in 2017. The price increase for energy-efficient measures was accompanied by a growth in demand, driven by the escalation of energy prices. The blue line in Figure 3.4. corresponds to the gas price changes, that is mirroring an increase in prices of renovations.

The price range for different energy-efficient upgrades varies from household to household. For example, the maximum investments for three favored types of retrofits are as follows: 100,787 UAH (3,382 EUR) for cavity wall insulation, 41,588 UAH (1,396 EUR) for double-glazed windows, and 51,251 UAH (1,720 EUR) for boiler replacement. (See Table 3.4.) Prices for installed measures include the price of materials and installation work.

Table 3.4.: Prices of EE measures, sample n=500.

Energy-efficient measures	N	Mean, UAH	Std. Dev.	Min, UAH	Max, UAH
Double-glazed windows	213	8,435	4506	1,525	41,588
Cavity wall insulation	131	16,731	11556	4,158	100,787
Boiler	53	9,935	6745	1,361	51,251
Attic insulation	50	15,309	10865	1,030	51,509
Thermoregulator	16	4,421	2639	1,012	8,744
Triple-glazed windows	22	16,233	15265	4,121	61,749
Hot water pipes insulation	22	5,554	8137	1,525	41,001
Thermostat	18	4,284	3204	1,949	11,692
Basement insulation	7	8,035	4951	2,060	15,375
Other EE measures	4	13,377	10136	4,112	27,815
Electric heater	2	2,436	689	1,949	2,923

Note: Prices in real terms adjusted to June 2019.

When analyzing this sample, it is essential to observe the perception of the average price of energy-efficient measures from the aspect of home size. For instance, when considering the most popular choice EE measures, the average cost of double-glazed windows for a home of 87 m^2 is 8,435 UAH (EUR). In such homes, which typically have 3.2 rooms, the average price of one double-glazed window can be calculated as 2,636 UAH (88 EUR), assuming one window per room. Investing in triple-glazed windows increases costs, with an average price of 16,233 UAH (545 EUR) for a home of 81 m^2. The price per window is 5,073 UAH (170 EUR). According to calculations by the State Agency for Energy Efficiency (SAEE), installing double-glazed windows, which typically range in price from 800 to 1,500 UAH per 1 m^2, can significantly reduce heating expenditures.[18]

Cavity wall insulation is the most expensive measure, costing 16,731 UAH (561 EUR) for a home with an average size of 90 m^2. The price per square meter corresponds to 6.2 EUR. On the other hand, attic wall insulation has an average investment cost of 15,309 UAH (514 EUR) for the square footage of 109 m^2, with a lower price per square meter at 5 EUR. It is important to highlight the specific technique employed for cavity wall insulation in multi-family apartments in Uzhhorod and across Ukraine. In these cases, households residing in multi-family houses typically insulate only the north-facing wall or corner of the house, depending on the location of their particular apartment. This insulation process is carried out individually, household by household, or through agreements involving multiple households. (Please refer to Figure 3.5. for visual representation.)

Figure 3.5.: Wall insulation in multi-family homes, Uzhhorod, Ukraine.

[18] https://saee.gov.ua/en/consumers/energozberezhenya-v-pobuti

Achieving full enveloping in multi-family homes requires the involvement of the homeowners association and the agreement of most apartment owners. However, it is crucial to acknowledge that such full enveloping of the entire house is not observed within this sample. Instead, it is primarily represented by single-family homes.

During the study period of 10 years, almost one-third of households implemented two EE measures, with an average cost of 17,571 UAH (590 EUR). Around 14% of residents installed three EE measures (14%), spending 26,202 UAH (879 EUR). A minority of households (4%) invested in four measures, paying 37,616 UAH (1,262 EUR), while the remaining 1% made five EE upgrades, with an average cost of 44,113 UAH (1,480 EUR). The average price for one EE upgrade corresponds to 7,779 UAH (261 EUR), and this choice is made by 24% of residents.

5. Econometric model and data analysis

Understanding the drivers of adopting energy-efficient measures can emanate tremendous value for policymakers. Knowledge of the factors that drive the adoption of energy-efficient measures is crucial for creating more effective and inclusive energy policies. By taking into account the varied needs and behaviors of different household types, policymakers can design targeted initiatives fostering a broader and more successful adoption of energy-efficient measures. As a result, society can move closer to achieving its sustainability goals and reducing energy consumption. Real-world data from the analysis can contribute to setting realistic targets for energy-saving initiatives. This data can also be utilized to monitor the effectiveness of policies in different countries and make necessary adjustments. By keeping track of trends in the housing industry, policymakers can forecast future energy demands and plan the adoption of new legislation in the construction sector. Policymakers can integrate energy efficiency adoption patterns into long-term energy planning, facilitating the development of future energy goals and policies. Lastly, it can help to track the evolution of the factors that trigger the implementation of energy-efficient measures to develop future successful policies.

To estimate what triggers households to invest in energy-efficient measures, a sample of 370 dwellings is used. (See Table 3.2) The interviewers randomly selected these households from the housing stock of Uzhhorod, which includes single-family houses, multi-family apartments, and semi-detached homes. The distribution of the sample aligns with the housing distribution in the city, with single-family houses accounting for 39%, multi-family apartments comprising 58%, and semi-detached homes representing 2%. (See Table 3.5.)

Table 3.5.: Descriptive statistics, sample n=370.

Variables	Description of variables	Mean, %			T-test	
		Full sample	At least one EE measure done	No EE measures done	T-test of the null that the means are the same	
		n=370	n=228	n=142		
		D=E+F	E	F	E vs F	
Socio-demographics						
income (UAH)	total monthly family income (after tax)	6,663.3	6,309.8	7,230.9	2.655	***
Inc1	dummy for income category ≤4251 UAH	38%	41%	35%	-1.208	
Inc2	dummy for income category ≤8751 UAH	50%	51%	49%	-0.427	
Inc3	dummy for income category ≤12501 UAH	10%	8%	14%	1.912	*
Inc4	dummy for income category >12501 UAH	1%	0.6%	3%	1.931	*
workabroad	dummy if one of family members works abroad	45%	51%	35%	-3.196	***
loweduc	dummy for middle education (school)	15%	21%	6%	-4.014	***
profeduc	dummy for professional-technical education	22%	20%	25%	1.010	
higheduc	dummy for higher education (BSc et al.)	62%	59%	68%	1.706	*
child	dummy for having a child	59%	68%	46%	-4.093	***
kids0_5	dummy for kids below 5 years	9%	13%	4%	-3.007	***
kids6_12	dummy for kids between 6-12 years	16%	21%	9%	-2.934	***
kids13_17	dummy for kids between 13-17 years	25%	27%	20%	-1.471	
kids18plus	dummy for kids older than 18 years	31%	35%	25%	-2.117	**
elderly	dummy for person over 65 living in home	31%	30%	31%	0.146	
homestay	dummy for person who stays at home during the day during heating season	42%	43%	42%	-0.188	
benefit	dummy for receiving benefit	7%	7%	6%	-0.253	
subsidy	dummy for receiving subsidies	15%	14%	15%	0.083	
Dwelling characteristics						
SFhome	dummy single-family house	39%	40%	37%	-0.579	
multifamily	dummy multi-family building apartment	58%	58%	59%	0.239	
semi-detached	dummy semi-detached house	2%	2%	4%	1.072	
hhsize	household size (n)	3.3	3.6	3.0	-4.214	***
agehouse	age of the house (years)	37.0	37.8	35.8	-0.830	
agehousemiss	dummy missing values of age of the house	12%	9%	17%	2.361	**
yearmovedin	year when family moved into the house	1992	1992	1991	-0.643	
squaremetres	size of the home (m^2)	83.2	88.4	74.8	-2.636	***
livrooms	number of rooms (excluding kitchen)	3.0	3.1	2.8	-2.754	***
dirtyarea	dummy for homes located in dirty/noisy areas	10%	11%	10%	-0.205	
leakinghome	dummy for homes with leaks from roof/dampness	17%	16%	20%	0.970	
sellintention	dummy if household planning to sell house	12%	10%	15%	1.358	
riskaverse	dummy for households that are not risk-takers	76%	77%	74%	-0.710	

*, **, and *** denote statistical significance at the 10%, 5%, and 1% level, respectively.
The T-test assumes unequal variances.

The studied sample represents households with an average total family income of 6,663 UAH after tax. This average income is considerably lower compared to the average total family income in the Zakarpattia region, which amounts to 16,181 UAH.[19] The disparity can be attributed to the prevalence of "grey" income in Ukraine[20] and potential errors in the official reporting by the State Statistic Service of Ukraine.[21] Additionally, the official statistical information does not encompass data on remittances sent by individuals working abroad. For instance, in 2019, remittances reached USD 11.9 billion, which increased to USD 12.1 billion in 2020.[22] In this sample, 45% of family members work abroad, increasing to 51% for households that have invested in at least one energy-efficient measure.

The number of children in the sample is comparable to the statistical data of the Zakarpattia region, with respective shares of 59% and 55%. The household size in the sample aligns with the demographic data, ranging from 3.3 to 3.5 individuals on average.[23] The houses and flats have a floor area similar to the official rates reported by the statistical office. The distribution of house types in the sample, with 39% single-family houses and 58% multi-family houses, is similar to that observed in Uzhhorod and corresponds to the overall housing stock in Ukraine (Emerson and Shimkin, 2015).

By utilizing this sample, a standard discrete choice probit model is used to estimate the factors that influence a household's choices to renovate. The sample preferences for various energy-efficient measures are presented in Table 3.6.

Among the 370 households in the sample, 62% invested in at least one energy-efficient measure. The most preferred measures were double-glazed windows, cavity wall insulation, and boiler replacement. Basement insulation and electric heater were the least favored measures among the households. Most families opted to invest in one or two EE measures, with a smaller proportion choosing to do three or four upgrades.

Descriptive statistics on prices of EE measures, the year of implementation, and the order of implementation are provided in Table 3.A., Table 3.B., and Table 3.C. below.

[19] http://uz.ukrstat.gov.ua/statinfo/vitrat/2020/struct_resurs_2010-2019.pdf
[20] https://www.bbc.com/ukrainian/features-56496903
[21] https://life.znaj.ua/366626-serednya-zarplata-v-ukrajini-derzhstat-rahuye-nepravilno-kushch
[22] https://zakordon.24tv.ua/skilki-groshey-perekazali-za-kordonu-ukrayinu-ukrayina-novini_n1721831
[23] http://uz.ukrstat.gov.ua/statinfo/vitrat/2021/harakter_dom_2010-2020.pdf

Table 3.6.: Share of EE measures, sample n=370.

Energy-efficient measures	Mean, %
Double-glazed windows	47
Cavity wall insulation	18
Boiler	12
Attic insulation	9
Thermoregulator	10
Triple-glazed windows	5
Hot water pipes insulation	5
Thermostat	4
Basement insulation	1
Electric heater	1
At least one of all EE measures done (ANYRENO)	62
At least one of the most cost- and energy-effective EE measures done (RENO3)	56
One EE measure	26
Two EE measures	24
Three EE measures	8
Four EE measures	3
Five EE measures	0

Table 3.A.: Descriptive statistics. Prices of EE measures, sample n=370.

Energy-efficient measures	N	Mean, UAH	Min, UAH	Max, UAH	Mean, EUR	Min, EUR	Max, EUR
Double-glazed windows	159	8,520	1,541	41,588	286	52	1,396
Cavity wall insulation	67	17,539	4,636	82,002	589	156	2,752
Boiler	41	10,357	1,361	51,251	348	46	1,720
Attic insulation	34	15,967	1,030	51,509	536	35	1,728
Thermoregulator	8	4,340	1,872	8,744	146	63	293
Triple-glazed windows	16	13,786	4,121	51,457	463	138	1,727
Hot water pipes insulation	20	5,749	1,525	41,001	193	51	1,376
Thermostat	13	4,185	1,949	11,692	140	65	392
Basement insulation	3	4,112	2,060	5,151	138	69	173
Electric heater	2	2,436	1,949	2,923	82	65	98

Table 3.B.: EE measures by year, sample n=370.

Energy-efficient measures	N	Mean	Std. Dev.	Min	Max
Double-glazed windows	173	2014	1.674	2008	2018
Cavity wall insulation	67	2016	1.027	2013	2018
Boiler	45	2017	1.314	2013	2018
Attic insulation	34	2015	1.175	2012	2018
Thermoregulator	38	2018	0.714	2015	2018
Triple-glazed windows	18	2016	1.425	2013	2018
Hot water pipes insulation	20	2015	1.182	2013	2018
Thermostat	13	2018	0.439	2017	2018
Basement insulation	3	2015	0.577	2015	2016
Electric heater	2	2018	0.000	2018	2018

Table 3.C.: Order of implemented EE measures, sample n=370.

Energy-efficient measures	First EE measure, %	Second EE measure, %	Third EE measure, %	Fourth EE measure, %	Fifth EE measure, %
Double-glazed windows	61.7	18.8	15.9	7.7	50.0
Cavity wall insulation	16.3	19.6	6.8	7.7	
Boiler	6.6	17.3	11.4	15.4	
Attic insulation	5.7	9.0	15.9	15.4	
Thermoregulator	1.8	15.8	22.7	30.8	
Triple-glazed windows	4.0	5.3	4.6		
Hot water pipes insulation	3.1	5.3	9.1	15.4	
Thermostat		6.0	6.8	7.7	50.0
Basement insulation	0.4	0.8	2.3		
Electric heater		1.5			
Total N (100%)	227	133	44	13	2

A probit model specification is applied with this sample to provide an estimation of questions: (iv) which households are more likely to invest in at least one EE measure - ANYRENO; (v) which households are more likely to invest in the most energy-effective measures, such as the thermal insulation of walls and attics and double-/triple-glazed windows - RENO3.

Determining households' choices to implement energy-efficient upgrades involves the consideration of socio-demographics, dwelling characteristics, financial initiatives, and behavioral motivation as key variables. Previous studies, including Jakob (2007), Urban and Sčasny (2012), Ameli and Brandt (2015a), and Trotta (2018b), have confirmed the impact of these factors.

In addition to the standard variables of interest, the analysis incorporated additional factors that could influence household behavior. To account for the significant share of "grey" income and the substantial contribution of remittances to family income sources in Ukraine, the dummy variable "workabroad" was introduced in the analysis. This dummy variable assumes a value of 1 if any family members worked abroad during the survey year (2019) and 0 otherwise. Since data on income is only available from the month when the survey was conducted (June 2019), controlling for education levels can help capture the disparity in the interest to invest in energy-efficient measures among different income groups. In Ukraine, socially vulnerable households receive government subsidies to cover part of their utility payments. Due to energy price jumps, the number of subsidies provided to households increased to 42% in 2016 compared to 2015.[24] However, subsidies are considered a discouraging factor for energy savings (Alberini and Umapathi, 2021). As a result, households may lack motivation to invest in energy-efficient measures.[25,26] To account for this, the dummy "subsidy" was introduced. This variable takes the value of 1 if the household received a subsidy during the study period and 0 otherwise. In addition, Ukrainian households may be eligible for discounted utility payments if they hold certain "benefits." Depending on the type of benefit, families can receive a discount ranging from 25% to 100%. Eligible beneficiaries include individuals with disabilities, veterans, families who have lost their breadwinners, Chornobyl decontamination workers, and others.[27] Concerning this factor, the dummy "benefit" was defined as 1 if the household received this allowance and 0 otherwise. To gain insights into residents' behavior regarding heating habits, the dummy variable "homestay" was introduced. This variable takes a value of 1 if some family members stay home during the day throughout the heating season and 0 otherwise. Consumers may exhibit

[24] https://www.slovoidilo.ua/2017/01/26/infografika/suspilstvo/yak-zminylysya-masshtaby-naraxuvannya-subsydij-iz-2014-po-2016-rik
[25] https://voxukraine.org/en/9-facts-about-the-system-of-subsidies-in-ukraine-and-the-real-gas-prices-for-the-population/
[26] https://zn.ua/ukr/ECONOMICS/diyucha-sistema-subsidiy-niyak-ne-motivuye-naselennya-ekonomiti-na-spozhivanni-gazu-213192_.html
[27] https://zakon.rada.gov.ua/laws/show/409-2014-%D0%BF#Text

uncertainty regarding the benefits of energy-efficient investments in terms of energy savings and comfort. Consequently, they may display a higher risk aversion toward implementing these technologies (Farsi, 2010; Fischbacher et al., 2020). To capture this aspect, the questionnaire included relevant questions, based on which the dummy variable "riskaverse" was defined. This variable takes a value of 1 if the respondent is less likely to take risks and 0 otherwise. Several authors have highlighted a link between the adoption of energy-efficient measures and the potential increase in property value, which can enhance its marketability in the future (Wilson et al., 2015). In order to account for this aspect, the study incorporated the use of the dummy variable "sellintention." This variable assigns a value of 1 to individuals who intend to sell their property in the near future and 0 otherwise.

The households in the analyzed sample have an average after-tax family income of 6,663 UAH. The sample mean is much lower than the average total family income in the Zakarpattia region, corresponding to 16,181 UAH.[28] Such difference is possible due to the large share of "grey" income in Ukraine[29] and potential errors in official reporting by the Statistical Office of Ukraine.[30] Furthermore, official statistical information does not include information on remittances sent from people working abroad. For example, in 2019, this amount reached 11.9 billion USD, and 12.1 billion USD in 2020.[31] In this sample, the share of family members working abroad is 45%, which is higher for households that invested in at least one EE measure, at 51%. The number of children in the sample is comparable to the statistical data of the Zakarpattia region, with shares of 59% and 55%. The household size of the sample corresponds to the demographical data, which is 3.3 to 3.5, respectively.[32] The distribution between the house types in the sample is 39% to 58%, similar to those in Uzhhorod and the housing stock of Ukraine (Emerson and Shimkin, 2015).

Following previous studies in this field, probit models were employed for the analysis (Gamtessa, 2013; Hrovatin and Zorić, 2018; Trotta, 2018a, Fischbacher et al., 2020). The estimated probit model explains factors affecting the following two dependent variables:

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[28] http://uz.ukrstat.gov.ua/statinfo/vitrat/2020/struct_resurs_2010-2019.pdf
[29] https://www.bbc.com/ukrainian/features-56496903
[30] https://life.znaj.ua/366626-serednya-zarplata-v-ukrajini-derzhstat-rahuye-nepravilno-kushch
[31] https://zakordon.24tv.ua/skilki-groshey-perekazali-za-kordonu-ukrayinu-ukrayina-novini_n1721831
[32] http://uz.ukrstat.gov.ua/statinfo/vitrat/2021/harakter_dom_2010-2020.pdf

- RENO3 - implementation of at least one of the following three EE measures: cavity wall insulation, attic insulation, and double-/triple-glazed windows, which are the most valuable in terms of energy- and cost-saving potential, and
- ANYRENO - implementation of at least one of the EE measures included in RENO3 *plus* basement insulation, thermoregulator and thermostat; replacement of a boiler; installation of electric heater; and other measures that the respondent implemented.

Several reasons compel the estimation of potential outcomes for these types of renovations - double-glazed windows, cavity, and attic insulation (RENO3). First, these upgrades are usually implemented together to ensure the entire building is enveloped and the total possible energy reduction effect is achieved. Second, these measures are commonly used in practice, and the government frequently provides financial incentives for their adoption. Third, these renovations are the most studied in this field and can reduce gas consumption. (Peñasco and Anadón, 2023). However, the effect of reduction can differ and is very heterogeneous, depending on the combination of measures, implementation timeframe, and order of implementation. Cavity wall insulation, when done alone, can save gas usage by 10.5%; when combined with a boiler, the savings can reach 13.5%. On the contrary, when combining these measures with loft insulation, the effect decreased to 11.9% (Adan and Fuerst, 2016). Another study confirms that cavity wall insulation and new condensing boilers can save gas use between 13.5-19.5%. The loft insulation reduction effect can be around 8.4-12.2% (Wyatt, 2013).

Estimating the impact of at least one renovation (ANYRENO) allows for a more comprehensive assessment, considering the diverse range of measures implemented at various times and in different orders. The analysis incorporates univariate probit regression for cavity and attic insulation, installation of double-glazed windows, triple-glazed windows, and replacement of a boiler. Given the limited number of observations for basement insulation, thermoregulator and thermostat; installation of electric heater; and other measures that the respondent implemented univariate regression did not yield statistical significance. The models include multiple explanatory variables to accommodate the diversity in household decisions regarding renovation, drawing from previous studies as a reference point.

Additionally, to estimate the variability in the number of renovations undertaken negative binomial regression is employed. The variable of interest is RENOCOUNT. It is a count variable ranging from 1 to 5, indicating the number of renovations for those who have undertaken some energy efficiency renovations, and zero otherwise. This can help to define the factors influencing renovation intensity.

6. Results

To establish the theoretical connection to the expected impacts of adopting energy-efficient upgrades, it's crucial to examine the analysis from the viewpoints of both the demand and supply sides. Social-demographic factors are primarily associated with the demand side because they reflect the characteristics and attributes of individuals or households that influence their preferences, income, status, household composition, behaviors, and decisions related to adopting energy-efficient measures. Dwelling characteristics are generally considered supply-side in the context of energy-efficient measure implementation. This is because the type of house and number of rooms is a structural attribute influencing the availability and feasibility of implementing specific energy-efficient measures. Table 3.7. and 3.8. display the average marginal effect of the probit regressions analysis separately for socio-demographics and dwelling characteristics.

Table 3.7.: Probit average marginal effects, socio-demographics, sample n=370.

	ANYRENO			RENO3		
Variables	Average marginal effect			Average marginal effect		
Socio-demographics						
Inc1 (income ≤ 4,251 UAH)	0.189	**	(0.084)	0.184	**	(0.079)
Inc2 (income ≤ 8,751 UAH)	0.163	**	(0.081)	0.185	**	(0.076)
workabroad	0.070	*	(0.052)	0.089	*	(0.050)
child	0.132	***	(0.051)	0.190	***	(0.047)
profeduc	-0.015		(0.062)	-0.006		(0.059)
loweduc	0.222	***	(0.077)	0.265	***	(0.078)
homestay	0.003		(0.052)	0.031		(0.050)
benefit	0.002		(0.100)	0.021		(0.096)
subsidy	0.008		(0.072)	-0.009		(0.069)
N	*370*			*370*		
Correctly classified	*66.49%*			*67.57%*		
LR chi2(19)	*43.15*			*27.74*		
Prob > chi2	*0.000*			*0.001*		
Pseudo R2	*0.088*			*0.055*		
Log likelihood	*-224.801*			*-239.475*		

Standard errors in parentheses
, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

The results indicate a positive probability of investments in ANYRENO and RENO3 among low- and mid-income households, particularly those with lower education levels and having a child and working abroad. The "workabroad" dummy is most likely to drive income. Among families earning income below UAH 4,251, a notable 63% have members working abroad and dwellings with a total budget of up to UAH 8,751, and a considerable 42% work abroad. The "grey" earnings can prove the ability of low-income households to invest in home upgrades. It is important to note that a study incorporates income data from a single month at the time of the survey (June 2019). This limited time frame might not provide a comprehensive or accurate representation of income information.

The findings from dwelling characteristics suggest that households residing in multi-family apartments, having larger number of rooms and larger household size are more prone to adopt ANYRENO or RENO3 measures. (Table 3.8.)

Table 3.8.: Probit average marginal effects, dwelling characteristics, sample n=370.

	ANYRENO			RENO3		
Variables	Average marginal effect			Average marginal effect		
Dwelling characteristics						
multifamily	0.110	*	(0.061)	0.135	**	(0.062)
semi-detached	-0.079		(0.161)	-0.127		(0.171)
livrooms	0.049	**	(0.025)	0.061	**	(0.026)
hhsize	0.072	***	(0.020)	0.053	**	(0.021)
agehouse	0.001		(0.002)	0.001		(0.002)
agehousemiss	-0.104		(0.097)	-0.151		(0.100)
yearmovedin	0.003		(0.002)	0.003		(0.002)
riskaverse	0.042		(0.057)	0.048		(0.058)
sellintention	-0.082		(0.076)	-0.107		(0.078)
N	*370*			*370*		
Correctly classified	*64.32%*			*64.05%*		
LR chi2(19)	*30.02*			*28.75*		
Prob > chi2	*0.0004*			*0.0007*		
Pseudo R2	*0.0609*			*0.0567*		
Log-likelihood	*-231.36616*			*-238.9679*		

Standard errors in parentheses
, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

When evaluating the effects from the demand-supply perspective, it is essential to understand that these categorizations are not fixed, and some characteristics might have aspects that relate to both the demand and supply sides. Furthermore, it is crucial to consider the significance of complex interactions between the variables.

Table 3.9. reports the average marginal effect for full set of estimates including both socio-demographics and dwelling characteristics. It is calculated as an average for each household that implemented at least one EE measure - ANYRENO or one of the three most energy valuable EE measures - RENO3.

Table 3.9.: Probit average marginal effects, sample n=370.

	ANYRENO			RENO3		
Variables	Average marginal effect			Average marginal effect		
Socio-demographics						
Inc1 (income ≤ 4,251 UAH)	0.224	***	(0.078)	0.228	***	(0.082)
Inc2 (income ≤ 8,751 UAH)	0.200	***	(0.073)	0.182	**	(0.077)
workabroad	0.091	*	(0.050)	0.072		(0.052)
child	0.103	*	(0.061)	0.032		(0.064)
profeduc	0.007		(0.059)	0.008		(0.061)
loweduc	0.268	***	(0.080)	0.219	***	(0.077)
homestay	0.009		(0.051)	-0.030		(0.053)
benefit	0.021		(0.094)	0.009		(0.099)
subsidy	-0.040		(0.069)	-0.022		(0.071)
Dwelling characteristics						
multifamily	0.136	**	(0.060)	0.174	***	(0.062)
semi-detached	-0.022		(0.151)	-0.061		(0.164)
livrooms	0.059	**	(0.025)	0.070	***	(0.026)
hhsize	0.044	*	(0.026)	0.046	*	(0.027)
agehouse	0.002		(0.002)	0.001		(0.002)
agehousemiss	-0.054		(0.094)	-0.114		(0.098)
yearmovedin	0.005	**	(0.002)	0.004	**	(0.002)
riskaverse	0.047		(0.055)	0.052		(0.057)
sellintention	-0.083		(0.075)	-0.103		(0.077)
N	*370*			*370*		
Correctly classified	*65.95%*			*65.68%*		
LR chi2(19)	*62.66*			*52.32*		
Prob > chi2	*0.000*			*0.000*		
Pseudo R2	*0.127*			*0.103*		
Log likelihood	*-215.047*			*-227.183*		

Standard errors in parentheses
, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

According to socio-demographics, five factors influence the decision to renovate: income level, if someone in the household worked abroad, child availability, and education degree. The results of building characteristics show a relationship with the type of house, the number of living rooms, the household size, and the year when the family moved into a home.

The findings remain consistent regarding the family profile when comparing results with the previous regressions in Table 3.7. and 3.8. When including a full set of estimates, the availability of a child is not associated with investments in RENO3. On the other hand, the year of moving into the house/apartment is getting statistical significance.

On average, the probability of implementing ANYRENO by the low-income households is more likely to be around 22% higher in contrast to the mid- and high-income households. A similar trend is for investments in RENO3. Families with a medium income are 20% more likely to implement at least one EE measure, and 18% are more likely to invest in one of the three most energy-efficient and energy-saving measures than high-income households. These outcomes can be associated with the need of low- and mid-income residents to insulate their homes to reduce high energy bills.[33] It might indicate a need to improve the house condition, which might be poorly maintained or affected by the construction materials' aging. At the same time, the income effect should be interpreted cautiously since data is available only from the year of conducting the study (June 2019). It thus can lead to an associated measurement error. In addition, households have a low inclination to provide authentic information on income due to the high level of "grey" income in Ukraine.

Households in which some family members work abroad are also positively correlated with investments in at least one energy-efficient measure (ANYRENO). This finding aligns with the income categories' results, as mainly working migrants come from lower-income households.

On average, the probability of investing in ANYRENO is more likely to be 27% higher for households with a lower level of education in comparison to respondents with higher levels of education. Likewise, for RENO3, the likelihood to invest is more likely to be 22% higher for low-educated people, in contrast to those who are moderately and highly educated. On the other hand, individuals with a high level of education have greater competence in obtaining expertise to understand the effects of energy efficient measures, which might discourage them from making

[33] The Fisher's exact tests confirms significant association between low- and mid-income categories. The Chi-squared test after regression suggests that the coefficient of inc1 is not different from the coefficient of inc2.

investments due to low rates of return. Additionally, highly educated respondents are more likely to have a higher salary, which suggests that they can afford to pay the costs of utilities or that their homes were previously in a better state of repair and did not require renovations. Other papers evidenced similar findings (Gamtessa, 2013; Goncharuk, 2013).

For ANYRENO, the results suggest a higher likelihood of implementing EE measures for families with at least one child than those without children (according to the number of children reported in the survey conducted in 2019). The probability is more likely to be 10% higher for those invested in any of the listed energy-efficient measures (ANYRENO), but it is not significant for RENO3.

Table 3.10. presents the results of the probit analysis, where the child dummy variable has been substituted with various age categories for children. Additional checks suggest that families with adult children are 10% more inclined to RENO3. Households with children from 6-12 years old have a probability to invest in RENO3 around 16%, then those with children in other age categories and childless people. For ANYRENO, this effect is also positive for children under 5 years (18%) and between 6-12 years (22%). These results can presume the importance of the warm, comfortable, and healthy environment parents aim to create for children to reduce the possibility of related health risks connected to respiratory diseases. Equivalent findings were concluded based on a British household survey, where around one-third of households with children below 16 adopted energy-efficient measures (Dolšak et al., 2007). Additionally, starting from the age of 6-12 and above, children usually sleep in a separate room, which, on average, is required to be heated more. The study of Milne and Boardman (2000) agreed that households with kids below age of 16 were keeping temperature higher for 0.7°C. These findings correlate with the positive results of the analysis of the number of rooms and household size.

It has not been confirmed that the receipt of a subsidy or benefit influenced the probability of renovation, most likely due to the constraints of a small sample size. Still, this discovery may suggest that subsidies do not serve as a strong incentive for households to pursue renovations, in contrast to the benefits.

Among dwelling characteristics for both variables of interest results states that households living in multi-family dwellings are more likely to invest in energy-efficient measures than those living in single-family or semi-detached homes. This probability effect is stronger for RENO3. Households living in apartments are 17% more likely to invest in measures with higher cost-saving and energy-efficient effects than those residing in single-family/semi-detached homes. For ANYRENO, the probability is 14%. This result can be associated with investment costs since financing these insulation measures for single-family houses requires higher funds in comparison to apartments. The supporting conclusion of the importance of investment costs was also made based on other studies (e.g. Dolšak et al., 2020).

The probability of investment in energy-efficient measures increases with the number of rooms. Each additional room is more likely to increase the probability of investing in energy-efficient measures by 7% for RENO3 and 6% for ANYRENO. Presumably, this result can be correlated with the number of windows since each room usually has a window that was replaced. Plus, the number of rooms in apartments is larger than in houses of the same square footage, which might confirm the association with a higher probability of implementing measures in multi-family houses with a larger number of rooms.

Household size also increases the probability of investing in EE measures. The marginal effect is very close for both variables of interest ranging at 5%. This outcome can be associated with a positive probability of investing in a family with a child and a larger number of rooms.

The study revealed that the year of moving into an apartment or house positively impacts the likelihood of implementing renovation measures. It suggests that the sooner a family moves into the house/apartment, the more likely it is that they will start to do renovations compared to those living in their house for a longer period. The probability is relatively low for both dependent variables, corresponding to 0.5%. This finding might indicate the behavior of people when the homeowner is changed. In contrast, the age of the house was not found to be statistically significant in this regard. Even though findings of Gamtessa (2013) emphasized a significant correlation for houses constructed after 1991. When moving into a new home, people like to modernize the dwelling according to their preferences, including investments in various energy-efficient measures and traditional repair work. The lack of significance in the "agehouse" variable aligns with the observation that the "yearmovedin" holds greater importance. It supports the notion that families residing in a house for an extended duration tend to have lower intentions of making changes, particularly among the older generations.

Motivation to renovate can also be driven by an increase in the dwelling's value or a will to make changes to the home, looking to the future plan to stay in the house, especially for young people or couples. An analogous finding was presented as a result of a survey among British households by Energy Saving Trust.[34] The results of this analysis have not confirmed this theory; "sellintention" did not exhibit statistical significance. The research did not reveal a significant relationship between risk aversion and adopting energy-efficient measures, likely attributable to the relatively small proportion of households willing to take risks. The results should be interpreted with caution in view of the extreme energy price hikes and geopolitical causes, even though the findings are consistent with previous studies. Table 3.10. displays the outcomes of the probit analysis, replacing the child dummy with different age categories of children.

Table 3.10.: Probit average marginal effects with kids age dummies, sample n=370.

	ANYRENO			RENO3		
Variables	Average marginal effect			Average marginal effect		
Socio-demographics						
Inc1 (income ≤ 4,251 UAH)	0.260	***	(0.079)	0.249	***	(0.083)
Inc2 (income ≤ 8,751 UAH)	0.248	***	(0.075)	0.217	***	(0.079)
workabroad	0.107	**	(0.050)	0.080		(0.052)
kids0_5	0.176	*	(0.105)	0.095		(0.099)
kids6_12	0.224	***	(0.076)	0.156	**	(0.076)
kids13_17	0.013		(0.064)	0.042		(0.066)
kids18plus	0.093		(0.058)	0.100	*	(0.060)
profeduc	0.007		(0.058)	0.015		(0.061)
loweduc	0.243	***	(0.080)	0.210	***	(0.078)
homestay	0.000		(0.051)	-0.023		(0.053)
benefit	0.000		(0.094)	-0.009		(0.099)
subsidy	-0.029		(0.068)	-0.016		(0.071)
Dwelling characteristics						
multifamily	0.126	**	(0.060)	0.164	***	(0.062)
semi-detached	-0.048		(0.149)	-0.075		(0.162)
livrooms	0.060	**	(0.025)	0.071	***	(0.026)
hhsize	0.023		(0.028)	0.012		(0.029)
agehouse	0.001		(0.002)	0.001		(0.002)
agehousemiss	-0.071		(0.093)	-0.121		(0.098)
yearmovedin	0.004	*	(0.002)	0.004	*	(0.002)
riskaverse	0.042		(0.055)	0.047		(0.057)
sellintention	-0.081		(0.075)	-0.109		(0.077)
N	*370*			*370*		
Correctly classified	*68.84%*			*64.05%*		
LR chi2(19)	*71*			*59.6*		
Prob > chi2	*0.000*			*0.000*		
Pseudo R2	*0.144*			*0.115*		
Log likelihood	*-210.878*			*-224.337*		

Standard errors in parentheses
, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

[34] https://www.yumpu.com/en/document/view/44329336/trigger-points-energy-saving-trust

The characteristics of the families concerning various socio-demographic factors align with the outcomes of the primary regression presented in Table 3.9. utilizing the child dummy variable. These households typically have low education, reside in multi-family homes with more rooms, have family members working abroad, and fall within the income range categorized as low to medium. Using a child dummy in main regression in Table 3.9. instead of categorizing children by age was influenced by the dynamic nature of children's ages during the ten-year implementation period of the energy-efficient measures. Given that children could transition from one age category to another within the study duration, the results from the regression presented in Table 3.10. should be interpreted with caution.

To portray what drive households towards implementation of the particular type of renovations the univariate probit was applied. This would also provide an additional check how different households are in terms of socio-demographical and dwelling characteristics and if the results mirror the main regression presented in Table 3.9.

Results presented in Table 3.11. suggest that low education is correlated mainly with installing double-glazed windows, which is the most numerous types of renovation households implement. Low-income households are 20% more likely to invest in double-glazed windows. Investments in double-glazed windows are also linked to working abroad and residing in multi-family apartments, with respective probabilities of 11% and 15%.

Families with at least one child are 7% more likely to invest in triple-glazed windows or replace new boilers (10%). When considering the wall's insulation or an attic, the number of living rooms and the year the family moved into the house are important determinants of the choice to renovate.

Risk aversion becomes a significant factor when contemplating the installation of triple-glazed windows in a residential setting, with a probability range of 7%. This might be correlated with comparatively higher price of these types of windows in comparison to double-glazed.

These results confirm the main findings of the earliest regression analysis of ANYRENO and RENO3. Table 3.11. excludes the estimation results concerning basement and hot pipe insulation, thermostat, and thermoregulator installations due to the limited number of renovations associated with these measures.

Income levels did not produce statistically significant estimates, which could imply that income becomes a significant factor only when considering a group of renovations collectively.

Table 3.11.: Univariate probit average marginal effects, sample n=370.

Variables	CAVITY Average marginal effect		ATTIC Average marginal effect		DOUBLE−GLAZED Average marginal effect		TRIPLE−GLAZED Average marginal effect		BOILER Average marginal effect	
Socio−demographics										
Inc1 (income ≤ 4,251 UAH)			0.044	(0.054)	0.137	(0.087)			0.008	(0.062)
Inc2 (income ≤ 8,751 UAH)			0.033	(0.050)	0.089	(0.082)			0.066	(0.057)
workabroad	0.061	(0.041)	−0.036	(0.033)	0.110 **	(0.058)			−0.014	(0.035)
child	−0.021	(0.042)			0.039	(0.053)	0.073 **	(0.031)	0.101 ***	(0.037)
profeduc			0.044	(0.036)	−0.026	(0.066)	−0.037	(0.033)	0.030	(0.043)
loweduc			0.040	(0.042)	0.202 ***	(0.075)	−0.015	(0.030)	0.056	(0.046)
homestay					−0.002	(0.054)				
benefit					0.110	(0.102)				
subsidy					−0.027	(0.073)	0.021	(0.027)		
Dwelling characteristics										
multifamily	−0.001	(0.050)			0.145 **	(0.064)				
semidetached	−0.041	(0.146)			−0.110	(0.181)				
livrooms	0.041 **	(0.019)	0.033 ***	(0.011)	0.035	(0.029)				
hhsize					0.037	(0.027)				
agehouse	0.000	(0.001)			0.000	(0.002)	0.000	(0.001)		
agehousemiss	−0.122	(0.086)			−0.080	(0.103)	−0.037	(0.051)		
yearmovedin	0.003 *	(0.002)	0.002 *	(0.001)	0.003	(0.002)				
riskaverse	0.069	(0.048)			0.018	(0.002)	0.071 *			
sellintention					−0.074	(0.081)				
N	*370*		*370*		*370*		*370*		*370*	
Correctly classified	*82%*		*91%*		*63%*		*95%*		*88%*	
LR chi2(19)	*17.18*		*15.09*		*38.53*		*15.51*		*12.40*	
Prob > chi2	*0.0459*		*0.0348*		*0.003*		*0.03*		*0.0536*	
Pseudo R2	*0.0491*		*0.066*		*0.075*		*0.1078*		*0.045*	
Log likelihood	*−166.429*		*−106.004*		*−236.5*		*−64.21*		*−130.753*	

Standard errors in parentheses
, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

In the context of retrofit intensity, households within the studied sample invested from one to five measures. Representation is provided in Table 3.12.

Examining variation in the number of renovations undertaken contributes to understanding of the drivers behind renovation intensity. This probability is modeled with negative binomial regression. The variable of interest is RENOCOUNT. It is a count variable that can take values from 1 to 5 numbers of renovations, for those that did some EE renovations, and zero otherwise. To account for the substantial number of zeros, the likelihood ratio was employed to assess overdispersion. The output suggests that the negative binomial regression model is not suffering from an overdispersion issue, and the estimated alpha is significantly different from zero. [35]

Table 3.12.: Number of EE measures, sample n=370.

	Number of measures (RENOCOUNT)					
	1	2	3	4	5	0
Percent, %	25.7	24.3	8.1	3.2	0.3	38.4

Table 3.13.: Negative binomial average marginal effects on renovation intensity, sample n=370.

Variables	RENOCOUNT Negative binomial average marginal effects		
Socio-demographics			
Inc1 (income ≤ 4,251 UAH)	0.497	**	(0.228)
Inc2 (income ≤ 8,751 UAH)	0.544	**	(0.216)
workabroad	0.182		(0.122)
child	0.301	*	(0.156)
profeduc	0.076		(0.147)
loweduc	0.312	**	(0.152)
homestay	0.010		(0.123)
benefit	-0.139		(0.244)
subsidy	-0.174		(0.166)
Dwelling characteristics			
multifamily	0.089		(0.148)
semi-detached	0.191		(0.380)
livrooms	0.091	*	(0.054)
hhsize	0.087		(0.061)
agehouse	0.001		(0.004)
agehousemiss	-0.277		(0.248)
yearmovedin	0.009	*	(0.005)
riskaverse	0.193		(0.139)
sellintention	-0.200		(0.200)
N	*370*		
LR chi2(18)	*55*		
Prob > chi2	*0.000*		
Pseudo R2	*0.052*		
Log likelihood	*-497.226*		

, **, and * denote statistical significance at the 10%, 5%, and 1% level, respectively.*

[35] The likelihood ratio (LR) test for the null hypothesis that alpha is equal to zero. The test statistic (chibar2(01)) is zero, and the p-value is 0.500. This high p-value indicates that there is no evidence to reject the null hypothesis of alpha=0.

The results suggest that the number of renovations is larger in households with low and medium income. A low level of education also increases the expected retrofit intensity. The sample observation suggests that low educated households are those earning low and mid income are those implementing energy efficient measures. The number of rooms increasing the expected number of renovations as well as year when family moved in. These findings are in line with primary finding of the probit regression on renovation decisions.

Drawbacks of this analysis stem from the distinctive features of each energy-efficient measure within the study. Each upgrade possesses unique characteristics in terms of its energy-saving potential, investment costs, and required implementation time, thus it is not comparable. For instance, a single major retrofit could value more in energy-saving potential than two smaller renovation projects (Gamtessa, 2013).

7. Discussion

7.1. Cost-benefit analysis

Cost-benefit analysis is fundamental and widely used to determine whether renovations are economically justified and feasible. Nevertheless, previous studies suggest that family decisions are also driven by other factors such as improvement of comfort, noise reduction, aesthetics of the house, or increasing the value of the property (Dolšak, 2023). Primary cost-benefit analyses of implemented measures are presented in Table 3.14. It contains Net Present Value (NPV) values for energy-efficient renovations for households categorized by income, education levels, and home type. The discount rate used in calculations is 5.5%, and the observation period is 20 years, which aligns with the average period suggested by EU regulations. For the NPV calculation, maintenance costs are considered constant before and after investments and thus excluded. The EE measures include the costs of the materials and installation works.

The data suggests that investing in at least one EE renovation (ANYRENO) appears to be financially most beneficial for middle-income households compared to low-income and high-income households when considering 10% annual savings. Mid-income households can save 4,859 UAH over the lifetime of their energy-efficient renovations after accounting for the initial investment costs. Among low-income households, the NPV for RENO3 renovations is 23,718

UAH, taking into account an assumed annual savings rate of 20%. Energy-efficient investments yield similar NPV weights for both low- and professional-educated households, indicating these projects' viability and potential benefits, with the largest rate for highly educated families.

Table 3.14.: Net Present Value of EE investments, sample n=370.

	The initial cost of EE measures, UAH		NPV, UAH	
	ANYRENO	RENO3	ANYRENO, 10% of savings	RENO3, 20% of savings
Inc1 (income ≤ 4,251 UAH)	16,188	16,446	4,001	23,718
Inc2 (income ≤ 8,751 UAH)	19,660	20,300	4,859	29,276
Inc3 (income ≤12,501 UAH)	12,422	12,236	3,070	17,646
low education	17,271	16,605	4,269	23,948
professional education	16,265	16,743	4,020	24,147
high education	18,200	18,899	4,498	29,191
average household	17,540	17,896	4,335	25,810
single-family home	21,754	22,100	5,377	31,873
multifamily	14,445	14,865	3,570	21,439

Investments in energy-efficient technologies for households living in single-family homes are more beneficial than those in multi-family homes. The observed discrepancy arises from the distinct scope of renovations undertaken. Single-family homes generally undergo complete renovations, while multi-family apartment households often concentrate on specific enhancements, such as insulating only the north-facing wall. This also mirrors the prices of renovations. On average, to implement RENO3 measures for single-family houses, an owner typically needs to invest at least 33% more compared to someone residing in a multi-family block house. For some projects, it can be several times higher for single-family homes than for multi-family apartments. Similar findings were confirmed by (Kadrić et al., 2022). Authors estimated 2.8 times higher price of EE upgrades for a person living in a single-family home.

In conclusion, all projects yield advantages relative to their investment costs, offering energy-saving benefits and enhanced comfort to households. The profile of the adoption of energy-efficient measures behavior is shown in Table 3.7. aligns with the predicted cost-benefit profile. Therefore, gaining insight into the determinants shaping their choice to invest in such measures holds substantial importance.

7.2. Energy costs and EE investments

Gas consumption is a complex phenomenon influenced by various factors such as economics, energy prices, behavior, technology, climate, and many others. Implementing EE measures is part of the puzzle that contributes to a holistic understanding of the dynamics shaping gas consumption patterns and bill size. Every household of this sample utilizes gas for heating, water heating, and cooking purposes. An average household with a salary of 6,663 UAH consuming 140 m^3 a month during the last heating season and contributes 20% of the family's monthly income to cover the monthly gas bill. Table 3.15. depicts how the percentage of the monthly salary varies across different income categories, levels of education, and availability of the children if the person worked abroad, highlighting the varying financial impact of gas expenses on households.

The results suggest that the average low-income household allocates 36.7% of its income to cover gas expenses. In contrast, the mid-income families category exhibits a lower proportion of 17.1% of their monthly salary. The lowest share of the monthly budget for gas bills contributes to high-income households, with 12.3%. Low-income dwellings invested in RENO3 and ANYRENO have a considerable share of the budget to pay for the gas bill. This percentage is lower for mid-income households and much lower for high-income families.

On average, families that do not work abroad pay lower gas bills than those who work overseas, with shares of 17.7% to 23.5%. These results confirm the findings of the probit analysis, suggesting that low-income and mid-income households that work abroad are more likely to invest in ANYRENO measures.

Education information implies that as education levels increase, the percentage of income allocated to gas bills tends to decrease. Low-educated families contribute 25.8% of the total family income to pay for gas compared to the highly educated, with 18.5%. This data also supports the findings of the analysis confirming a higher probability of investing in EE measures by people with lower education.

The gas bill for families living in multi-family apartments is lower than that of single-family homes, with a share of 17.3% to 21.5% for those invested in ANYRENO and 17.3% to 21.7% for households invested in RENO3. It is conceivable because of the size of the house. Additionally, multi-family apartments typically share walls with neighboring units, which can result in lower gas bills compared to single-family homes. This data aligns with the analysis outcomes, affirming that families living in multi-family dwellings are more likely to adopt EE measures.

Families with a child exhibit higher gas consumption than childless households, and a percentage of the income contributed to the gas bill. In general, households with a more significant number of children show an upward trend in gas consumption and gas payments. This confirms the finding that households with at least one child are more likely to invest in ANYRENO.

Table 3.15.: Share of gas consumption and gas bill, sample n=370.

	Average monthly gas use, m3 (heating season 102018-042019)			Percentage of income to the monthly gas bill, %		
	Average household	Households invested in ANYRENO	Households invested in RENO3	Average household	Households invested in ANYRENO	Households invested in RENO3
Inc1 (income ≤ 4,251 UAH)	135	139	138	36.7	37.8	37.9
Inc2 (income ≤ 8,751 UAH)	137	139	137	17.1	17.6	17.4
Inc3 (income ≤ 12,501 UAH)	162	149	145	12.3	11.3	11.0
Inc4 (income > 12,501 UAH)	238	218	218	12.5	11.7	11.7
low education	157	159	156	25.8	27.5	27.2
professional education	135	125	125	21.4	21.7	21.2
high education	138	138	137	18.5	20.0	19.5
average household	140	140	139	20.0	21.1	21.1
sfhome	167	169	167	25.1	27.1	27.5
multi-family	123	120	120	17.0	17.3	17.3
child	149	150	148	20.4	21.5	21.7
no kids	128	120	120	19.3	20.1	19.8
work abroad	145	145	142	23.5	24.1	24.3
not working abroad	137	135	136	17.7	18.5	18.5
one kid	137	139	135	18.5	19.3	19.2
two kids	162	160	160	22.5	23.7	24.1
three kids	158	154	154	21.1	20.2	20.2
four kids	236	236	236	43.6	43.6	43.6
one livroom	110	105	105	19.9	17.3	17.3
two livrooms	118	114	112	17.6	17.8	17.7
three livroom	139	138	135	19.1	19.8	19.6
four livrooms	154	146	141	21.0	21.3	21.1
five livrooms	184	166	169	27.0	29.0	28.5
six livrooms	244	271	271	32.6	38.7	38.7
seven livrooms	232	199	199	20.2	30.0	30.0
riskaverse	139	139	137	20.1	21.5	21.5
no risk averse	144	144	144	19.6	19.8	19.8

Note: Gas prices are adjusted in real terms as of June 2019.
The calculations do not consider the discount obtained from benefits or any lump sum received from subsidies.

Additionally, there is a correlation between the number of living rooms, growing gas consumption, and the monthly gas payment percentage. It can vary considerably from 17.6% of the monthly income for a one-room dwelling up to 32.6% for a six-room house. This correlation remains consistent when examining household size. This finding mirrors the results of the probit regression. Households with a more significant number of rooms and larger household size are those who are more likely to invest in both energy efficient measures ANYRENO and RENO3.

All households are categorized as "energy poor" because their utility bills amount to more than 10% of their income, underscoring the necessity to conserve energy and reduce the associated costs.

7.3. An extra EE investment

From the sample of 346 households that have already invested in at least one upgrade, approximately 80% have expressed their intentions to do further renovations. A similar pattern was observed among those 154 households that have not yet initiated renovations (85%). So, what would be the cost of extra energy-efficient investments? The average price of the first EE measure for an average household with an income of 6,663 UAH would be 8,658 UAH. (See Table 3.16.). Each new measure would require a higher financial contribution. This observation suggests that households may begin with the less expensive energy efficiency measures and progressively make further investments as they observe the positive effects in terms of energy saving or level of comfort. The lower costs associated with the fourth measure are due to the limited number of observations in this category.

Table 3.16.: Cost of one more EE investment, sample n=370.

	Cost of one more EE investment, UAH
First	8,658
Second	9,538
Third	14,262
Fourth	1,854
Fifth	21,706

Note: The costs are adjusted to real terms as of June 2019

Table 3.17. presented below shows the cost of an additional first energy-efficient investment made by households with varying income levels and education backgrounds,

availability of children, among other factors. Individuals with mid incomes (Inc2) demonstrate a notably higher investment value (10,030 UAH) compared to those in lower or higher income brackets (Inc1 and Inc3). An extra upgrade would require an expenditure equivalent to two months' income for low-income households. In contrast, high-income households allocate only 63% of their monthly income towards the same upgrade. This observation aligns with the broader understanding that financial constraints can limit the ability of low-income households to pursue energy-efficient upgrades, which often require upfront investments and would require additional support from the government.

Dwellings with low and high education backgrounds would need to make similar contributions towards new investments of 9,181 UAH and 9,314 UAH, respectively. The lowest amount needs to be allocated to individuals with professional education (6,333 UAH). The disparity in investment amounts between dwellings likely comes from not only income or education differences but also from knowledge about technologies, access to resources, and behavioral factors.

Table 3.17.: Cost of one more EE investment by household type, n=370.

	Cost of one more EE investment, UAH
Inc1 (income ≤ 4,251 UAH)	7,767
Inc2 (income ≤ 8,751 UAH)	10,030
Inc3 (income ≤ 12,501 UAH)	7,955
low education	9,181
professional education	6,333
high education	9,314
average household	8,658
sfhome	9,735
multi-family	7,901
child	8,471
no kids	8,969
work abroad	8,578
not working abroad	8,737

Note: The costs are adjusted to real terms as of June 2019

Households living in single-family homes incur the highest expenses for additional energy-efficient measures, totaling 9,735 UAH. At the same time, those residing in multi-family housing units allocate fewer resources, amounting to 7,901 UAH. This suggests that single-family homes often encompass larger spaces and more extensive infrastructure, and there is a greater need for higher investment amounts in EE measures. Conversely, multi-family units typically feature more constrained areas and shared systems, limiting the potential for individual renovation investments and, thus, lower costs. The additional household investment does not exhibit a notable difference based on whether they have children or if at least one member works abroad. These amounts align with the average value.

Households characterized by low socioeconomic status may face challenges when investing in energy-efficient measures. Limited income or financial resources can hinder their ability to adopt such measures and counter the potential setbacks of energy-related events. However, these households might explore various coping strategies, such as seeking assistance from family and friends and available energy support programs. In the case of this study, there is a need to count remittances sent from family members who work overseas, and subsidies or "benefits" received from the government. Of the households that underwent renovations, 51% reported that at least one family member is employed abroad, potentially allowing them to allocate a portion of the remittances toward covering renovation costs.

Financial support and assistance from the government through subsidies play a significant role for households. Although only a minority of households from the sample gain from subsidies in this instance (14.5%), the average amount received by households from 2016 to 2018 was 818 UAH.

Table 3.18. displays the amount of subsidies received in the last heating season (October 2018 to April 2019) by the various groups of families. The data suggests that, on average, the highest subsidy was received by dwellings with low education, families living in single-family homes, and those with children and not working abroad.

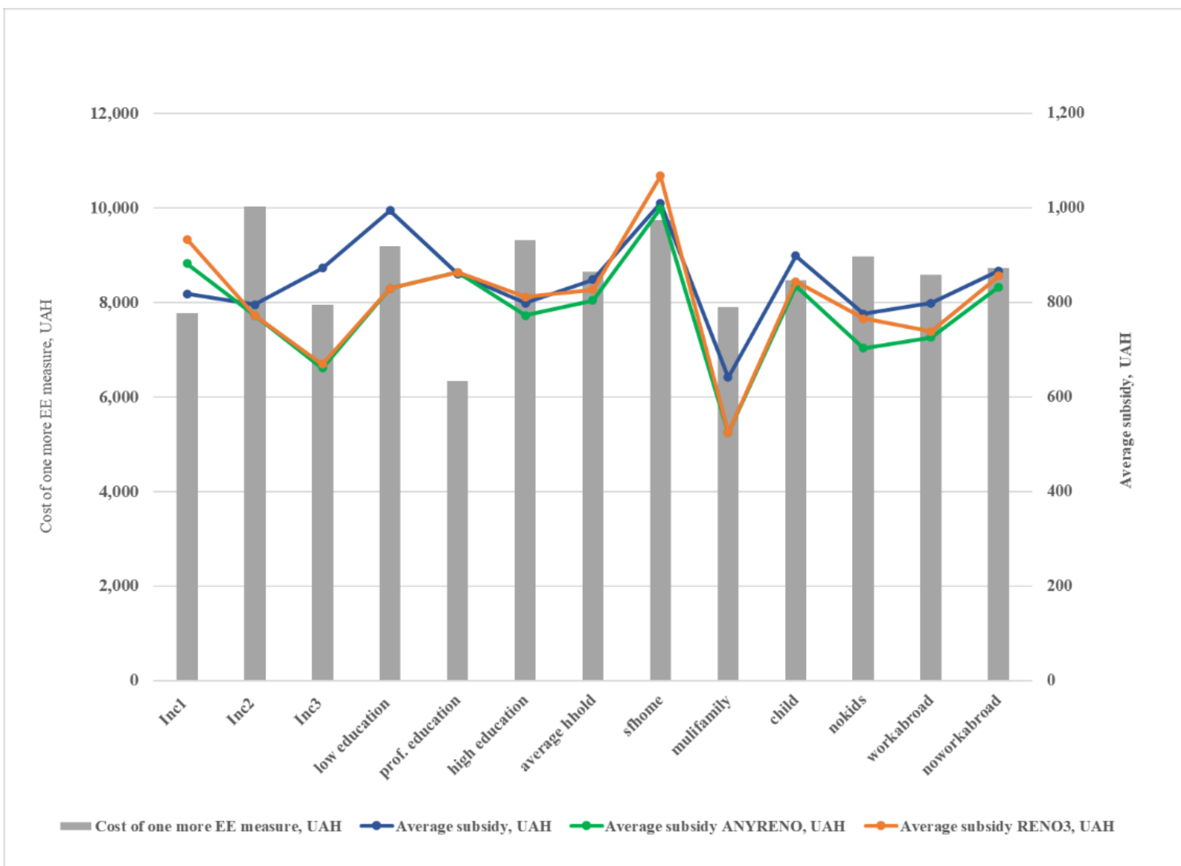
This result aligns with the information presented in Table 3.17. It indicates that households receiving the highest subsidies tend to be those that must allocate a substantial sum for extra investment in energy-efficient renovations, specifically among families that did renovations. (See Figure 3.6.) For low-income “renovators” the data reveals an average subsidy of 883 UAH and 934 UAH and a required EE investment of 7,776 UAH. This suggests that even with subsidies, families with moderate incomes still face significant out-of-pocket expenses for EE improvements, emphasizing the importance of these investments. On the other hand, this situation underscores the significance of subsidies in enabling households to save money for energy-efficient upgrades.

Table 3.18.: Average household subsidy, sample n=370.

	Heating season 102018-042019		
	Average subsidy, UAH	Average subsidy ANYRENO, UAH	Average subsidy RENO3, UAH
Inc1 (income ≤ 4,251 UAH)	818	883	934
Inc2 (income ≤ 8,751 UAH)	795	773	773
Inc3 (income ≤ 12,501 UAH)	873	661	669
low education	994	830	830
professional education	861	864	864
high education	799	773	812
average household	848	804	827
sfhome	1,010	999	1,068
multi-family	642	525	525
child	899	835	844
no kids	776	703	766
work abroad	799	726	739
not working abroad	867	833	857

Note: Subsidies are adjusted to real terms as of June 2019

Figure 3.6.: Average subsidy v. Cost of one more EE investment, sample n=370.



Similar findings also pertain to the type of dwelling and the presence of children in the household. These factors appear to influence the investment decisions and expenses related to energy-efficient renovations in a manner consistent with the patterns observed in the data. On average, families residing in single-family houses receive a subsidy of 1,010 UAH. They would need to contribute 9,735 UAH to implement an additional energy-saving upgrade. In contrast, households living in multi-family apartments receive a substantially lower subsidy, averaging 642 UAH. They would have to set aside 7,901 UAH to pursue an additional energy-efficient upgrade. Families living in single-family houses face a substantially higher cost for the next EE upgrade, even after factoring in the subsidy.

The variation in the subsidies for families with and without children is more visible than in the cost required for the next EE improvement. The cost of implementing additional upgrade for families with children totals 8,471 UAH. A subsidy is expected to cover approximately 10% of these costs.

This situation implies that, while subsidies provide financial assistance to households, the cost burden for the EE improvement is significantly heavier for some households. However, despite the varying costs of EE improvements, subsidies can provide valuable financial support, reducing the overall burden on households and making EE upgrades more accessible and affordable. Owing to the limited sample size, the variable representing subsidies did not significantly impact the estimation of energy-efficient investments (13.7% from "renovators"). Nonetheless, the analysis did reveal a negative correlation between the investment in ANYRENO and RENO3. This finding could suggest that subsidies do not motivate households to do renovations. Conversely, the "benefit" or the discounted price for utilities demonstrated a positive connection with energy-efficient investments despite lacking statistical significance. It is essential to recognize that the outcome is affected by the limited representation of these households, comprising 7% of the entire sample.

In Ukraine, where energy costs take a significant part of the budget, the potential for reduced energy bills via energy-efficient measures is a strong motivator for homeowners. Renovations that lead to lower energy consumption can translate into substantial long-term savings. Most of the above outcomes are consistent with the principal findings derived from the primary probit regression analysis. The cost-benefit profile exhibited by the households corresponds to the conclusions drawn regarding the likelihood of adopting energy-efficient measures. The obtained outcomes affirm that households with lower income and lower education levels that have kids and live in homes with more rooms pay the highest gas bills. Consequently, these households exhibit a heightened interest in implementing energy-saving measures.

Furthermore, the assessment of the Net Present Value outlined in the previous section has illustrated the favorable effects of such energy-saving projects on these households. The gathered information can be employed to create profiles of households, enabling the targeted provision of financial assistance for energy-efficient measures. This approach recognizes that these households benefit significantly from energy-efficient measures, even though they might be cautious in the investment due to high initial expenses.

8. Conclusions and policy implications

The availability of original household data provided a great possibility to track the implementation of energy-efficient measures for a 10-year period in Ukraine, which has not been done before. Results revealed that homeowners have a high interest in implementing the EE improvements, and these rates are higher during the gas price growth period. Households invest, on average, in two or three measures and choose the measures with higher energy-saving potential. The investment costs for such measures varied considerably: from 16,731 UAH (561 EUR) to 100,787 UAH (3,380 EUR) for cavity wall insulation and from 8,435 UAH (283 EUR) to 41,558 UAH (1,394 EUR) for double-glazed windows. The figures suggest that investments are made in a step-by-step manner. Each new renovation is performed within a shorter period, suggesting that previous expertise and knowledge are helping to start with the following investments (Huang et al., 2021). The maximum number of selected renovations reached five and 5 within the most extensive time frame of 10 years. Families are choosing to implement from one to five EE measures. The period between the first and last renovation is around three years for most households. These findings align with a study by Maia et al. (2021). They estimated that the step-by-step approach resulted in 11–22% higher energy savings in comparison to the one–step approach. Moreover, the renovation process can take from 1 to 14 years or from 2 to 11 years. These findings play a crucial role in helping Ukraine meet its decarbonization objectives set for 2035 through the enhancement of the housing stock.

The analysis confirms that both socio-demographics and dwelling characteristics play an essential role in explaining the likelihood of investments in energy-efficient measures by household owners. The main findings suggest that low-educated and low-income homeowners living in multi-family apartments, with a larger number of rooms and a larger household size, having at least one child, that recently moved into the apartment are more likely to invest in energy-efficient measures in comparison to high-income households, living for a longer time in single-family and semi-detached houses, with a lower number of rooms, a smaller household size, and having no kids. Furthermore, working abroad also triggers the implementation of EE measures. Households prefer to renovate their homes following a step-by-step approach and do so on average within three years, choosing to implement from one up to five EE measures. Government policies and financial initiatives should support and encourage homeowners to adopt multiple EE measures to reach the expected energy-saving effect and reduction of CO_2 emissions. The insufficient focus on the supply-side aspect of retrofit policy formulation can lead to lost chances for enhancing retrofit performance. (Kerr and Winskel, 2020). These findings can contribute to designing targeted policies for specific household groups and particular energy-efficient measures. Policymakers can direct financial incentives toward families who are less likely to implement energy-efficient measures, thus addressing equity in adopting these technologies. The information can be used to design customized educational campaigns, effectively explaining the benefits of energy-saving measures to the public.

The reasons for investing in home renovations can be various since every household is unique. With this in mind, all households that invested in renovations were given a multiple-choice question with the 16 most evident reasons why to renovate. The results indicate that up to 93% of households aim to make their home warmer in the winter, 60% to make it more comfortable, 51% to reduce the noise from the street, and 40% to reduce the gas bills. The obtained results, defined by these households, were: 74% could make their home warmer in winter, 69% found their home to be more comfortable, 61% noticed a reduction in noise from the street, and 20% reduced their gas bills. In addition to this, 45% were able to decrease gas consumption (a multiple-choice question).

The preferences of households towards implementing energy-efficient measures require a more profound understanding from various perspectives. These should include longer timeframes, the variety of the measures, their combinations, their order, and precise information on the month and year of investment to build a panel dataset that can help provide explicit analysis. Environmental preferences and behavioral patterns should be incorporated into the analysis, considering the growing social interest in being pro-environment. At the same time, the house type, state of maintenance, comfort, and indoor-outdoor temperature should also be controlled. This study would contribute from the interconnection of these factors that trigger households decision to renovate. Furthermore, it would expand the insights by incorporating additional data gathered from households in other regions of Ukraine.

This research provides a unique and primary analysis of the determinants of energy-efficient measures implemented in Ukraine by the example of Uzhhorod from 2008 to 2018, including a detailed description of the frequency, rates, types, and prices of EE measures, along with the approach and order which households follow during implementation. This chapter contributes to the literature on energy-efficient investments implemented in Ukraine. It can be helpful for policymakers in developing future energy strategies, considering the needs and preferences of residential consumers, not only in renovating existing buildings but also for new build projects. Furthermore, it could stimulate statistical data collection by government authorities, which would allow the study to be applied to other parts of Ukraine to compare the region-specific factors that motivate renovations by individual households and homeowners associations. By considering the diverse needs and behaviors of different household types, policymakers can accelerate the transition to a more sustainable and energy-efficient future.

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Chapter 4.

Replies to Opponents' Reports on Dissertation Thesis

Acknowledgments:

I am grateful to my opponents and committee members for their insightful and valuable comments. They significantly enhanced the quality of the thesis and provided interesting suggestions for further study. I hope the following replies meet their expectations. The replies are ordered alphabetically.

Thank you very much once more!

1. Souvik Datta Ph.D.

First of all, I want to express my sincere appreciation to Souvik Datta for his keen interest in and appreciation of my dissertation, as well as for his valuable recommendations to enhance the quality of each chapter. All comments related to the formatting of the thesis, minor typos and redundant information were incorporated as recommended. Below are the replies for raised questions and comments. To ensure clarity, I will first recap these comments and then proceed with my responses.

1.1. What are the demands requested by the IMF?

By accepting a loan from IMF, Ukraine took the responsibility to fulfill the recommendations and reform the country in all sectors. These included fiscal and structural reforms, financial and social sector improvements, and modification of the energy sector. Energy sector reforms address vulnerabilities by reducing subsidies, increasing energy efficiency, and implementing market-oriented pricing mechanisms.

One of the main changes that addressed all users was the increase in electricity and gas tariffs. Ukraine agreed to maintain the adjustments of the energy prices to industrial and budget consumers to align with the actual energy import costs, considering new import prices and exchange rate movements. These tariff adjustments could help reduce fiscal imbalances, improve the financial health of energy providers, and encourage more responsible energy consumption. The country agreed with the requirement to demonopolize the energy market for natural competition and provide users access to different suppliers. An essential requirement accepted by Ukraine was related to increasing the number of households with energy meters installed at a building level. The IMF required changes in the legal field related to the sustainable and green development of the country. This included changes in the building code related to the energy efficiency of the buildings. (IMF, 2014) The country agreed to follow a long-term economic reform plan focusing on achieving stability, improving economic governance, promoting transparent practices, and ensuring strong and sustainable economic growth while prioritizing protecting the most vulnerable.

1.2. Provide a table to show representation.

We construct two measures of attentiveness: Quantity attentiveness and Bill attentiveness. The share of quantity-attentive households represents 35.40%, bill-attentive 29.40%. About 14% of the respondents are both quantity- and bill-attentive, and 15% indicated that they "did not know" the tariffs per kWh. A description is provided in Section 5 Chapter 1 (See page 35). Table 1.10. represents the shares. (See page 48)

1.3. The electricity demand model is introduced too abruptly. What is the basis of this model? Is it the household electricity demand model based on the energy services demand function? A more detailed background would be appropriate here.

Indeed, the energy services demand is an essential concept in energy policy, economics, and sustainability because it shifts the focus from simply supplying energy to understanding how it is used to meet societal needs. Energy services demand refers to the demand for the end-use services that energy provides rather than just the demand for energy in its raw form. In other words, it focuses on how energy is utilized to fulfill specific needs or functions in different sectors of the economy, such as residential, commercial, industrial, and transportation sectors. For example, in the residential sector, energy services demand might include the need for lighting, space heating, cooling, refrigeration, cooking, entertainment, and other activities that require energy consumption. Detailed description was added to Section 4 of Chapter 1. (See page 30).

1.4 The discussion of using the average price as opposed to the marginal price is an old one. Since this is an important theme in this chapter, the references and discussion should be more extensive and not restricted to Ito (2014). Please perform a more extensive literature review of this discussion.

As was advised, I performed an extensive literature search and provided deeper interpretation of a choice between average and marginal price. Information was included to Section 4 of Chapter 1 (See page 31-32)

1.5. What is the median income?

The median income is 4250 UAH. Information on median income was incorporated into the text to Section 5 of Chapter 1. (See page 35)

1.6. Can you please explain in more detail why month and year dummies are important in the logistic regression?

The information was incorporated in*to Section 5 of Chapter 1.* (See page 40)

1.7. The histogram shows several major spikes, like the one between 100 and 150 kWh and between 150 and 200 kWh. There might be multiple explanations for this observation. Maybe you can discuss this in a few more sentences.

The explanation was incorporated into the text of Section 6 of Chapter 1. (See page 42-43)

1.8. Why is the sample split into terciles and not, for example, quartiles? A little more explanation would be helpful.

Splitting a sample into terciles rather than quartiles is a choice based on the analysis goals and characteristics. In the context of our study, the decision to use terciles was motivated by several factors. The sample size needed to be bigger; thus, dividing it into quartiles could lead to each subgroup having a limited number of observations. Terciles provided a more balanced distribution of data across groups. Having larger groups in terciles enabled us to enhance the statistical power of the analysis, allowing for more reliable detection of differences or patterns among the groups. Additionally, our sample had a natural cluster into three distinct categories or levels, making terciles a more appropriate choice for capturing the variability within the sample. Furthermore, terciles can simplify the interpretation of results and are preferable for comparison with other results in a similar field.

1.9. It would be interesting to see how the model performs when observations a month prior and a month after the tariff change are excluded, as opposed to the current models where only a narrow period around the tariff change are included.

When excluding observations one month prior and one month after a price change the elasticity becomes stronger and its effect increases with time. (See Table 4.1.) When comparing obtained results with the main findings displayed in Table 1.11. (without exclusion of the months) it can be stated that current results are almost twice as large. This can be attributed to a combination of factors related to consumer adaptation, market dynamics, and behavioral changes, limited substitutability, and necessity of an electricity as a good. When comparing these results with worldwide studies on the residential price elasticity of electricity demand, we can conclude that our results are consistent.

Table 4.1.: Effects over time (limited).

	(A) 2 months before + 2months after	(B) 3 months before + 3months after
Coefficient on log marginal price	– 0.46707	– 0.50714
St Err	0.1492	0.1455
t statistic	– 3.13	–3.48
Nobs	2,879	5125
Households	482	482

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 clusteredat the respondent level.

1.10. How does the consumer welfare loss compare to the levelized cost of electricity? There are also emissions of other pollutants avoided due to consumption of less electricity. Maybe, those also be included in the welfare calculations.

The levelized cost of energy (LCOE) in Ukraine depends on the type of energy source, the technology used, and the specific project's location and financing. For fossil fuels, this cost ranged between 0.5 USD/kWh and 1.8 USD/kWh; in 2019, it ranged at 0.10 USD/kWh. Ukraine has experienced significant growth in renewable energy capacity, particularly in solar and wind power. The LCOE for solar photovoltaics decreased from 0.52 USD/kWh to 0.12 USD/kWh from 2011 to 2021. In recent years, the Ukrainian government has adopted changes to reform the energy sector and address issues related to the feed-in scheme for renewables. Furthermore, Ukraine has been working on integrating its energy markets with the European Union's. This integration is expected to facilitate the exchange of electricity and promote cleaner energy sources. Besides renewable energy, Ukraine has been focusing on improving energy efficiency in various sectors, including residential and industrial, which can bring savings. Positive changes in energy production can potentially mitigate welfare losses in multiple ways. These changes can enhance energy security, affordability, and access while reducing environmental pollution and creating economic opportunities.[1]

The carbon intensity of electricity generation refers to the CO_2 emissions produced per unit of electricity generated. It is associated with the long-term increase in global temperatures, which has far-reaching environmental, social, and economic implications. Because of its central role in climate change, there is a strong emphasis on tracking and mitigating CO_2 emissions in Ukraine. Still, it is essential to recognize the importance of monitoring and mitigating other emissions for their impacts on the environment and human health. In this study, we aimed to prioritize only CO_2 emissions. Policymakers and regulatory bodies in Ukraine gave precedents to reducing CO_2 emissions as a key policy objective. Therefore, we provided a quantification relationship between energy demand and CO_2 emissions, which can bring valuable policy formulation and decision-making insights.

1.11. There are a few papers on gas demand in the residential sector that have been published since 2018. It would be nice to have a more up-to-date literature review and not rely on the 2018 study by Auffhammer and Rubin.

The literature has been updated and incorporated into the Section 1 of Chapter 2. (See pages 61-62)

1.12. Which effect in Sexton (2015) are you referring to here?

The explanation was added to Footnote 7, Section 1 of Chapter 2. (See page 63)

1.13. What do you mean by "skills" here?

The explanation was incorporated into the text of Section 6 of Chapter 2. (See pages 93-94)

1.14. The first question asked here is, according to me, not very interesting. If there are price hikes consumers are expected to reduce their consumption. The more interesting question is how much. I suggest that you reformulate this question to reflect this.

In this research, we aimed to explore whether consumers can effectively adapt their behavior toward significant energy price growth. Our primary goal was to provide a conclusive response to the question of whether it is indeed possible for consumers to reduce their gas demand when confronted with substantial tariff hikes. This question addresses the core issue of consumer adaptability and behavioral change in the context of rising energy costs. As a secondary priority, we aimed to quantify the extent of this demand reduction across the households. For this reason, we are retaining the research questions in their original form.

1.15. I find the way the subsidy variable has been introduced a bit problematic. It is an important variable in the model and a more detailed analysis of it would be very helpful. For example, the variable is in logarithm. If there are any observations where the amount of

[1] https://ourworldindata.org/grapher/levelized-cost-of-energy?country=~UKR

subsidy is zero, then the logarithm is undefined. I did not notice the summary statistics of the subsidy variable in the chapter and, hence, I cannot tell if there are households who did not receive any subsidies. I would prefer to have the subsidy variable included in the model without any transformation. Also, there are instances where the amount of subsidy is not observed but is indicated by a binary variable. It would be helpful to compare the results of models with two subsets of the original data. Assuming that there are households without any subsidies, it would be helpful to have a dataset where there are households without subsidies and those where the amount of subsidy is known and another dataset where there are households without any subsidies and those where the subsidy amount is not known (i.e., with a subsidy binary variable). Since the price of elasticity of gas demand is the coefficient of interest this can show if there are any differences between households where the subsidy amount is known and those where the subsidy amount is unknown.

As was correctly pointed out that taking the logarithm of the subsidy variable may lead to undefined values when the subsidy amount is zero. This transformation is commonly used to address issues of high variability or to linearize relationships. In case of this dataset the unknown values of subsidies are set as missing, only after the subsidy was changed to logarithm the missing values was replaced by zeros. This eliminates a problem with taking a logarithm.

Table 2.5. includes the information on the share of households with subsidies. This share is 11.01% for non-renovators vs. 16.25 % for renovators. It is crucial to emphasize that subsidies are not uniform over the study period. Households apply for subsidies each season, but eligibility criteria may determine whether they receive them. This means the share of households receiving subsidies varies across different periods or seasons. Additionally, there are households that have subsidies, but amounts is unknown. In this sample there is 1042 observations, where the subsidy amounts are available and 179 observations when households are receiving subsidy, but amount is not known. Households may enter or exit subsidy programs over time. The dynamic nature of subsidy application further complicates the analysis, as households move in and out of subsidy-receiving status.

When applying subsidies without transformations, the regressions do not yield feasible results. In the estimation process, challenges arise in the form of endogeneity issues or the model being underidentified or having weak instruments. This could mean that the estimated effect of subsidies on gas demand might be confounded by unobserved factors, leading to unreliable results. This occurrence can be ascribed to the limited proportion of households benefiting from subsidies, along with a lack of detailed information regarding the precise subsidy amounts. This adds an additional layer of complexity, as the subsidy variable is not fully observed, potentially leading to missing or incomplete data. The non-significance of coefficients on the log of subsidy in main regressions in the Chapter 2 may align with the same reasoning.

Indeed, the subsidy inquiry is considerate and requires careful examination, as it involves nuances and opportunities for enhancing the research. This research topic would benefit from further exploration in the future when more time and resources can be allocated to investigate and address the issues raised thoroughly.

1.16. The discussion of the instruments is not sufficient. I do not agree that benefits are an appropriate instrument because benefits affect income directly and, therefore, the gas demand.

The explanation was incorporated into the text. Section 3 of Chapter 2. (See page 81)

1.17. What are the costs of implementing energy efficiency measures? The order of the energy efficiency investment is important because if the household performs a costly EE improvement, the household may wait longer for the next EE improvement due to budget and liquidity constraints. As far as I can tell, there is no discussion of this issue.

The section was updated with the required information in Section 4 of Chapter 3. (See pages 115-116)

1.18. It would be interesting to see in Figure 3 how the EE measures are associated with gas prices so please include the gas prices in the same figure with the prices reported in the right-hand axis.

The gas prices were added to the EE measures in Figure 3.4. in Section 4 of Chapter 3. (See page 119)

1.19. Maybe the reduction in EE improvements is because the potential to engage in such measures has been exhausted and not just due to a difficult economic situation.

The section was updated with the required information in Section 4 of Chapter 3. (See page 117)

2. James Tremewan Ph.D.

To begin with, I would like to thank James Tremewan for his genuine interest and support to my dissertation. Most significantly, I am thankful for his insightful suggestions that contributed significantly to enhancing its quality. All minor comments related to typos and mistakes and all redundant information has been corrected as recommended. The subsequent comments, which relate to each chapter of the dissertation, will be elaborated upon in a detailed manner, one by one.

2.1. Summary. I would like to see an overview comparing the findings of the three following chapters, showing the big picture of what was learned from the survey. For example, which determinants of behavior change are the same across the three chapters, which are different, and why might this be the case? Are there similarities in how the magnitudes of the elasticities estimated in the first two chapters relate to those found in the literature? Why are energy-efficiency upgrades treated separately from gas consumption levels?

Summary now integrates the most up-to-date literature for each chapter and provides an analysis of how the magnitudes of the elasticities estimated in the first two chapters align with those reported in the existing literature. Furthermore, it examines whether and how the determinants of behavior change across the three chapters. The summary explores the rationale behind treating energy-efficiency improvements separately from gas consumption levels. (See pages 1-13)

2.2. Summary. On this last point, could you not employ a model which simultaneously estimates the probability of an upgrade, and price elasticities for those who upgraded and those who didn't? This would allow you to estimate the total impact of the price increase, and how much of the reduction in consumption was due to efficiency upgrades, which is important for evaluating welfare. This is probably too big an endeavor for the thesis but could be discussed as an avenue for future work if you think this approach has promise (and possibly there are not enough observations in the current data set for this anyway).

Quantifying the tangible energy savings achieved through EE upgrades has posed significant challenges for several reasons. These include the potential for rebound effects, unobserved variations among households, and self-selection bias. Even when making efforts to account for these factors, prior studies have yielded a broad spectrum of energy savings estimates, often with a need for more precision in their calculations.

If households make energy-efficiency improvements to their homes, does this also help reduce consumption? To answer this question, we performed another study. The results were published in the IES working paper but are not included in the dissertation thesis: Alberini, A., Khymych, O., and Scasny, M. (2019). The Elusive Effects of Residential Energy Efficiency

Improvements: Evidence from Ukraine. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3373720

We collected monthly natural gas meter readings from a selected group of homes in Transcarpathia, Western Ukraine. This region has been an early adopter of the country's shift away from district heating. Our data spanned from January 2013 to April 2017, when residential natural gas tariffs increased by more than 700%. These meter readings, combined with information detailing energy efficiency upgrades in these households (such as insulation of walls, attics, or basements; installation of new windows; boiler replacements; and insulation around pipes), were used to create a panel dataset.

We aimed to estimate the impact of these energy efficiency renovations on natural gas consumption while accounting for variables like weather conditions, income levels, and government energy assistance. Recognizing that the decision to undertake these renovations and natural gas consumption may be interconnected (people often perform renovations to reduce consumption), we employed an instrumental variable (IV) approach. This IV was generated through a cross-validation technique based on a supply-side rationale.

Our results demonstrated that the estimated effects of these renovations varied considerably in magnitude, even for similar types of energy efficiency upgrades. This variance depended on whether the renovations were instrumented for, and the level of detail included in the fixed effects. In our regression analyses, the coefficients associated with these renovations were typically negative, but they were only practically and statistically significant when we used the instrumental variable approach. These findings aligned with our survey respondents' challenges in evaluating whether these renovations had led to gas or cost savings.

The IV estimates indicated that insulation, in particular, led to reductions in natural gas consumption ranging from 13% to 24%, with a potential internal rate of return (IRR) on the investment of up to 5% over 20 years. Our study underscored that thoughtful utilization of an existing government Warm Loan program could result in positive IRRs, making energy efficiency upgrades financially attractive in an otherwise underperforming housing market.

Previous studies have indicated that consumers exhibit limited enthusiasm for weatherization and energy efficiency enhancements because they perceive that these improvements do not yield substantial energy savings to justify the costs. Our research highlights the challenge analysts and consumers face in evaluating the energy savings resulting from EE upgrades, even in an environment characterized by roughly rising energy costs, heightened visibility, and simplified monitoring processes. The seasonal fluctuations in natural gas consumption and the difficulty in recalling differences between cold and mild winters may have hindered consumers' ability to assess these savings accurately. These challenges could discourage homeowners from investing in energy efficiency measures unless they view these upgrades as a means to enhance their property values.

2.3. The last sentence of page 8 appears to contradict itself. Could be clarified.

The statement on page 8 in Chapter 2, suggesting that "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," is consistent with the results expressed in the conclusions section.

We expected stronger elasticities for households attentive to their consumption, bills, and tariffs. Received outcomes of the analysis suggest that respondents who are attentive to quantity tend to exhibit moderately higher elastic demand (−0.3486) than those who are not attentive (−0.2393). Individuals who are attentive to their bills show no difference in price elasticity compared to those who are not bill-attentive. However, households that are both attentive to quantity and bills had stronger price elasticity of electricity demand (−0.5630) compared to those not quantity- and bill-attentive (−0.3054). The findings should be taken with caution because of limited price variability within this subgroup and small sample size: 1935 observations for both quantity- and bill-attentive households. There is a weak difference between households aware of a tariff (−0.3054) and those not (−0.309). Considering both attentiveness and knowledge of tariffs, the estimated price elasticity remains confined to a limited range.

2.4. I was a bit confused by the description of pricing as "one-part". I had thought that this meant simple linear pricing, but maybe it is also used in the literature for block pricing. I'm not sure on this.

A one-part or flat-rate tariff is a pricing structure commonly used in various industries, including utilities and services. It involves charging customers a fixed, uniform fee for a particular service or product, regardless of their level of usage or consumption. Everyone pays the same amount, regardless of how much they use or consume. One-part tariffs are straightforward to understand for both consumers and service providers. There is no need for complex pricing structures based on usage levels. In contrast, service providers may use more complex pricing structures in some industries, such as two-part tariffs (combining a fixed fee with a variable fee based on usage), to better align pricing with consumption.

2.5. Figure 1: in the text it says the benefits line represents a 25% discount, but it looks more like 50%. Were there no benefits after April 2015?

Thank you for pointing out the issue in Figure 1.1. The line is corrected to correspond to a 25% tariff reduction for benefit users. (See page 26)

Households become eligible for benefits based on a consistent criterion. If a household already received these benefits in 2013, they would continue to do so in subsequent years. In our study, individuals receiving benefits continued to enjoy discounted prices beyond April 2015, throughout the entire duration of the research period.

However, this status can change if a benefit recipient's family member passes away or officially changes their residence by registering in a new apartment or home. Receiving a subsidy requires an application procedure. Households must apply for the subsidy before starting each heating or non-heating season. The eligibility criteria are checked for each case individually by the respective social organization in each region of Ukraine. If a household meets all the specified conditions, it will be entitled to a subsidy, but it will apply for only one heating or non-heating season.

2.6. It is not clear what you are trying to say in the final paragraph, and how it relates to your findings. Do you regard your estimates as relatively inelastic?

The final paragraph of Chapter 2 suggests that while people were responsive to changes in electricity prices and could reduce their usage to some extent when prices went up, the degree of their response could have been more pronounced. In other words, the demand reduction was relatively small even when electricity prices increased. The electricity demand is inelastic, indicating that consumers are not highly sensitive to price changes, and their consumption habits do not change drastically in response to price fluctuations. It is important to note that the price elasticity of electricity demand is significantly less than one. We do regard our estimates to be relatively inelastic. This suggests that consumers view electricity as a necessity rather than a luxury. Even when prices rise, they are not significantly reducing their consumption because they rely on electricity for essential needs like lighting, heating, and cooling. It implies that consumers may have limited ability to substitute electricity with other sources of energy, which are less energy intensive. In the case of our study, 15.8 % were using electricity for heating purposes, and no dwelling has switched the energy source.

Additionally, low-income households may be disproportionately affected by electricity price increases and become "fuel-poor" because they have less flexibility to reduce their consumption. This directly impacts consumers' affordability since electric companies have a monopoly power and could raise prices without losing a substantial number of customers. Policymakers should consider an alternative approach to encourage energy conservation and efficiency because traditional price-based incentives may be less effective due to the inelastic demand. This underscores the importance of considering the socioeconomic implications of energy pricing policies.

In summary, a low-price elasticity of electricity demand suggests that consumers are relatively insensitive to price changes regarding their electricity consumption. It has implications for energy policy, market dynamics, and the economic impact on consumers, particularly those with lower incomes.

2.7. It would help to explain early why you are excluding households who made energy efficiency renovations. This has advantages and disadvantages, and if your decision is not made clear it will raise questions in the mind of the reader.

I agree with the comment. It is indeed crucial to explain why to disentangle these two effects. The explanations related to these issues have been integrated into the text of Section 3 in Chapter 2. (See pages 78-79)

2.8. Table 4 (etc.): is it not more natural to use real income to compare waves?

In this case, the research is focused on a short-term analysis. Using nominal income is sufficient because it aligns with how individuals typically assess their ability to make decisions in the short term. In this estimation income does not bring quantitative value. Short-run price elasticity analysis often focuses on how consumers react to price changes, where inflation's impact on income may be relatively minor and not immediately reflective of consumer behavior. Furthermore, it's important to note that we have access to income data for only one month during the study period.

2.9. What was the precise question about income? Should it have included remittances from family members abroad? Is there reason to believe it is under or overstated in your survey compared to what the tax authorities are told, especially with respect to "grey" income?

A notable contrast exists between real income data and statistical representations in Ukraine and many other developing countries. This variation can be influenced by different factors, encompassing limitations in data-gathering methods, the tendency to underreport income, the presence of an informal economy, and the prevailing economic conditions. Our survey questionnaire inquired about total family income with the following: Combining all sources, including salaries, pensions, government aid, etc., what is your household's total monthly income (take-home, net of taxes)?

Up to 1200 UAH;
1201-3500 UAH;
3501-5000 UAH;
5001-7500 UAH;
7501-10000 UAH;
10001-15000 UAH;
15001-20000 UAH;
More than 20000 UAH;
Don't know

We provided a set of predefined income categories to ensure uniformity in responses. We believe that households underestimate their income. Individuals who rely on government assistance or social welfare programs may underreport income to continue receiving these funds. Some people engage in illegal activities or have income from sources that are not legitimate - remittances, for example. There is often a reluctance to disclose personal financial information due to privacy concerns. In Ukraine, significant economic activity occurs in the informal sector, where transactions are often cash-based and not officially recorded.

2.10. Footnote 31: I think this refers to table 9, not table 7. In table 9, why are some of the F-statistics not reported? It says that the J-tests fail to reject at the 1% level: does this mean that they reject at the 5% level? In this case, there is reasonable evidence that your instruments are endogenous, which should be discussed. You should be able to calculate this unless there are not more instruments than endogenous variables… was this the case in one of the regressions?

Indeed, Footnote 31 is related to Table 9. This issue was corrected. (now Table 2.9.)

The F-statistics for columns (B), (C), and (E) are not reported because of the limitations associated with small sample sizes. The Hansen J test is a critical diagnostic tool in IV regression. It evaluates the overall validity of the instruments by assessing whether they are uncorrelated with the error term in the regression equation. The failure to reject the null at the 1% level implies a high confidence level in the instruments' validity. It indicates that the instruments are suitable for mitigating endogeneity. However, when a test is conducted at the 5% significance level, it is less stringent than the 1% level. In IV regression analysis, the number of instruments should exceed the number of endogenous variables. In the case of our study, over-identifying restrictions are held for the Hansen J test for all estimated. For four out of the five 2SLS regressions displayed in Table 2.9., the Hansen J test, fails to reject the null that the instruments are valid at the 1% level. In one of the regression analyses, the test was excluded and was not calculated. The Hansen J was not rejected at 5% level, which might suggest low confidence level in the instruments' validity. This exclusion may indicate that, even when the orthogonality conditions are satisfied, the standard J statistics failed to produce a valid test statistic.

2.11. You say you ask for estimates of both average bills and consumption levels to identify salience, but only seem to split the sample according to accuracy of consumption level estimates. I would have thought that bills would be more important, given that they include some price information, which is what the important underlying variable.

By categorizing respondents into these four groups, the study sought to gain insights into how well individual households could capture the financial impact of price increases, with a focus on their gas consumption, during the specified heating seasons. We used these estimates as a proxy to investigate the extent to which households were aware of and affected by the significant rate increases. Given the difficulty in verifying the accuracy of the bill information, we opted to utilize gas use data and compare respondents' estimates with the actual averages. This approach granted us enhanced flexibility in distinguishing between different types of users and assessing the strength of salience.

Gas consumption often varies seasonally, with higher usage during colder months for heating purposes. Precise gas use data can capture these seasonal fluctuations more accurately than bills, which may not directly reflect consumption patterns. Some households may actively conserve energy, leading to lower bills despite rate increases. Gas use data can better capture variations in consumption due to conservation efforts, allowing for a more nuanced salience assessment. Overall, while bill information can offer some insights into the financial aspect of utility costs, precise gas use data are preferred for assessing the salience of rate changes because they offer a more direct and accurate measure of consumption behavior, making it easier to attribute changes in usage to changes in rates.

2.12. First sentence of page 64: this seems to suggest that the government expected (price?) subsidies to reduce consumption, which seems strange. Clarify.

In Ukraine, gas subsidies are a form of financial assistance provided to households to help them afford their gas utility bills. These subsidies are funded from the government's general revenue and paid directly by the government to the gas utility companies. As a result, eligible consumers receive a reduced gas bill but do not receive cash payments. Instead, the government covers a portion of their gas expenses to make energy more affordable. To assess the financial sustainability of this subsidy program, we examined whether the tax revenue collected through gas bills (specifically, the 20% value-added tax included in the gas tariff) is sufficient to cover the cost of these subsidies. Suppose consumption decreases due to tariff increases but remains relatively insensitive to the subsidies. In that case, it might indicate that the tax revenue is insufficient to cover the full cost of the subsidies. It could raise fiscal and budgetary concerns for the government, as it may need to allocate additional funds to maintain the subsidy program or consider alternative approaches to managing energy affordability for consumers.

It is conceivable that the government expected that via prices and subsidies to reduce gas consumption. The subsidy program aimed to help low-income households cover utility bills. Each year, subsidy eligibility criteria were stricter, and the number of households receiving subsidies was fewer. The Ukrainian government faced budgetary constraints and needed to manage its spending by reducing subsidies and raising prices. With low prices and high subsidies, households were neglecting energy use. By increasing gas prices (through reduced subsidies or tariff adjustments), the government has aimed to encourage consumers to use gas more efficiently and reduce their consumption. Consumers become more conscious of their usage when energy prices rise and seek economizing ways. As part of a broader sustainability and climate policy, the government encourages households to reduce their carbon footprint through lower gas consumption and investment in energy-efficient renovations.

2.13. You refer to most "energy- and cost-effective" renovations. It would be good to inform the reader at this point (or before) how the different measures rank in these respects.

Certainly, it is important for the reader to be informed about the renovations that offer the greatest energy and cost savings. The necessary information has been included in Section 3 of Chater 3. (See page 114)

2.14. The difference between sample and regional income is huge, and the explanations aren't very satisfying. I would have thought that, if anything, households would be less likely to report grey income to the Statistical Office than to you. Is there some difference in the definitions of income?

The difference between real and statistical data on income in Ukraine, as in many other countries, can be significant due to various factors. These disparities can arise from limitations in data collection methods, underreporting of income, the informal economy, and economic conditions. It is essential to recognize that while efforts can be made to improve data collection accuracy, there may still be limitations and challenges in capturing the complete picture of household income. Striking a balance between obtaining accurate data and respecting respondents' privacy and their inability to recall and report income is a real challenge in survey and data collection efforts.

The survey questionnaire addressed the following question on total family income: Combining all sources, including salaries, pensions, government aid, et cetera, what is your household's total monthly income (take-home, net of taxes)? By offering a set of predetermined income categories, we ensured all respondents answered within the same framework. Moreover, we included validation checks to ensure that responses were consistent with the selected income category. The Statistical Office information on total family income includes all types of sources of income:

- Earned income, including salaries, fees, and other contractual payments from both primary and part-time employment;
- Payments under civil law contracts;
- Retirement benefits, support for retired judges, state social assistance for individuals without pension rights, and disability support;
- Profits from business activities and independent professional work, with data sourced from tax authorities or income and expense records;
- Creative endeavors and royalties;
- Unemployment benefits, including one-time payments for entrepreneurial ventures by the unemployed;
- Rental income, confirmed by certificates from tax authorities;
- Monthly insurance benefits for industrial accidents;
- Temporary incapacity benefits, assistance to low-income families, single mother child support, and part of the state childbirth benefit;
- Income from property sales;
- Dividends, securities, or corporate rights sales income;
- Deposits, including funds in deposit accounts;
- Returns from deposit placements;
- Lottery or gambling winnings;
- Inheritance;
- Scholarships (excluding social scholarships);
- Other taxable incomes following the prevailing legislation;

There is a possibility that households might lack a clear understanding of what constitutes their full salary, especially when income sources are complex or include various components. This lack of clarity can lead to inaccurate income reporting in the survey.

2.15. What are the precise questions used to elicit risk aversion?

The survey instrument included the following questions related to risk aversion. The risk assessment questions enable participants to express their inclination to accept and evaluate risks within specific contexts:

F6. Suppose you are the only income earner in your family, and you have a good job guaranteed to give you (your family) the current income every year for life. You are given the opportunity to take a new and equally good job, with a 50-50 chance it will double your (family) income and a 50-50 chance it will cut your family income by a third. Would you take the new job?

1. Yes;
2. No.

F7. *If respondent replied YES to F6, please ask.* Suppose the chances were 50-50 that it would double your (family) income and 50-50 that it would cut in half. Would you still take the new job?

1. Yes;
2. No.

F8. *If respondent replied NO to F6, please ask.* Suppose the chances were 50-50 that it would double your (family) income and 50-50 that it would cut it by 20%. Would you then take the new job?

1. Yes;
2. No.

2.16. What is the justification for using precisely the measures RENO3 and ANYRENO? Without a really convincing explanation, it will be assumed that they are just chosen as a result of data mining.

A well-defined theoretical framework guided the analysis. This framework helped identify critical relationships essential to address the research question. Extensive research was conducted prior to the analysis. Reviewing the existing literature in the field helped identify independent variables that have consistently shown significance in previous studies and are mostly implemented in various countries. The justification was added to Section 5 of Chapter 3. (See pages 129-130)

2.17. Relatedly, did you try a count model, e.g. Poisson or negative Binomial, or just an ordered probit? These all seem like reasonable alternatives. This avoids the problem that with binarizing the data is that there are many, many, ways of doing so…

I appreciate the suggestions of the models. The analysis was enriched by the negative binomial regression to estimate the effect of the renovation intensity. (See pages 139-140)

2.18. In the main text you go into a lot of detail explaining differences between families with children of different ages. Why not report these in the main results table, rather than the specification with just a child dummy.

Using a child dummy variable instead of categorizing children by age was influenced by the dynamic nature of children's ages during the ten-year implementation period of the energy-efficient measures. Given that children could transition from one age category to another within the study duration, this approach was chosen to ensure accurate and consistent analysis results. The results of the regression were incorporated into the results in Section 6 of Chapter 3. (See pages 136-137)

2.19. third paragraph: are the numbers for "obtained results" percentages of households who said they held those aims, or percentages of the whole sample?

Thank you for bringing this to my attention. It is related to households that did renovations. The information was corrected in Section 6 of Chapter 3. (See page 150)

3. Nithin Umapathi Ph.D.

To start, I want to express my sincere gratitude to Nithin Umapathi for his interest in and support for my dissertation. In particular, I am grateful for his valuable suggestions, as they have a substantial impact on enhancing the overall quality of the dissertation, especially Chapter 3, which is currently in the process of being prepared for submission to a publication.

The following comments and recommendations will be addressed and answered in detail one by one.

3.1. The main result of this analysis is a description of a pattern of EE adoption by household characteristics based on a probit regression. While there is value in profiling the households that undertook different EE initiatives, the explanations provided for the key result - that the households with lower incomes, lower education and with a household member working abroad are more likely to invest in EE are unsatisfactory. At a basic level, my prior tells me that the key driving EE investments are renovation cost, amortization of investment, technical barriers, behavioral nudges, and financial incentives. I would expect that low educated and lower income households are more credit constrained, hence less likely to adopt unless the cost is commensurately lower, so some interaction effects would be helpful in the regression based on the type of renovation and education status. In any case, the result is counterintuitive and interesting. However, the explanation that such households may be dwelling in inferior housing is unsatisfactory as the regression controls for the age of the building among other proxies for housing quality.

Homeowners are often motivated to refurbish their homes due to enhanced comfort, enhanced soundproofing, improved aesthetics and state of repair, increased functionality, sustainability, and not only saving energy. I agree with the comment that results require better explanation.

As advised, I have employed and an interaction between various groups of education and the type of renovation, as well as interaction between levels of income and the type of renovation. Unfortunately, these estimates were unproductive in generating estimable and significant results. This outcome could be ascribed to the fact that a considerable number of households engaged in two or more energy-efficient renovations. Opting for this approach would be more advantageous to analyze the probability of investing in a particular type of insulation. This perspective offers valuable insights into how households interact with and respond to specific energy-efficient measures, shedding light on the dynamics of adoption and the underlying motivations. Table 3.11. presents the average marginal effect of the univariate binary probit regressions analysis. Subsequently, it is followed by a discussion in Section 7 in Chapter 3. (See page 137-138)

3.2. More generally, this chapter would benefit from presentation of a simple model of household choice in adopting EE upgrades. The model could predict/present some of the expected effects, and thus inform how certain socio-economic and building characteristics *would correlate with EE adoption. In other words, it would help to have a simple model introduced in this chapter that would provide a theoretical link from the predicted effects.*

I fully agree with the suggestion to incorporate a simplified household choice model in adopting EE upgrades that outlines the theoretical connection to the anticipated effects of adopting energy-efficient upgrades. For this purpose, I looked at the analysis by considering the likelihood of investing in energy-efficient measures from the perspectives of both demand and supply sides, as well as performing univariate analysis for particular types of EE measures. The analysis is provided in the results section in Section 7 of Chapter 3. (See pages 131-132)

3.3. My next question is why such correlations even matter? and what would be the policy implication? One policy implication I can think of is to understand the returns to EE investments by different household socio-economic characteristics (SES). Since there is such heterogeneity in adoption, there may be inefficiencies (under-investment) which targeted subsidization could address. As a first step, it would be useful to have a basic cost-benefit calculation for the households for these renovations and if it even makes sense for an average household. Similarly, what is the cost benefit by type of household (low, high ed, low income/high income, etc.). Alternatively, it would be helpful to understand if the socio-economic characteristics proxy building type and, thus renovation cost.

As advised, cost-benefit analysis is a fundamental and commonly employed approach for evaluating whether renovations are economically justified and viable. The elaboration on this comment is implemented in Section 7 of Chapter 3. (See page 140-141)

3.4. Second, is there a way to link data on billing to understand whether certain household types (as classified in Table 7) have bigger bills as percentage of household income (net of HUS) and are therefore more likely to invest in EE? This is related to the previous question. In other words, does the profile of adoption behavior shown in Table 7 align with the predicted cost-benefit profile? This would help find evidence of types of inefficiency by socio-economic characteristics and generate evidence for subsidization according to certain profiles of households which have highest gap in terms of benefit and EE investment cost.

I value the recommendation to establish a connection between the adoption behavior profile presented and the anticipated cost-benefit profile. Table 3.15. provides descriptive statistics of various household profiles by the gas consumption levels and percentage of income to the monthly gas bill. The discussion is provided in Section 7 Chapter 3. (See pages 142-144)

3.5. An extension of the above analysis would be helpful that could predict or quantify the value of extra EE investment for different types of households defined in the thesis to close the gap (e.g. educated vs. less educated, higher vs. lower income, family with children vs. without building type etc)? This is because much of the subsidization of consumption is via the HUS program. And it would be a very good contribution to see whether the profile of HUS beneficiaries are also similar to the profile of those with the *highest gap in terms of benefits and actual investment in EE. This would make a very strong case for developing policy tools that could profile such households, so that they could be supported with EE subsidies to graduate them from energy assistance. In other words, complement HUS payments with energy efficiency subsidies (lumpsum or debt financed). It would be very helpful to know if profile of HUS beneficiaries is similar to those with high benefit to cost ratios for EE renovations. Then targeting energy efficiency subsidy becomes much easier. Showing this approach as a formal methodology to target EE subsidies, would be a very good policy relevant contribution.*

Absolutely, this recommendation constitutes a substantial contribution to this thesis. Its potential to elevate the overall quality and depth of the research is greatly appreciated. In addition to this, I have also incorporated a comprehensive analysis of the amount of subsidies received by these households to provide a well-rounded perspective. The discussion is represented in Section 7 of Chater 3. (See pages 144-149)

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