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Abstract

Since a large share of residential energy use is spent on space heating, it is highly relevant to understand the factors that determine its demand. Using an extensive panel dataset derived from repeated in-home surveys, we model the demand for energy in residential space heating, with a focus on social household characteristics. Our dataset, which covers the years 1992 to 2013, also allows us to explore possible heterogeneity between household groups. As a main result, we report a price elasticity of heating expenditures of 0.658. We find both technical characteristics such as building type and age as well as socio-demographic factors like age and gender to be significant determinants in explaining heating expenditures. Furthermore, we uncover significant heterogeneity in price responsiveness between different groups. For example, low-income households exhibit stronger price reactions than richer ones. Our findings have profound implications for evaluating the effectiveness of policy measures that aim at influencing energy use. Our results prove to be robust to a variety of checks.

JEL classification: C23, D12, Q41
Keywords: Germany, Space heating, Heating expenditures, Heterogeneity

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1 Introduction

Space heating and hot water preparation remain two of the major components of total energy consumption in Germany. In 2013, 28.1% of final energy use in Germany was consumed by private households. Some 84.6% of this usage was allotted to space heating (69.0%) and hot water (15.6%), which together account for a total consumption of 2201.8 PJ (BMWi 2014). These figures highlight the significant impact space heating has on overall energy consumption and, subsequently, on residential greenhouse gas emissions. Any attempt to curb energy use in light of the declining stock of non-renewable resources and significant externalities associated with burning fossil fuels has to take household energy consumption and behavior into account. Understanding the determinants of residential energy consumption is therefore of paramount importance for the evaluation of policy measures that aim at shaping energy demand. This is especially true when considering the ambitious goals set by the German Federal Government. Germany has made a commitment to cut greenhouse gas emissions by 40% until 2020 and by 80% to 95% until 2050, compared to the base year 1990 (BMUB 2015).

An extensive number of studies has estimated residential energy demand as well as corresponding price and income elasticities for different countries, the majority of which target either residential electricity use or gasoline used for private transport. Furthermore, few of the studies that focus on energy demand for space heating explicitly account for possible heterogeneity between groups, and most investigations only estimate a mean elasticity that is reported for the entire sample. However, a more differentiated view could be beneficial from a research perspective. Exploring the heterogeneity in energy demand can help us further understand the underlying economic mechanisms that determine energy behavior. Furthermore, our research enables policy makers to tailor programs and measures to specific groups of consumers.

Heterogeneity between groups can manifest itself in a variety of ways. For instance, richer households might exhibit weaker reactions to price changes if they already reached satiation, meaning that they already achieved their desired level of utility from thermal comfort which they could not increase any further by heating more, even when prices fall. Furthermore, a principal-agent problem between landlords and renters might affect the heating behavior of tenants compared to homeowners. Given that the share of homeowners in Germany is only 52.6%[1], differences in heating behavior between owners and renters are of particular interest for economists and policy makers alike. Subsequently, understanding the heterogeneity between groups of households would give politicians the ability to adjust policy measures to different groups, such as homeowners or the elderly. In the presence of significant heterogeneity, this approach would be more cost-effective than uniform regulation geared towards the entire population, which might only induce the desired behavior for specific types of consumers.

In this paper, our research question is twofold. Firstly, we want to examine what determines household expenditures for space heating, with a focus on price and income elasticities. We also include social characteristics and attitudes in our analysis, which is made possible by the extensive nature of our data. Secondly, we investigate possible heterogeneity between different groups of consumers, which we identify by utilizing quantile regression, using interaction terms, and splitting the data into appropriate subsamples. To this end, we employ panel data methods on a long-running panel study in Germany, using data from 1992 to 2013 for almost 17,000 households in total. For the full sample, we find a price elasticity of

[1] Home ownership in Germany is lower than in any other EU country, with an average rate across the EU-28 of 70.0%, Source: Eurostat/SILC 2015.

expenditures for heating ranging from 0.647 to 0.672 across specifications. Furthermore, we uncover empirical evidence for significant heterogeneity between household groups.

The remainder of this article has the following structure. Section 2 presents the relevant literature, concentrating on efforts to measure determinants of demand for space heating, while section 3 discusses the methodology employ for our estimations as well as the dataset we used. Section 4 discusses the results obtained in light of our main research questions. Section 5 concludes and suggests avenues for future research.

2 Selected Literature

The empirical analysis of residential energy demand has seen many additions over the last decades, with substantial differences between studies regarding time frame, energy carriers, regions, methods, and data aggregation level. One of the earliest studies of household energy use was conducted by Houthakker (1951), who analyzed electricity demand in Great Britain. Not least because of the energy crisis in the 1970s, the topic garnered more and more interest among economists. Subsequently, numerous researchers started investigating energy behavior and its possible determinants, often focusing on the estimation of price and income elasticities of demand for different energy fuels. Bohi (1981) as well as Bohi and Zimmerman (1984) provide an exhaustive overview of the early literature on analyzing both residential and industrial energy demand. The authors cover theoretical foundations in deriving elasticities while also summarizing empirical studies for the energy carriers electricity, natural gas, gasoline, and coal. Madlener (1996) reviews the literature on residential energy demand by estimation method.

Other authors have reviewed the literature on specific energy fuels. For electricity, surveys of empirical studies can be found in Taylor (1975) and, more recently, Espey and Espey (2004). In the latter article, which is a meta-analysis of 36 studies that were published between 1971 and 2000, reported price elasticities for electricity ranging from 0.08 to -2.01 in the short run and from -0.07 to -2.5 in the long run (Espey and Espey 2004). For household gasoline demand, extensive surveys are provided by Dahl (1986), Dahl and Sterner (1991), and Espey (1998). Similarly, Al-Sahlawi (1989) summarizes works that derive price and income elasticities for the demand for natural gas.

2.1 Space Heating Demand and Expenditures

When concentrating on studies that focus on space heating in addition to using household level data, as in our study, the field of contributions narrows down significantly. In an early effort to model energy demand for space heating in (West) Germany, Schuler et al. (2000) analyze a household survey conducted by the German Statistical Office in 1988 containing around 44,000 observations. Utilizing OLS regressions on the household level, the authors find that building characteristics are an important factor in determining energy use. In contrast to this, socio-economic factors can only explain a small part of the behavioral differences in the intensity of energy use between households in the sample. The authors introduce rebound effects as one possible explanation for the observed energy use, but conclude, without investigating further, that these effects are likely to be small.

Rehdanz (2007) uses data from the German Socio-Economic Panel (SOEP) to investigate space heating and hot water preparation expenditures for German households for the years 1998 and 2003. Using panel-corrected least squares, the author specifies seven different models, separating households by their geographical location (West or East Germany), the year of observation (1998 or 2003), and the home ownership status (owner or renter). Rehdanz (2007) finds a significant influence of a range of technical and socio-economic variables on households' expenditures on heating. Especially noteworthy are the differences between tenants and owners. While owners' expenditures increase more strongly when facing an increase in energy prices, renters spend more money on heating in general when controlling for other influencing factors.

One of the key differences between the study by Rehdanz and ours is the fact that we use panel methods to extend our analysis to the years from 1992 to 2013, which allows for a larger sample size. Furthermore, we explore heterogeneity between different groups of occupants to uncover how their specific energy consumption behavior might deviate from that of the average consumer. However, the drawback is that we are unable to observe the fuel used for heating by individual households, since this was only observed in the 1998 and 2003 waves. While a number of studies find fuel type to be a significant determinant of energy use for heating (Rehdanz 2007, Meier and Rehdanz 2010), Alberini et al. (2011) do not find significant differences in energy consumption across households heating with gas as compared to electricity.

Another relevant study that models heating expenditures, using panel data from Great Britain, is Meier and Rehdanz (2010). Similarly to Rehdanz (2007) and our own study, they examine the influence of socio-economic and technical characteristics on the expenditures per room for space heating. Utilizing a random effects model with log-linear specifications, the authors find all of the observed technical and socio-economic variables to be significant in the base model, which encompasses all households in the sample for the years 1991 to 2005. When considering fuel price changes for natural gas and oil, the observed increase in expenditures is lower for renters than for homeowners, suggesting that renters curb their consumption more strongly in reaction to increases in price. The change in expenditures per room, when confronted with a price increase, ranges from 0.36 to 0.83, whereas income elasticities vary between 0.01 and 0.06.

For the Netherlands, Brounen et al. (2012) exploit cross-sectional data from 2007 covering more than 300,000 owner-occupied dwellings. They consider both gas and electricity consumption regardless of end use. While they disregard price changes as a possible influence on energy consumption, the authors find most of their included variables to be statistically significant. Most notably, these include type, size and age of dwellings as well as number of household members, occupants' age and income. Projecting their results into the future, they conclude that the aging of the Dutch population alone could easily offset the savings of a possible home insulation program. This underlines the importance of demographic factors in the analysis of energy demand.

2.2 Heterogeneity in Energy Demand

The vast majority of studies estimating price and income elasticities in the context of consumer energy demand focus on obtaining the mean elasticity that is subsequently assumed to be valid for all households. However, this ignores the possibility of significant heterogeneity between households that cannot be captured by estimating a single number for the entire population. For example, low income households might have much lower (or higher) price elasticities compared to richer ones due to several factors such as satiation or (lack of) access to substitutes.

In the context of space heating, we are not aware of any other studies investigating this issue. However, there is a small number of papers aiming at explaining the existence and magnitude of heterogeneity in gasoline demand, utilizing a variety of methods. Two early efforts were conducted by Archibald and Gillingham (1980, 1981), who estimated short-run price elasticities for gasoline demand separately for single- and multi-car households.

Wadud et al. (2010) explore heterogeneity in gasoline demand using household level panel data for the US. Using a random effects model with a translog specification, the authors discover heterogeneity by interacting both price and income with a number of demographic variables. The authors find that price elasticities decrease in magnitude with increasing income. On the other hand, income elasticities are lower for higher income households, possibly because households with higher income levels are already near satiation. Furthermore, households with multiple vehicles and multiple wage earners are more responsive to price changes compared to those with only one car and one or zero wage earners. This might be due to the increased flexibility of these types of households. Specifically, multiple wage earner households could rearrange their work and commuting schedules, while households with multiple vehicles might start using the more efficient of their cars more intensively (Wadud et al. 2010).

Frondel et al. (2012) provide further evidence for heterogeneous reactions to price changes for private car travel in Germany. In attempting to explain heterogeneity in direct rebound effects, which can be explained through price elasticities, the authors employ quantile regression on panel data ranging from 1997 through 2009. They find significant differences in price responses of drivers in different quantiles. Specifically, the price elasticity is lower in magnitude for households that drive more, whereas consumers who have very low demand for private car travel react more strongly to price changes. While the authors also interact fuel prices with different demographic variables, they do not find any of the interaction terms to be statistically significant, thereby contradicting the findings from Wadud et al. (2010).

Investigating a dataset for cars from the state of California with more than 5 million observations, Gillingham (2014) derives estimates for vehicle-miles-traveled (VMT) with respect to gasoline prices. The richness of his dataset allows the author to also explore heterogeneity in demand response by using quantile regression, splitting the sample into subgroups, interacting the gasoline price variable with demographic factors, and conducting k-means clustering. The author finds a medium-run price elasticity of VMT of -0.22 across the entire sample, with significant heterogeneity between groups. Higher income households tend to react more strongly to price changes, which the author hypothesizes could possibly be due to within-households vehicle switching or other forms of substitution that are more likely to be available to richer households. The author also notes that stronger price shocks might also result in higher absolute magnitudes of price elasticity due to the increased saliency of the price change compared to periods of lower variation in prices (Gillingham 2014).

3 Data and Model

3.1 Data

In the present study, we utilize data from the German Socio-Economic Panel (SOEP), a longitudinal panel survey conducted yearly by the German Institute for Economic Research (DIW Berlin). Initiated in 1984, this survey uses questionnaires to gather representative micro-level data on German households regarding their economic, social, and demographic situation[2].

Each individual in the sample who is at least 17 years old is being questioned to assess characteristics including level of education, detailed job history, and political preferences. Furthermore, one member of each household (who in SOEP is referred to as the head of household) fills out an additional questionnaire with questions regarding household-specific characteristics such as the size of the dwelling, appliance stock or the total household income. The household head also answers an additional set of survey questions for each child living in the household.

Since one of the goals of the survey is to allow for long-term observations, the same participants are being interviewed every year. To mitigate attrition caused by interviewees opting out or passing away, and in order to maintain the representative nature of the survey, additional samples are being drawn irregularly, usually every three to five years. At the same time, people moving out of a sample household (e.g. due to divorce or children leaving their parents' home) remain in the sample as a new household. Non-sample people who move into a SOEP household are also included in all subsequent iterations of the survey, even if they leave the household again later on. This procedure aims at reproducing endogenous population developments. For a more thorough description of the SOEP panel, see Wagner et al. (2007).

For our study, we combined personal and household data from the survey, clustered at the household level. Since some of the variables that interest us have only been gathered more recently, we only investigate data from the period between 1992 and 2013. 29.0% of tenants state that the costs for heating and hot water are included in the rent. Since this significantly diminishes the role of prices for the heating decision, we drop these observations from our dataset. Apart from this, we cannot observe the specific nature of the individual contracts that households have. Further exclusion of households that reside in institutions such as retirement homes or student dormitories results in a main sample of 84,623 observations from 16,946 households in an unbalanced panel.

As the fuel type used for heating can only be observed for the waves of 1998 and 2003 of the sample, we do not include it in our investigation. Furthermore, the survey only monitors the expenditures of households for heating and hot water, but not their actual consumption or the prices they face. However, as of 2010, 56.0% of households in Germany use gas for heating (Federal Statistical Office 2012). An additional 32.4% heat with oil; considering that the prices for gas and oil have remained highly correlated (Brigida 2014; Nick, Thoenes 2014), we use real gas prices as a proxy for the price of space heating in our analysis[3]. For most households, the survey is being conducted in the first quarter of the year, and some of the questions relate to the year before[4]. Therefore, we add the consumer gas price from the previous year to our dataset (in 2013 terms). We also include the respondents' state of residence to account for possible unobserved regional differences in both prices and climate. However, spatial climatic variation between regions in Germany is very low. Table 1 presents an overview of the selection of variables that we use for our analysis.

[2] Similar panels from other countries include the PSID (US), BHPS (UK), SLID (Canada), and HILDA (Australia), see Wagner et al. (2007).

[3] Note that this approach has also been employed in a different context by Dieckhöner (2012).

[4] Specifically, renters are asked what their average monthly cost of heating is, whereas homeowners are being asked what their cost of heating was in the preceding calendar year.

Table 1: Variable definitions

Variable	Description
SPACE	size of dwelling, in square meters (1 m^2 = 10.76 ft^2)
ROOMS	number of rooms
CONDITION	condition of home (in good condition, partial renovation, major renovation, ready for demolition), 1 or 0
NEW_WIND	1 if new windows were installed in the previous year, 0 otherwise
NEW_HEAT	1 if new heating system was installed in the previous year, 0 otherwise
TYPE	type of building (farm house, single or double house, row/terrace house or duplex, building containing 3 to 4 dwellings, building containing 5 to 8 dwellings, building containing 9 or more dwellings, high rise building, other), 1 or 0
YEAR	vintage class of building (before 1919, 1919–1948, 1949–1971, 1972–1980, 1981–1990, 1991-2000, 2001-2010, 2011 or later), 1 or 0
CENTRAL_HEAT	1 if household has a central heating system, 0 otherwise
LN_INCOME	log of yearly real net household income, in €
ADULTS	number of adults (age 17 or older) in household
CHILDREN	number of children (age 16 or younger) in household
OWNER	owner or tenant of dwelling, 1 or 0
GENDER	share of male household members
AGE	mean age of all household members
GREENS	share of adult household members who support the Green Party
ENV_WORRIES	environmental worry of adult household members, scale 0-2
EDUCATION	mean education level of adult household members, in years
FULLTIME	share of adult household members working full time
PARTTIME	share of adult household members working part time
UNEMPLOYED	share of adult household members registered unemployed
RETIRED	share of adult household members in retirement
HOMEMAKER	share of adult household members staying at home
STATE	Federal State (Schleswig-Holstein, Hamburg, Lower Saxony, Bremen, North Rhine-Westphalia, Hesse, Rhineland-Palatinate, Baden-Wuerttemberg, Bavaria, Saarland, Berlin, Brandenburg, Mecklenburg-Western Pommerania, Saxony, Saxony-Anhalt, Thuringia), 1 or 0
LN_PRICE_GAS	log of real gas price, in Eurocents per kWh
LN_EXP	log of yearly real heating expenditures, in €
LN_EXP_SPACE	log of yearly real heating expenditures per square meter, in €
LN_EXP_CAP	log of yearly real heating expenditures per inhabitant, in €

3.2 Descriptive Statistics

The relevant descriptive statistics of our technical and socio-demographic variables can be seen in Tables 2 and 3, respectively. We do not observe ownership decisions regarding the equipment stock. Therefore, we take the endowment as given and model conditional demand, similarly to Baker et al. (1989), Rehdanz (2007), Meier and Rehdanz (2010), and Brounen et al. (2012), among others.

Table 2: Summary Statistics: Building Characteristics

Variable	Mean	St. Dev.
SPACE	112.805	46.643
ROOMS	4.419	1.770
CENTRAL_HEAT	0.948	0.221
NEW_HEAT	0.024	0.153
NEW_WIND	0.047	0.212
CONDITION_1 (In Good Condition)	0.740	0.439
CONDITION_2 (Partial Renovation)	0.238	0.426
CONDITION_3 (Major Renovation)	0.022	0.145
CONDITION_4 (Ready For Demolition)	0.001	0.028
TYPE_1 (Farm House)	0.030	0.169
TYPE_2 (1-2 Fam. House)	0.444	0.497
TYPE_3 (1-2 Fam. Rowhouse)	0.205	0.404
TYPE_4 (Apt. In 3-4 Unit Bldg.)	0.095	0.293
TYPE_5 (Apt. In 5-8 Unit Bldg.)	0.142	0.349
TYPE_6 (Apt. In 9+ Unit Bldg.)	0.079	0.270
TYPE_7 (High Rise)	0.005	0.074
TYPE_8 (Other)	0.0001	0.009
YEAR_19	0.155	0.361
YEAR_48	0.148	0.355
YEAR_71	0.258	0.438
YEAR_80	0.131	0.337
YEAR_90	0.112	0.316
YEAR_00	0.152	0.359
YEAR_01	0.044	0.206

For the person-related variables, we computed the mean of all adult members of the household. An alternative specification would be to only use the data of the household head. However, we assume that heating decisions are not made only by the head of the household,

Table 3: Summary Statistics: Economic and Socio-Demographic Characteristics

Variable	Mean	St. Dev.
OWNER	0.668	0.471
ADULTS	2.045	0.807
CHILDREN	0.526	0.906
AGE	45.520	19.027
GENDER	0.489	0.256
ENV_WORRIES	1.130	0.543
GREENS	0.060	0.212
EDUCATION	12.346	2.518
FULLTIME	0.448	0.388
PARTTIME	0.150	0.267
UNEMPLOYED	0.071	0.212
RETIRED	0.268	0.413
HOMEMAKER	0.160	0.278
STATE_1 (Schleswig-Holstein)	0.033	0.179
STATE_2 (Hamburg)	0.011	0.106
STATE_3 (Lower Saxony)	0.107	0.310
STATE_4 (Bremen)	0.007	0.085
STATE_5 (North Rhine-Westphalia)	0.215	0.411
STATE_6 (Hesse)	0.073	0.260
STATE_7 (Rhineland-Palatinate)	0.056	0.230
STATE_8 (Baden-Wuerttemberg)	0.132	0.338
STATE_9 (Bavaria)	0.159	0.365
STATE_10 (Saarland)	0.015	0.121
STATE_11 (Berlin)	0.023	0.150
STATE_12 (Brandenburg)	0.031	0.174
STATE_13 (Mecklenburg-Western Pommerania)	0.016	0.126
STATE_14 (Saxony)	0.050	0.219
STATE_15 (Saxony-Anhalt)	0.035	0.183
STATE_16 (Thuringia)	0.035	0.185
LN_INCOME	10.394	0.580
LN_PRICE_GAS	1.780	0.186
LN_EXP	7.048	0.581 7
LN_EXP_SPACE	2.403	0.551
LN_EXP_CAP	6.222	0.701

but by all (adult) household members.

We included the variables on occupation (FULLTIME, PARTTIME, UNEMPLOYED, RETIRED, and HOMEMAKER) to assess whether they influence expenditures, because some of these groups are likely to spend more hours in the home, for example unemployed or retired people (Longhi 2015). We use the share of all adult members in the household falling into that category, meaning that for any given household, values can range between 0 and 1. People can also fall into multiple categories if they occupied more than one role over the course of a given year. Table 4 shows the correlations between selected variables. These correlation coefficients can give us a first indication of possible inference between some of the variables. Notably, the expenditures variable shows a comparatively strong positive correlation with INCOME, SPACE, and OWNER.

Table 4: Correlation matrix of selected variables

	SPACE	ROOMS	OWNER	ADULTS	CHILDREN	AGE	GENDER	EDUCATION	LN_INCOME	LN_EXP
SPACE	1	0.804	0.411	0.336	0.207	-0.101	0.040	0.257	0.515	0.398
ROOMS	0.804	1	0.403	0.367	0.250	-0.124	0.040	0.207	0.454	0.364
OWNER	0.411	0.403	1	0.186	-0.007	0.153	0.025	0.101	0.272	0.207
ADULTS	0.336	0.367	0.186	1	0.094	-0.257	0.097	-0.012	0.443	0.204
CHILDREN	0.207	0.250	-0.007	0.094	1	-0.649	0.013	0.062	0.190	0.025
AGE	-0.101	-0.124	0.153	-0.257	-0.649	1	-0.120	-0.127	-0.213	0.091
GENDER	0.040	0.040	0.025	0.097	0.013	-0.120	1	0.051	0.128	-0.005
EDUCATION	0.257	0.207	0.101	-0.012	0.062	-0.127	0.051	1	0.446	0.116
LN_INCOME	0.515	0.454	0.272	0.443	0.190	-0.213	0.128	0.446	1	0.266
LN_EXP	0.398	0.364	0.207	0.204	0.025	0.091	-0.005	0.116	0.266	1

Figure 1 depicts the distribution of real heating expenditures among households[5]. The mean value for yearly real expenditures in our sample is € 1344.23 with a median of € 1191.08. 99% of households spend less than € 3966.92 per year, or € 330.58 per month, on heating.

[5] For the sake of clarity, we omit observations beyond the 99.9% quantile in this figure, which eliminates 85 out of 84,623 observations.

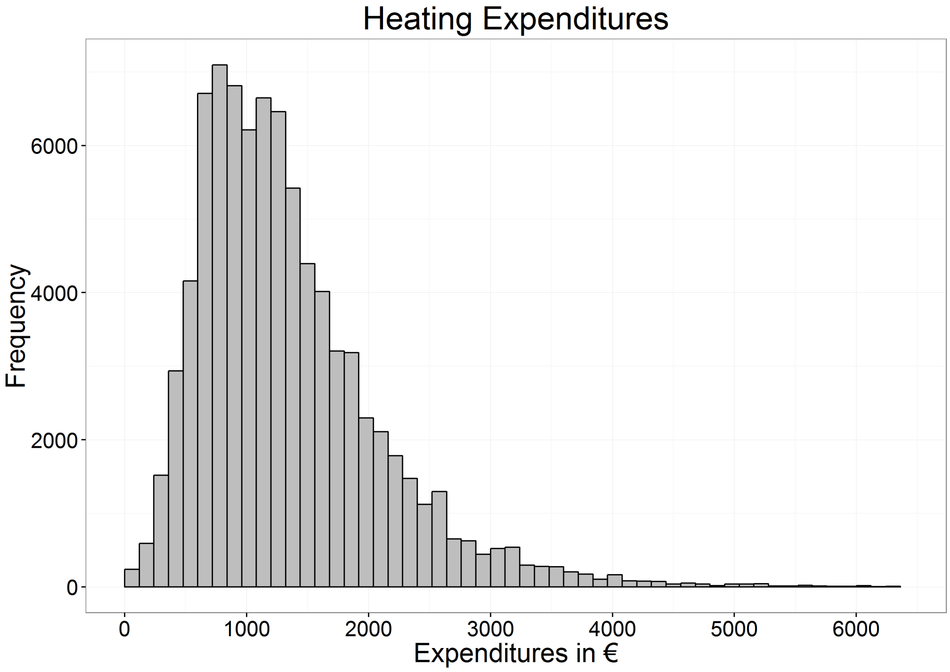


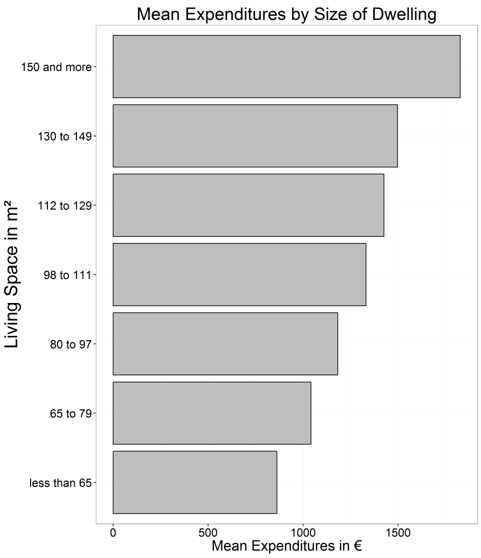
Figure 1: Histogram of real heating expenditures per year

Figure 2 shows the relationship between expenditures for heating and living space, household size, type of dwelling, and age of building, respectively. Unsurprisingly, there is a positive relationship between the size of the home and the expenditures for heating. Physically, more energy is needed to heat larger areas. Furthermore, more spacious homes typically accommodate more inhabitants and have more separate rooms. Therefore, there are likely more hours during the day when heating services are required as well as more rooms that need to be heated at any given time. As figure 2b shows, a higher number of inhabitants results in higher heating expenditures. However, the large discrepancy between single and multi-person households, followed by a much smaller increase for additional inhabitants, suggests the existence of economies of scale. Figure 2c shows that dwellings in apartment buildings use less energy than houses. Naturally, the latter tend to be larger, which might explain part of the difference[6]. For different vintage classes of buildings, we find that newer buildings use less energy, but homes constructed between 1971 and 1990 consume more energy for heating than older buildings. Differences in size might again explain some of the variation. Furthermore, newer buildings have to adhere to stricter rules regarding insulation and are thus much more energy efficient on average.

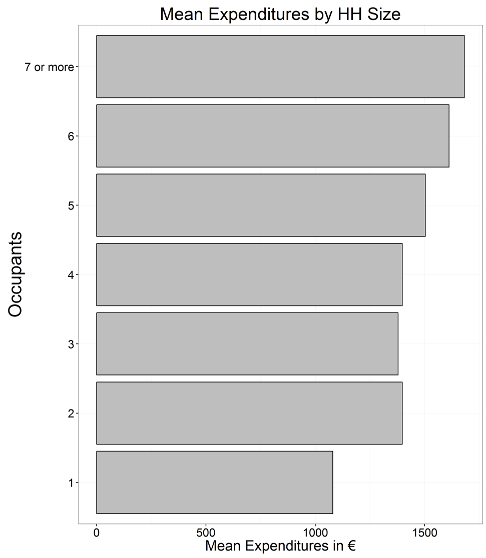
While these figures can give us an indication of the possible influence of some of these variables on heating expenditures, further analysis is necessary in order to isolate the specific effects and gain insights regarding their significance and magnitude.

Figure 3 shows the development of natural gas prices for household consumers in Germany. After a period of decline between 1991 and 1999, real gas prices for consumers have increased sharply since 2000. From 1991 to 1999, the gas price decreased from 5.46 eurocent/kWh to 4.16 eurocent/kWh in 2012 terms. Over the following years, prices consistently increased, reaching 7.03 eurocent/kWh in 2012, which is 45.8% higher than in 1999 and 28.8% above the price in 1992 in real terms. Prices for the other two main sources of residential heat-

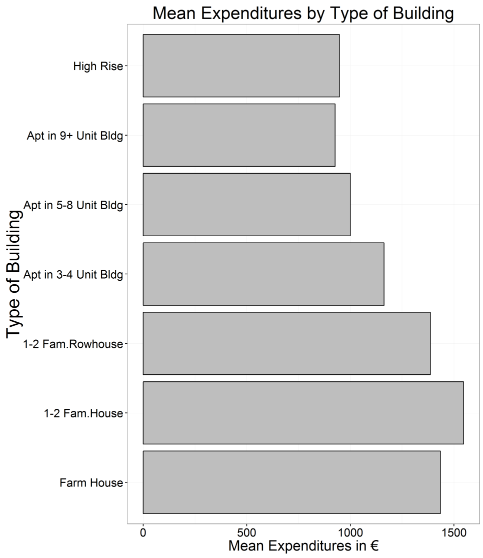
[6] Another explanation are spillover effects. Apartments that are sandwiched between other apartments are heated passively, something that does not happen for free-standing buildings.



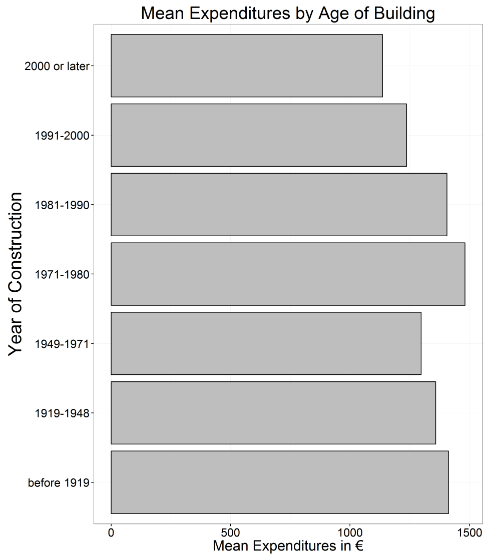
(a) By size of dwelling



(b) By number of occupants



(c) By type of building



(d) By age of building

Figure 2: Heating expenditures in €

ing energy in Germany, oil and electricity, have developed similarly in recent years. Their respective prices also declined until 1999, followed by an increase resulting in prices of 6.31 eurocent/kWh for oil and 28.83 eurocent/kWh for electricity, which is equivalent to an increase in real terms between 1991 and 2012 of 118.76% and 20.83%, respectively.

3.3 Model

Following similar papers, we model conditional demand, meaning that we neither observe nor account for possible changes in the household's appliance stock. Instead, we analyze energy behavior given the current equipment stock of the households. Other researchers have also employed discrete-continuous models, which include both the (discrete) demand for specific appliances and technologies and the (continuous) demand for energy to use them (Vaage

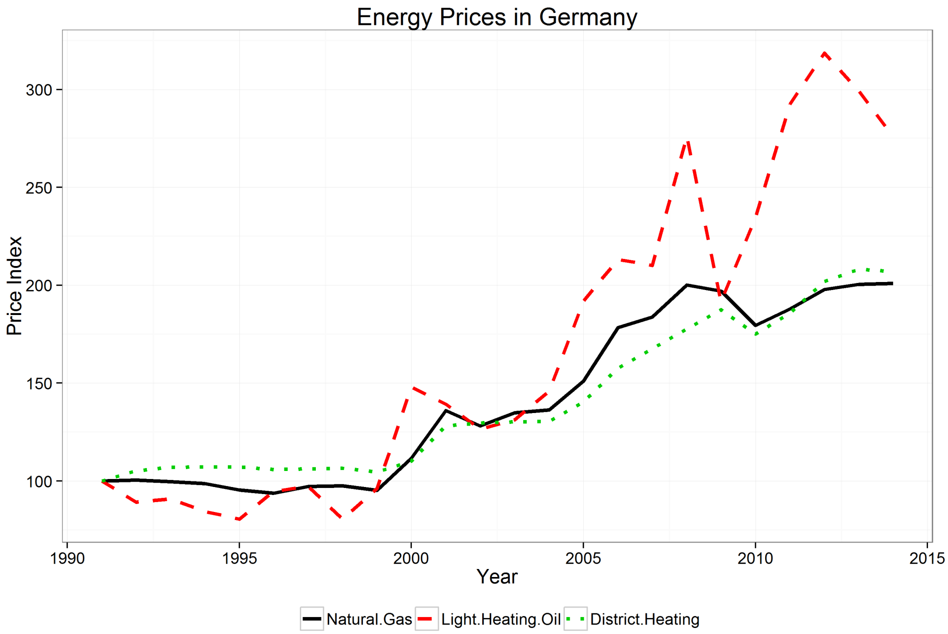


Figure 3: Real fuel prices in Germany (1991 = 100)

2000, Nesbakken 2001, Liao and Chang 2002)[7]. While this approach potentially allows for a more realistic approach to examining interconnected decisions of ownership and consumption, it also makes modeling more complex and requires more detailed data.

Following the standard neoclassical microeconomic framework, we assume households to maximize their utility from heating and to choose the amount of space heating they consume accordingly. In line with recent literature (Meier and Rehdanz 2010; Lange et al. 2014), our model of heating expenditures has the form

$$ln(E_{i,t}) = \beta_p ln(P_{i,t}) + \beta_t T_{i,t} + \beta_s S_{i,t} + \gamma_i + \epsilon_{i,t} \quad (1)$$

with $E_{i,t}$ as the heating expenditures of household i at time t, $P_{i,t}$ as the consumer gas price, $T_{i,t}$ as building characteristics, γ_i as time invariant household fixed effects, $S_{i,t}$ as socio-demographic and socio-economic variables, and $\epsilon_{i,t}$ signifying the error term.

We use a double-log specification, regressing on three different measures of expenditures for heating: total expenditures, expenditures per capita (as used by Brounen et al. 2012 and Longhi 2015) and expenditures per square meter of living space (as employed by Rehdanz 2007[8]). We do not equivalize per capita expenditures, meaning that we do not use weights to distinguish between different household members such as adults and children.

While using a random effects model would result in higher explained variation as well as higher significance for some of the variables, the Hausman test rejects the hypothesis that errors are uncorrelated with the regressors (Hausman 1978). Additionally, the long-term nature of the dataset provides us with enough variation to make the use of a fixed effects model feasible. We also avoid the problem researchers often encounter when using fixed effects

[7] For a more general microeconomic discussion on the discrete-continuous framework, see Hanemann (1984).
[8] Meier and Rehdanz (2010) use expenditures per room due to dwelling size not being measured in their dataset.

models with time-invariant variables: we cluster several variables at the household level that are unlikely to change for the specific individual, such as gender or level of education. This results in sufficient year-to-year variation in our sample due to individuals leaving or joining the household.

4 Results

4.1 Regression Results

In the first step of our analysis, we aim at finding determinants of energy expenditures among the variety of technical, economic, and demographic variables at our disposal. Table 3 shows the results of our fixed effects regression for three model specifications, regressing on expenditures, per capita expenditures, and expenditures per square meter of living space, respectively. Standard errors are corrected for heteroskedasticity according to Arellano (1987).

Table 5: Regression Results

Variable	Log of Expenditures (1)	Log of Expenditures per Capita (2)	Log of Expenditures per m^2 (3)
SPACE	0.001*** (0.0001)	0.001*** (0.0001)	−0.006*** (0.0002)
ROOMS	0.018*** (0.003)	0.017*** (0.003)	0.006* (0.003)
CONDITION_2 (Partial Renovation)	0.024*** (0.006)	0.022*** (0.006)	0.024*** (0.006)
CONDITION_3 (Major Renovation)	0.028 (0.018)	0.031* (0.018)	0.035* (0.018)
CONDITION_4 (Ready For Demolition)	0.068 (0.081)	0.063 (0.076)	0.085 (0.082)
NEW_WIND	−0.018** (0.008)	−0.021** (0.009)	−0.020** (0.008)
NEW_HEAT	−0.027** (0.013)	−0.028** (0.013)	−0.028** (0.013)
TYPE_2 (1-2 Fam. House)	−0.040 (0.054)	−0.032 (0.053)	−0.064 (0.052)
TYPE_3 (1-2 Fam. Rowhouse)	−0.062 (0.056)	−0.051 (0.055)	−0.096* (0.054)
TYPE_4 (Apt. In 3-4 Unit Bldg.)	−0.157*** (0.056)	−0.126** (0.055)	−0.140*** (0.054)
TYPE_5 (Apt. In 5-8 Unit Bldg.)	−0.169*** (0.056)	−0.137** (0.055)	−0.121** (0.054)
TYPE_6 (Apt. In 9+ Unit Bldg.)	−0.268*** (0.059)	−0.218*** (0.058)	−0.188*** (0.057)
TYPE_7 (High Rise)	−0.323*** (0.105)	−0.299*** (0.104)	−0.283** (0.114)
YEAR_48	−0.031 (0.026)	−0.029 (0.026)	−0.003 (0.026)
YEAR_71	−0.020 (0.026)	−0.016 (0.026)	0.012 (0.026)
YEAR_80	−0.055* (0.030)	−0.053* (0.030)	−0.048 (0.030)
YEAR_90	−0.073** (0.034)	−0.073** (0.034)	−0.062* (0.034)
YEAR_00	−0.115*** (0.029)	−0.120*** (0.030)	−0.118*** (0.030)
YEAR_01	−0.281*** (0.034)	−0.276*** (0.034)	−0.279*** (0.034)
CENTRAL_HEAT	0.045*** (0.014)	0.044*** (0.014)	0.031** (0.014)
LN_INCOME	0.044*** (0.009)	−0.022** (0.009)	0.024*** (0.009)
ADULTS	0.068*** (0.006)	−0.289*** (0.007)	0.058*** (0.006)
CHILDREN	0.058*** (0.007)	−0.264*** (0.008)	0.042*** (0.007)
OWNER	−0.028*** (0.011)	−0.029*** (0.011)	−0.037*** (0.011)
GENDER	−0.042** (0.021)	−0.031 (0.025)	−0.046** (0.021)
AGE	0.006*** (0.001)	0.010*** (0.001)	0.006*** (0.001)
ENV_WORRIES	0.008* (0.004)	0.008** (0.004)	0.009** (0.004)
GREENS	−0.022 (0.013)	−0.026* (0.014)	−0.023* (0.013)
EDUCATION	0.004 (0.004)	0.003 (0.004)	0.002 (0.004)
FULLTIME	−0.009 (0.010)	0.005 (0.010)	−0.009 (0.010)
PARTTIME	−0.016* (0.010)	−0.023** (0.010)	−0.017* (0.010)
UNEMPLOYED	0.020* (0.012)	0.005 (0.012)	0.019 (0.012)
RETIRED	−0.022* (0.013)	−0.030** (0.013)	−0.020 (0.013)
HOMEMAKER	0.014 (0.009)	0.008 (0.009)	0.011 (0.009)
LN_PRICE_GAS	0.672*** (0.017)	0.647*** (0.018)	0.658*** (0.017)
STATE_2 (Hamburg)	−0.046 (0.138)	−0.009 (0.115)	−0.045 (0.131)
STATE_3 (Lower Saxony)	−0.104 (0.119)	−0.053 (0.114)	−0.133 (0.113)
STATE_4 (Bremen)	−0.144 (0.207)	−0.047 (0.215)	−0.165 (0.197)
STATE_5 (North Rhine-Westphalia)	−0.003 (0.108)	0.067 (0.099)	−0.024 (0.102)
STATE_6 (Hesse)	0.051 (0.122)	0.128 (0.117)	0.021 (0.117)
STATE_7 (Rhineland-Palatinate)	−0.050 (0.129)	0.038 (0.122)	−0.107 (0.124)
STATE_8 (Baden-Wuerttemberg)	−0.001 (0.113)	0.084 (0.104)	−0.029 (0.109)
STATE_9 (Bavaria)	−0.031 (0.126)	0.060 (0.120)	−0.050 (0.122)
STATE_10 (Saarland)	0.079 (0.139)	0.161 (0.130)	0.040 (0.134)
STATE_11 (Berlin)	−0.257* (0.138)	−0.233* (0.141)	−0.230* (0.130)
STATE_12 (Brandenburg)	−0.087 (0.130)	−0.025 (0.124)	−0.079 (0.132)
STATE_13 (Mecklenburg-Western Pommerania)	−0.053 (0.157)	−0.002 (0.140)	−0.112 (0.146)
STATE_14 (Saxony)	−0.009 (0.133)	0.048 (0.127)	−0.056 (0.133)
STATE_15 (Saxony-Anhalt)	−0.058 (0.192)	0.007 (0.190)	−0.079 (0.186)
STATE_16 (Thuringia)	0.033 (0.231)	0.056 (0.246)	−0.065 (0.233)
N	84,623	84,623	84,623
R^2	0.123	0.257	0.145
Adjusted R^2	0.098	0.205	0.116
F Statistic (df = 50; 67627)	189.306***	467.546***	229.596***

*Notes:****,**, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors in brackets.

Many of the variables show very similar magnitudes across specifications. However, coefficients differ significantly for some variables, which allows us to uncover some additional insights.

Unsurprisingly, a larger living space corresponds with higher heating expenditures. However, the cost per square meter decreases slightly, but significantly, with an increased dwelling size, which suggests the existence of economies of scale. Given the high correlation between number of rooms and living space with a correlation coefficient of 0.80, it is no surprise that the number of rooms also increases total and per capita expenditures.

The self-assessed condition of the home has a significant influence on the expenditures, with a worse state of the home being associated with higher costs. However, the worst category, denoted in the survey as 'ready for demolition', is not significant, possibly due to the small number of dwellings falling under this category. Only 0.1% of households characterize their home in this way. Rehdanz (2007) finds similar effects with the same categorization of building condition. Meier and Rehdanz (2010) observe more specific building problems, such as damp walls or condensation, and find those to have an increasing effect on heating expenditures.

The type of building is also significant for heating expenditures across specifications. Single, double, and duplex homes are associated with higher heating costs than apartment complexes. Separating the latter category further shows lower expenditures for apartment buildings that contain more dwellings. Given that this also holds true for specification (3) suggests that this disparity between building types is not merely a function of living space, which, on average, is larger for single and row houses than for apartments. Our findings confirm previous evidence, for example by Meier and Rehdanz (2010) and, to a lesser extent, by Brounen et al. (2012)[9].

Furthermore, newly installed windows or heating systems also reduce expenditures. However, there is no further information available regarding the specific properties of the newly installed systems, which makes an accurate assessment challenging. Also, the energy savings of those modernization measures might be even larger over longer time periods.

In other studies, the relationship between building age and energy use can be described as an inverted U-shape: newer buildings use the least amount of energy, followed by the very oldest dwellings. Buildings of medium age have the highest energy use per square meter (Brounen et al. 2012; Leth-Petersen and Togeby 2001). There are several explanations for this heterogeneity in expenditures among vintage classes of buildings. Numerous pieces of legislation that aim to improve the energy efficiency of newly built homes have been introduced over the last three decades, both at the EU and the national level. In Germany, the Energy Saving Ordinance, which was first introduced in 2001 and most recently amended in 2014, demands that all newly constructed buildings fulfill strict efficiency standards. Therefore, it should not be surprising that newer buildings use less energy. For the oldest buildings, different building techniques might be responsible for the lower consumption levels (Aksoezen et al. 2015; Chong 2012). Additionally, older buildings have a higher chance of having undergone thermal retrofits, which would further lower energy use. We cannot corroborate these results in our estimations, since in our sample expenditures strictly increase with building age. Also, we are unable to observe the extent to which buildings have been retrofitted, apart from the previously discussed dummy variables for new windows and new heating systems. Especially noteworthy is the massive decline in heating costs for buildings constructed since 2001. Our

[9] Note that the definitions of building categories are not always consistent across different data sources. For example, the SOEP survey does not distinguish between semi-detached and row houses.

results are therefore more in line with Rehdanz (2007), who uses the same data source.

We find a highly significant income elasticity with values ranging from -0.022 to 0.044, which is largely consistent with comparable studies. Brounen et al. (2012) reports 0.055 for the Netherlands, while Meier and Rehdanz (2010) find values ranging from 0.009 to 0.037 for Great Britain using six different models. For Germany, Rehdanz (2007) indicates elasticities between 0.010 and 0.095, depending on the model specification used. One of the few negative values is reported by Berkhout et al. (2004), who find an elasticity of -0.270 using data from the Netherlands. On the higher end of the spectrum, Yu et al. (2014) estimate a value of 0.21 for residents in urban China.

The number of inhabitants has a positive influence on expenditures, with adults having a stronger effect than children. The evidence from other studies regarding children is mixed: while some researchers find that more children result in higher energy consumption (Hirst et al. 1982; Baker et al. 1989; Meier and Rehdanz 2010), others report a negative relationship (Rehdanz 2007). A third group finds the number of children to be insignificant (Nesbakken 1999; Vaage 2000). On a per capita basis, a higher number of household members leads to lower energy expenditures, which suggests the existence of scale effects. Longhi finds a decrease of per capita expenditures of 32% to 38% per additional inhabitant, which is not far from our own result of 26.4% to 28.9% (Longhi 2015, see also Brounen et al. 2012).

Ceteris paribus, homeowners spend less on space heating than tenants. A possible reason for this is the landlord-tenant problem, which, more broadly, can be explained as a principal-agent problem, which has been examined repeatedly in the context of energy use (Allcott and Greenstone 2012; Davis 2012; Levinson and Niemann 2004): The landlord usually has to pay for energy-saving renovations like better insulation or a new, modern heating system, but the tenant then reaps the rewards through a lower heating bill, giving the landlord little incentive to undertake those renovations in the first place[10]. This problem is aggravated in some countries by legislation that restricts landlords in their ability to pass on renovation cost to their tenants in the form of rent increases. In Germany, for example, the yearly rent can be increased by a maximum of 11 percent of the modernization cost (section 559 I BGB).

We observe that a larger share of female adults in the household increases expenditures for space heating. In the past, researchers have seldom discussed the role of gender in energy use, with the exception of the developing world (Clancy and Roehr 2003). For industrial countries, Elnakat and Gomez (2015) present one of the few studies that explicitly explore the role of women as household heads. Using survey data collected in 2012 in the area of San Antonio, Texas, the authors find that female-dominated households use twice as much gas and 54% more electricity than male-dominated homes. These differences persist at a significant, albeit smaller, level when controlling for dwelling size and other factors (Elnakat and Gomez 2015). Gender differences in preferences for warmth can also be explained biologically (Kim et al. 1998).

The average age of occupants also has a small positive influence on expenses. Other studies confirm this, but find the relationship between age and energy use to be non-linear: energy consumption generally increases with age, before then declining again after a certain age threshold (Baker et al. 1989; Meier and Rehdanz 2010). There is evidence for this exact relationship in our data as well: the RETIRED variable, which, unsurprisingly, is highly correlated with average household age and significant in specification (2), has a negative sign.

[10] Other ways in which the landlord-tenant/principal-agent problem can manifest itself include renters whose energy use is covered by the rent (therefore facing zero marginal cost of using energy) and occupants not being able to detect the owner's insulation choice, see Gillingham et al. (2012).

The level of education, however, has no significant influence on heating expenditures. This confirms previous research by Guerra-Santin and Itard (2010), who also find no significant impact of education on energy consumption for heating. However, many other studies do not explicitly focus on the educational level of inhabitants as a possible factor of impact on energy use.

We use two variables to proxy for environmental consciousness: GREENS indicates the share of adult household members who stated that they support the German Green Party. Since the Greens are not among the historically large parties in Germany, and because many households either do not strongly support a specific party or decline to state their preferences, the variable is larger than zero for only about 7.5% of observations. As our results show, the variable has a significant negative influence on expenditures only for one of our model specifications.

The other variable we use to model environmental attitudes is the question of how much interviewees worry about the environment on a 3-point scale ranging from 'not concerned at all' to 'very concerned'. Interestingly, people who state that they are worried about the environment, again taken as the average value of all adult household members, actually spend more money on space heating. The majority of studies in this field disregard environmental values or attitudes as possible explanatory variables for energy use, focusing instead on technical or economic factors. More recently, however, psychological factors and personal environmental attitudes have also started to receive more attention, which corresponds with the increased interest in behavioral economics in recent years (van den Bergh 2008, Wilson and Dowlatabadi 2007). Lange et al. (2014) incorporate households' environmental beliefs and attitudes, in addition to standard technical and socio-economic factors, into their analysis of household expenditures for space heating. Using data from the 2008-2009 wave of the British Household Panel Survey (BHPS), the authors find that while environmental behavior lowers heating expenditures, there is no clear correlation between expenditures and eco-friendly attitudes and beliefs. For electricity use, Sapci and Considine (2014) find evidence that higher environmental concern corresponds with lower consumption.

The gas price, which we use as a proxy for the price of heating, has a highly significant influence on expenditures, with values between 0.647 and 0.672. Recall that we do not regress on energy use for heating, but on heating expenditures. Accordingly, a value of 1 would correspond to a situation of perfectly inelastic demand, whereas a value of 0 would mean that demand is perfectly elastic. Any value between 0 and 1 would imply relatively inelastic demand, which is the case in our analysis. Two other studies that are easily comparable, given that they also use heating expenditures and not consumption as their dependent variable, find values between 0.33 and 0.65 for Germany (Rehdanz 2007) and between 0.36 and 0.83 for Great Britain (Meier and Rehdanz 2010) across different fuel types and model specifications.

4.2 Evidence for Heterogeneity

After discussing possible determinants of heating expenditures in section 4.1, we now focus on the heterogeneity between different groups using three different methods: firstly, we utilize interaction terms between the log of the real gas price and five other explaining variables to reveal heterogeneity between different groups of consumers. Furthermore, our sample is sufficiently large to allow us to separate it into different subsamples, which enables us to uncover additional information about possible heterogeneity. Finally, we also employ quantile regression to obtain information about the relationship between heating expenditures and other variables, especially price. For the sake of clarity and comparability with other studies in the related literature, we focus on the log of heating expenditures per m^2 (specification (3) from Table 4) as our dependent variable from now on.

4.2.1 Interaction Terms

Table 5 shows the results for a model specification that includes five interaction terms between the price of natural gas and several socio-demographic variables. All the explaining variables from Table 4 are still included in the specification, but are not shown in this table for the sake of brevity. The results show that higher income is associated with higher elasticity of heating expenditures, which corresponds to lower price elasticities. Applying a different method, Madlener and Hauertmann (2011) find similar results in their study on rebound effects in residential space heating in Germany. The number of adults is also positively correlated with price elasticity. Specification (3) confirms the findings from Table 3 in that owners have higher expenditure elasticities than tenants, which corroborates similar findings reported in Madlener and Hauertmann (2011).

Table 6: Regression results including interaction terms

Variable	(1)	(2)
SPACE	-0.006^{***} (0.0002)	-0.006^{***} (0.0002)
ROOMS	0.006^{*} (0.003)	0.006^{*} (0.003)
NEW_WIND	-0.020^{**} (0.008)	-0.020^{**} (0.008)
NEW_HEAT	-0.029^{**} (0.013)	-0.028^{**} (0.013)
CENTRAL_HEAT	0.036^{***} (0.014)	0.031^{**} (0.014)
LN_PRICE_GAS	-0.451^{*} (0.273)	0.658^{***} (0.017)
LN_INCOME	-0.161^{***} (0.051)	0.024^{***} (0.009)
ADULTS	0.058^{***} (0.006)	0.058^{***} (0.006)
CHILDREN	0.046^{***} (0.007)	0.042^{***} (0.007)
OWNER	-0.185^{***} (0.048)	-0.037^{***} (0.011)
GENDER	−0.063 (0.104)	-0.046^{**} (0.021)
AGE	0.009^{***} (0.002)	0.006^{***} (0.001)
GREENS	-0.024^{*} (0.013)	-0.023^{*} (0.013)
ENV_WORRIES	0.008^{**} (0.004)	0.009^{**} (0.004)
EDUCATION	−0.003 (0.011)	0.002 (0.004)
FULLTIME	−0.009 (0.010)	−0.009 (0.010)
PARTTIME	-0.018^{*} (0.010)	-0.017^{*} (0.010)
UNEMPLOYED	0.016 (0.012)	0.019 (0.012)
RETIRED	−0.016 (0.013)	−0.020 (0.013)
HOMEMAKER	0.010 (0.009)	0.011 (0.009)
LN_PRICE_GAS*LN_INCOME	0.103^{***} (0.028)	
LN_PRICE_GAS*OWNER	0.088^{***} (0.029)	
LN_PRICE_GAS*GENDER	0.008 (0.057)	
LN_PRICE_GAS*AGE	-0.001^{*} (0.001)	
LN_PRICE_GAS*EDUCATION	0.003 (0.006)	
State fixed effects	Yes	Yes
Building type effects	Yes	Yes
Building condition effects	Yes	Yes
Building age effects	Yes	Yes
N	84,623	84,623
R^2	0.146	0.145
Adjusted R^2	0.117	0.116
F Statistic	210.519^{***} (df = 55; 67622)	229.596^{***} (df = 50; 67627)

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors in brackets. Column (2) reproduces column (3) from Table 4 for comparison.

While our analysis in section 4.1 shows that male-dominated households spend less on heating than those with more female inhabitants, there is no significant difference between men and women regarding their price elasticity. The level of education, which is not significant in determining heating expenditures (see Table 4), is also not significant when interacted with the consumer price of natural gas. The interaction between average price and age is significant, but very small in magnitude. As discussed previously, the relationship between age and heating behavior might be non-linear.

To summarize, the data suggest that there is substantial heterogeneity regarding the price elasticities between different consumer groups, given that three of our five interaction terms are statistically significant.

4.2.2 Subgroups

In order to gain additional insights about the heterogeneity in responsiveness across different groups of households, we also divide our sample into different subsamples. Table 6 displays the results of regressing on expenditures per square meter while splitting the sample into five groups, divided by real household income in 2013 terms.

Table 7: Regression results, sample separated by real income

Variable	<20k	20k-30k	30k-40k	40k-50k	>50k
	(1)	(2)	(3)	(4)	(5)
SPACE	−0.008*** (0.001)	−0.008*** (0.0004)	−0.006*** (0.0004)	−0.006*** (0.0004)	−0.005*** (0.0003)
ROOMS	−0.00001 (0.011)	0.028*** (0.007)	0.0001 (0.008)	0.002 (0.008)	0.010* (0.006)
NEW_WIND	−0.030 (0.024)	−0.037* (0.020)	−0.025 (0.019)	−0.014 (0.022)	−0.011 (0.016)
NEW_HEAT	0.061* (0.033)	−0.030 (0.030)	−0.077*** (0.030)	0.028 (0.034)	−0.033 (0.027)
CENTRAL_HEAT	0.035 (0.024)	0.030 (0.028)	−0.029 (0.037)	−0.006 (0.037)	0.053 (0.035)
LN_INCOME	0.010 (0.022)	0.079* (0.044)	0.063 (0.054)	0.061 (0.079)	0.024 (0.022)
ADULTS	0.041* (0.022)	0.079*** (0.017)	0.057*** (0.016)	0.036* (0.020)	0.054*** (0.013)
CHILDREN	0.064** (0.026)	0.071*** (0.018)	0.036** (0.016)	0.015 (0.022)	0.038** (0.015)
OWNER	−0.043 (0.032)	−0.056** (0.024)	−0.029 (0.021)	−0.002 (0.028)	−0.054** (0.025)
GENDER	−0.093* (0.049)	−0.065 (0.055)	0.033 (0.067)	−0.089 (0.077)	−0.099 (0.063)
AGE	0.005*** (0.002)	0.008*** (0.002)	0.006*** (0.002)	0.007*** (0.002)	0.008*** (0.001)
ENV_WORRIES	0.020** (0.008)	0.006 (0.009)	0.014 (0.009)	0.007 (0.013)	0.020** (0.010)
GREENS	−0.026 (0.034)	−0.031 (0.029)	0.007 (0.035)	−0.033 (0.037)	−0.008 (0.025)
EDUCATION	0.002 (0.011)	−0.0003 (0.012)	0.006 (0.011)	0.006 (0.014)	−0.0002 (0.007)
FULLTIME	−0.002 (0.021)	−0.019 (0.022)	−0.020 (0.024)	−0.008 (0.031)	−0.033 (0.025)
PARTTIME	−0.013 (0.023)	−0.020 (0.022)	−0.019 (0.023)	−0.071*** (0.027)	−0.022 (0.022)
UNEMPLOYED	0.011 (0.022)	0.027 (0.025)	0.009 (0.030)	−0.073* (0.043)	−0.023 (0.042)
RETIRED	−0.014 (0.024)	−0.057* (0.029)	0.011 (0.032)	0.008 (0.040)	0.001 (0.033)
HOMEMAKER	0.041** (0.017)	−0.014 (0.018)	−0.002 (0.022)	0.019 (0.034)	−0.028 (0.021)
LN_PRICE_GAS	0.543*** (0.045)	0.589*** (0.036)	0.634*** (0.037)	0.662*** (0.048)	0.689*** (0.036)
State fixed effects	Yes	Yes	Yes	Yes	Yes
Building type effects	Yes	Yes	Yes	Yes	Yes
Building condition effects	Yes	Yes	Yes	Yes	Yes
Building age effects	Yes	Yes	Yes	Yes	Yes
N	15,900	19,761	18,240	11,883	18,839
R^2	0.123	0.141	0.146	0.164	0.158
Adjusted R^2	0.079	0.091	0.093	0.100	0.118
F Statistic	28.591***	41.881***	39.527***	28.441***	52.629***
	(df = 50; 10198)	(df = 50; 12757)	(df = 50; 11606)	(df = 50; 7244)	(df = 50; 13995)

*Notes:****,**, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors in brackets.

The gas price, which remains one of the variables we are most interested in, is highly significant across all groups. Notably, the coefficient increases with increasing income, indicating that the price elasticity decreases for wealthier households. This confirms our findings from the interaction between price and income that is depicted in Table 5. Previously, Hauertmann and Madlener (2011) found similar results when investigating price elasticities with the goal of obtaining estimates for the direct rebound effect.

Table 8 presents the same regressions as before with the sample separated by average age of all household members, including children. Interestingly, the youngest households exhibit the weakest price reaction. In this group, a 1% increase in price increases expenditures by 0.657%. This coefficient is significantly smaller for households where the average age of all inhabitants is between 30 and 50 years, implying a higher price elasticity in absolute terms. This trend reverses, however, for the oldest households, where elasticities are higher than in the middle three age groups, but lower than for the youngest subgroup.

Table 9 depicts our results when splitting the sample by number of inhabitants. We only consider the total number of people in the household, regardless of how many of them are adults and children. We observe significant differences in the expenditure elasticity with respect to the gas price across household sizes. The price reaction of single-person households is smaller than the reaction of three- and four-person households, but larger than the one for homes with exactly 2 or more than 4 inhabitants. Other variables show remarkably consistent coefficients, most notably SPACE and, to a lesser extent, AGE.

Table 8: Regression results, sample separated by age

Variable	<30	30-40	40-50	50-60	>60
	(1)	(2)	(3)	(4)	(5)
SPACE	−0.006*** (0.0003)	−0.005*** (0.0005)	−0.007*** (0.001)	−0.006*** (0.0005)	−0.006*** (0.0004)
ROOMS	0.002 (0.005)	0.003 (0.008)	−0.008 (0.009)	0.024** (0.010)	0.009 (0.007)
NEW_WIND	−0.034* (0.018)	−0.025 (0.023)	0.011 (0.022)	0.008 (0.020)	−0.001 (0.015)
NEW_HEAT	−0.074*** (0.028)	0.011 (0.030)	0.013 (0.031)	0.054 (0.035)	0.007 (0.023)
CENTRAL_HEAT	0.010 (0.029)	0.075** (0.038)	0.048 (0.049)	0.032 (0.037)	0.052** (0.024)
LN_INCOME	0.031 (0.021)	0.023 (0.019)	0.014 (0.025)	0.020 (0.020)	0.015 (0.017)
ADULTS	0.062*** (0.013)	0.036** (0.017)	0.038 (0.025)	0.018 (0.030)	0.053*** (0.020)
CHILDREN	0.065*** (0.012)	0.023 (0.020)	0.074** (0.038)	−0.296* (0.177)	(omitted)
OWNER	−0.052*** (0.017)	−0.109*** (0.028)	−0.021 (0.037)	−0.061* (0.031)	−0.036 (0.030)
GENDER	−0.026 (0.050)	−0.147*** (0.054)	0.015 (0.084)	0.017 (0.084)	−0.061 (0.045)
AGE	0.011*** (0.002)	0.016*** (0.003)	0.012*** (0.003)	0.015*** (0.003)	0.012*** (0.002)
ENV_WORRIES	0.012 (0.008)	0.019* (0.010)	0.016 (0.012)	0.011 (0.011)	0.012* (0.007)
GREENS	−0.004 (0.026)	−0.059* (0.030)	0.004 (0.033)	−0.032 (0.037)	−0.036 (0.029)
EDUCATION	0.010 (0.007)	−0.002 (0.009)	−0.0002 (0.013)	−0.004 (0.013)	−0.005 (0.011)
FULLTIME	−0.044** (0.019)	−0.008 (0.024)	−0.054* (0.028)	−0.006 (0.026)	0.051** (0.023)
PARTTIME	−0.020 (0.016)	−0.006 (0.024)	−0.032 (0.031)	0.014 (0.027)	−0.036 (0.023)
UNEMPLOYED	0.033 (0.021)	−0.019 (0.029)	−0.020 (0.030)	0.058** (0.026)	−0.009 (0.030)
RETIRED	0.157 (0.108)	0.014 (0.065)	−0.020 (0.050)	0.064** (0.031)	−0.018 (0.017)
HOMEMAKER	0.015 (0.017)	0.047* (0.027)	−0.048 (0.034)	−0.019 (0.029)	0.022 (0.014)
LN_PRICE_GAS	0.657*** (0.036)	0.490*** (0.047)	0.444*** (0.059)	0.472*** (0.053)	0.559*** (0.035)
State fixed effects	Yes	Yes	Yes	No	Yes
Building type effects	Yes	Yes	Yes	Yes	Yes
Building condition effects	Yes	Yes	Yes	Yes	Yes
Building age effects	Yes	Yes	Yes	Yes	Yes
N	23,481	15,875	9,991	10,785	24,491
R^2	0.136	0.111	0.117	0.115	0.135
Adjusted R^2	0.100	0.075	0.076	0.078	0.104
F Statistic	54.150***	26.769***	17.573***	27.194***	59.967***
	(df = 50; 17213)	(df = 50; 10711)	(df = 49; 6516)	(df = 35; 7326)	(df = 49; 18833)

*Notes:****,**, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors in brackets. State effects in model (4) and number of children in model (5) omitted due to multicollinearity issues.

Table 9: Regression results by household size

Variable	1	2	3	4	5+
	(1)	(2)	(3)	(4)	(5)
SPACE	−0.007*** (0.001)	−0.006*** (0.0003)	−0.007*** (0.001)	−0.006*** (0.0003)	−0.005*** (0.001)
ROOMS	0.021* (0.011)	0.001 (0.006)	−0.007 (0.009)	0.008 (0.007)	0.009 (0.009)
NEW_WIND	−0.037* (0.021)	−0.011 (0.012)	−0.011 (0.022)	−0.030 (0.020)	−0.052 (0.041)
NEW_HEAT	0.025 (0.031)	−0.004 (0.020)	0.003 (0.031)	−0.059* (0.031)	−0.121* (0.067)
CENTRAL_HEAT	−0.001 (0.026)	0.064*** (0.021)	0.047 (0.037)	−0.046 (0.040)	0.005 (0.070)
LN_INCOME	0.026 (0.019)	0.016 (0.014)	0.009 (0.020)	0.055** (0.022)	0.016 (0.061)
ADULTS	(omitted)	−0.062 (0.053)	0.010 (0.094)	−0.213 (0.136)	0.038* (0.023)
CHILDREN	(omitted)	0.023 (0.065)	0.020 (0.095)	−0.233* (0.136)	0.022 (0.023)
OWNER	−0.110*** (0.031)	−0.022 (0.021)	−0.074*** (0.025)	−0.021 (0.023)	−0.093** (0.038)
GENDER	−0.271 (0.179)	0.050 (0.141)	0.137 (0.169)	−0.101 (0.360)	−0.298 (0.242)
AGE	0.012*** (0.002)	0.012*** (0.001)	0.017*** (0.002)	0.021*** (0.003)	0.017*** (0.005)
ENV_WORRIES	0.013 (0.008)	0.006 (0.006)	0.019* (0.010)	0.012 (0.011)	0.019 (0.017)
GREENS	−0.012 (0.025)	−0.046* (0.024)	−0.067* (0.039)	0.012 (0.030)	0.071 (0.053)
EDUCATION	−0.002 (0.012)	0.007 (0.008)	−0.010 (0.011)	0.001 (0.010)	0.005 (0.013)
FULLTIME	0.003 (0.021)	0.001 (0.017)	−0.010 (0.023)	−0.0004 (0.026)	−0.025 (0.048)
PARTTIME	−0.022 (0.024)	−0.010 (0.017)	−0.020 (0.021)	−0.003 (0.022)	−0.099*** (0.036)
UNEMPLOYED	−0.007 (0.025)	0.013 (0.020)	0.003 (0.028)	0.053* (0.028)	0.025 (0.049)
RETIRED	−0.055** (0.023)	−0.007 (0.018)	0.048 (0.044)	−0.079 (0.088)	0.191 (0.174)
HOMEMAKER	0.027 (0.017)	−0.018 (0.015)	0.009 (0.025)	0.018 (0.023)	0.074** (0.037)
LN_PRICE_GAS	0.458*** (0.048)	0.538*** (0.029)	0.427*** (0.047)	0.396*** (0.046)	0.597*** (0.074)
State fixed effects	Yes	Yes	Yes	Yes	Yes
Building type effects	Yes	Yes	Yes	Yes	Yes
Building condition effects	Yes	Yes	Yes	Yes	Yes
Building age effects	Yes	Yes	Yes	Yes	Yes
N	16,038	32,614	14,938	15,060	5,973
R^2	0.111	0.137	0.137	0.169	0.166
Adjusted R^2	0.078	0.103	0.096	0.127	0.125
F Statistic	29.136***	77.888***	33.184***	46.957***	19.097***
	(df = 48; 11247)	(df = 50; 24517)	(df = 50; 10459)	(df = 49; 11306)	(df = 47; 4517)

*Notes:****,**, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors in brackets. Number of adults and number of children omitted in model (1) because, in the framework of the survey, a single person household can only consist of one adult.

4.2.3 Quantile Regression

To uncover additional details about our sample, we employ a quantile regression approach. While standard OLS regressions estimate the conditional mean of the distribution, quantile regression allows us to derive coefficients for different quantiles of the dependent variable (Koenker and Bassett 1978). Therefore, we can discover whether households who spend more on heating react differently to price changes compared to those who consume less. Table 10 shows the results for the quantile regression at the 0.1, 0.3, 0.5, 0.7, and 0.9 quantiles of logged heating expenditures per m^2 of living space.

Table 10: Quantile Regression results, full sample

Variable	Q_{10} (1)	Q_{30} (2)	Q_{50} (3)	Q_{70} (4)	Q_{90} (5)
SPACE	−0.005*** (0.0002)	−0.004*** (0.0001)	−0.004*** (0.0001)	−0.004*** (0.0001)	−0.004*** (0.0001)
ROOMS	0.009** (0.003)	0.006*** (0.002)	0.002 (0.002)	−0.004* (0.002)	−0.007*** (0.002)
NEW_WIND	−0.063*** (0.017)	−0.014 (0.010)	0.002 (0.010)	0.013 (0.011)	0.012 (0.012)
NEW_HEAT	−0.070** (0.028)	−0.026* (0.014)	0.013 (0.013)	0.023 (0.014)	0.036** (0.016)
CENTRAL_HEAT	0.205*** (0.017)	0.130*** (0.011)	0.091*** (0.010)	0.064*** (0.010)	0.038*** (0.013)
LN_INCOME	0.092*** (0.008)	0.085*** (0.005)	0.074*** (0.005)	0.069*** (0.005)	0.068*** (0.007)
ADULTS	0.058*** (0.005)	0.045*** (0.003)	0.038*** (0.003)	0.032*** (0.003)	0.024*** (0.004)
CHILDREN	0.033*** (0.005)	0.026*** (0.004)	0.024*** (0.003)	0.027*** (0.004)	0.021*** (0.005)
OWNER	−0.161*** (0.008)	−0.119*** (0.006)	−0.105*** (0.005)	−0.099*** (0.006)	−0.103*** (0.008)
GENDER	−0.073*** (0.014)	−0.046*** (0.008)	−0.028*** (0.008)	−0.023*** (0.009)	−0.013 (0.011)
AGE	0.006*** (0.0004)	0.005*** (0.0002)	0.004*** (0.0002)	0.004*** (0.0002)	0.003*** (0.0003)
ENV_WORRIES	−0.015*** (0.005)	−0.011*** (0.004)	−0.012*** (0.004)	−0.006 (0.004)	−0.004 (0.005)
GREENS	−0.073*** (0.018)	−0.083*** (0.009)	−0.071*** (0.010)	−0.071*** (0.011)	−0.089*** (0.012)
EDUCATION	0.005*** (0.002)	0.003*** (0.001)	0.003*** (0.001)	0.004*** (0.001)	0.003* (0.001)
FULLTIME	−0.065*** (0.015)	−0.041*** (0.009)	−0.036*** (0.008)	−0.034*** (0.010)	−0.038*** (0.010)
PARTTIME	−0.023 (0.014)	−0.025*** (0.009)	−0.034*** (0.008)	−0.023** (0.009)	−0.024** (0.012)
UNEMPLOYED	0.049*** (0.016)	0.055*** (0.010)	0.050*** (0.010)	0.052*** (0.010)	0.068*** (0.014)
RETIRED	−0.090*** (0.018)	−0.052*** (0.010)	−0.040*** (0.009)	−0.032*** (0.011)	−0.014 (0.013)
HOMEMAKER	−0.013 (0.012)	0.003 (0.008)	−0.007 (0.007)	−0.011 (0.009)	0.003 (0.010)
LN_PRICE_GAS	0.699*** (0.020)	0.691*** (0.011)	0.688*** (0.010)	0.666*** (0.012)	0.646*** (0.017)
Constant	−0.344*** (0.089)	0.228*** (0.052)	0.634*** (0.052)	1.042*** (0.054)	1.515*** (0.071)
State effects	Yes	Yes	Yes	Yes	Yes
Building type effects	Yes	Yes	Yes	Yes	Yes
Building condition effects	Yes	Yes	Yes	Yes	Yes
Building age effects	Yes	Yes	Yes	Yes	Yes
N	84,623	84,623	84,623	84,623	84,623

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard Errors are calculated via bootstrap methods and are in brackets.

While most of our coefficients are highly significant, they also do not vary much between quantiles. Notably, additional income raises expenditures less for households that already spend comparatively high amounts on space heating. Similarly to previous works who found the same result for driving (Wadud et al. 2010, Gillingham 2014), this might be due to the fact that those households already achieve their preferred level of thermal comfort. Subsequently, they do not increase their consumption as much when their income increases, compared to households that spend less on space heating in the first place.

When comparing the price elasticities at the different quantiles, the coefficients decrease with increasing expenditures. This means that households who spend more on heating have a stronger price reaction. However, while the difference between the groups is statistically significant, it is relatively small. The coefficient at the median, depicted in model (3), is very close to the mean result when compared to an OLS regression (0.688 compared to 0.684[11]). The same is true for most of the other variables.

4.3 Robustness of Results

In order to confirm the significance of our results, we perform a variety of robustness checks. We focus on specification (3) from Table 5, regressing on heating expenditures per m^2. Fol-

[11] Full OLS regression results are not included here, but are available from the authors upon request.

lowing, among others, Gillingham (2014), we estimate the base model from Table 5 with linear specification for expenditures, income, and price to rule out possible misspecification. Our coefficients state that a price increase of 1 eurocent increases yearly heating expenditures per m^2 by €1.33. Given the average natural gas price and heating expenditures, this implies a price elasticity of expenditure of 0.671. Given that this value is very similar to the original coefficient depicted in Table 5 (0.658), we conclude that there is no problem of misspecification due to the log-log nature of our model.

80.9% of our observations originate from households living in West Germany. While this distribution is representative for the population in Germany, it is conceivable that a regression for East Germany alone would yield very different results that simply do not show up in our estimation due to the relatively small share of observations from East Germany. However, when we run separate regressions for households from West and East Germany, we find most of the coefficients to be nearly identical. For instance, the income and price coefficients are 0.021 and 0.657 for West Germany and 0.037 and 0.656 for East Germany (including Berlin).

Since the price development for natural gas can be divided into two very distinct phases, this might also be a source of potential bias due to possible asymmetry in price reactions. Between 1991 and 1999, real prices were stable and declined slightly. Since 2000, however, prices have increased consistently and continue to do so. When running separate regressions for the time periods of 1992-2001 and 2002-2013, we find a higher absolute value for the gas price elasticity in the first time period (0.856 compared to 0.575 for the second period[12]). This implies that the price reaction is weaker when facing declining prices compared to experiencing price increases. A possible explanation for this asymmetry is that households might invest in energy efficiency or develop energy-saving habits when prices rise, but would not reverse these efforts when suddenly facing lower prices (Frondel and Vance 2013). Consequently, the reduction in consumption following a price increase would be higher than the increase in consumption after a price decrease of the same magnitude. Therefore, our results should be treated with caution when applied to an environment of strictly falling or strictly rising prices. At the same time, this result can be interpreted as an indicator for possible asymmetry in price reactions.

5 Conclusions and Outlook

In this study, we investigated possible determinants of space heating expenditures for households via a fixed effects framework. We put the emphasis on including social characteristics which, in this research area, are not as well explored as technical variables. Our analysis yields evidence that both technical variables, most notably building age and dwelling size, as well as socio-demographic aspects, especially income, age, and gender, are important contributing factors when explaining household expenditures for heating.

Furthermore, we explored possible heterogeneity between groups of households using a variety of methods. The data strongly suggest the existence of significant heterogeneity between socio-economic groups, for example when separating by income or household size. Most notably, younger occupants react less strongly to price changes than older ones, and poor households are more price responsive than richer ones. While the quantile regression approach also provides significant evidence for heterogeneity, the absolute differences in price responsiveness are relatively low between groups when using this method.

[12] Recall that the coefficient for the entire sample is 0.658.

Our results have implications for policy makers who attempt to target consumer behavior, since the data indicate that consumer reactions to certain policy measures, such as mandatory efficiency standards or subsidies for retrofitting homes, would create divergent results for different groups of consumers. Subsequently, tailoring programs to specific groups might be a better choice than uniform legislation for the entire population.

There are several avenues of future research that arise from this work. Utilizing actual consumption data as well as observing the fuel type and heating system used by households would likely yield additional insights and allow to compare our results more easily with other studies that investigate household demand for energy. Another possible extension would be the estimation of welfare effects for price changes as well as different policy measures that directly or indirectly influence energy prices. More detailed data regarding the insulation of homes as well as the efficiency of the heating systems used could also be valuable, especially in trying to estimate (the heterogeneity of) direct rebound effects in space heating. More generally, the theoretical concept of rebound and its role in space heating is not yet fully understood in the literature.

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