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Regional determinants of residential energy expenditures and the principal-agent problem in Austria

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Abstract. The aim of this paper is twofold: 1) to examine the determinants of residential energy expenditures and compare them on a regional level; and, 2) attempt to identify and measure the effect of possible principal-agent (PA) problems on residential energy efficiency in Austria. The results of this paper are partially based on findings from a master's thesis, which focused more directly on the PA problem. This paper expands on those results to include regional aspects in energy expenditures. A conditional demand model is regressed on a large number of variables representing housing characteristics, socioeconomic factors, occupancy type, and regional characteristics sourced from the EU Statistics on Income and Living Conditions dataset. The analysis indicates that significant regional differences exist in the determinants of residential energy expenditures and that PA problems appear to be an unimportant factor in energy efficiency in Austria, even at the regional level. The paper concludes with some possible explanations as to why this is the case.

Key words: energy efficiency, principal-agent, housing tenure, energy expenditures, regional aspects

1 Introduction

Concern about climate change and greenhouse gas emissions has brought about renewed attention to energy conservation with a particular focus on the energy efficiency of buildings in the residential sector. The private household sector in Austria, for example, was responsible for 24% of final energy consumption in 2011 – 87% of which was attributed to space heating, water heating, and cooking (Statistik Austria 2013). Given their large share of residential energy consumption, these three energy uses serve as important indicators for energy efficiency performance in Austria. Economic literature of the past 30 years, however, has identified both market failures and non-market barriers as potential factors that deter the adoption of efficient technology in the residential sector. These include imperfect information, positive externalities, hidden costs, and misplaced or split incentives (see especially Blumstein et al. 1980, Gillingham et al. 2009, Golove, Eto 1996, Hirst, Brown 1990, Howarth, Andersson 1993, Jaffe, Stavins 1994, Sorrell et al. 2004, Sutherland 1991). Among these barriers, information problems and split incentives – typically referred to together as the principal-agent (PA) problem – have a prevailing effect in the residential sector (Gillingham et al. 2009, Sathaye, Murtishaw 2004, Sorrell et al. 2004). Furthermore, regional characteristics may affect investment levels in and implementation of energy efficient technology in the residential sector. These characteristics could be the result of topographical, climatic, socioeconomic, or institutional differences at the regional (e.g. subnational) level.

Agency theory posits that a PA problem exists whenever an agent acts on behalf of a principal (e.g. managing property that is owned by the principal) but the interests of the two parties are not aligned, information is asymmetric, and transaction costs exist (Bannock et al. 1992, Murtishaw, Sathaye 2006, Ross 1973). One such manifestation of the PA problem concerning energy efficiency is the landlord-tenant relationship: The tenant/principal pays rent to the landlord/agent in exchange for use of the dwelling. As described by Meier, Eide (2007), the tenant pays energy costs that are largely determined by the infrastructure present in the building, while the landlord makes (or declines to make) investments in the building so as to lower its energy consumption. The landlord has no incentive to make efficiency investments because only the tenant benefits from these reduced costs. Likewise, the tenant has no incentive to make investments since any increase in asset value would be realized by the owner (and the tenant may not occupy the dwelling long enough to recover their investment costs). If energy prices rise, the landlord still lacks any incentive to respond by making additional investments in efficiency. In this sense, the energy consumption is somewhat "insulated" from energy prices, and cost-effective opportunities for energy efficiency improvement may be ignored (IEA 2007, Meier, Eide 2007, Sorrell et al. 2004). It is believed that this results in tenant-occupied households paying higher energy bills for inefficient dwellings than those that are owner-occupied.[1]

Since it is generally acknowledged that energy use in buildings can be significantly reduced through cost-effective investments in efficient technology, it is important to understand the regional differences in energy consumption patterns and characteristics that may have an impact on energy efficiency decision-making. This is especially important in federal systems, such as Austria, where the federal subdivisions are responsible for energy policy implementation and regional energy suppliers exist. Furthermore, it is also critical to examine the magnitude of PA problems that potentially keep economically sound investments from being realized, given the information problems and transaction costs involved. A thorough investigation could identify policy pathways that enhance and encourage investment in energy efficient buildings. The aims of this paper, therefore, are to: 1) examine the determinants of energy consumption patterns in Austria and identify any regional differences; and, 2) identify and measure the effect of the PA problem on residential energy expenditures in Austria. In other words, the paper is guided by two overarching research questions: 1) what regional differences exist in the determinants of residential energy expenditures; and 2) does market failure due to a PA problem contribute to higher energy expenditures for renters than for owners? The work presented in this paper is partially based on the results of a master's thesis that focused more specifically on the PA problem investigation. The paper expands on this in order to examine regional differences in energy consumption patterns and the manifestation of the PA problem within those regions.

The focus of the study is on energy consumption attributed to space heating, water heating, and cooking using individual household-level data collected in the EU Statistics on Income and Living Conditions (EU-SILC). The analysis specification includes a large number of building and socioeconomic characteristics, including occupancy type, regressed in a conditional demand model with household energy expenditure per square meter as the dependent variable. Due to the regional characteristics of Austria (i.e. topography, federal subdivision system, and socioeconomic differences between states), it is expected that differences exist in the determinants of energy outlays. These are detected and measured by the statistical significance of the independent variables, especially the socioeconomic, occupancy type, and fuel source variables. The occupancy type variable is also the critical explanatory variable used to identify and measure the PA problem – its size, sign, and significance are all relevant and can be measured Austria-wide or at the regional level.

[1] Due to limitations to length and scope of the paper, a full, theoretical background of the PA problem is not discussed here. A full discussion in the context of this study is given in the full thesis, and especially in Meier, Eide (2007), IEA (2007), and Murtishaw, Sathaye (2006). Contact the author directly for a copy of the original thesis, or visit this link on ResearchGate.com: DOI:10.13140/2.1.3457.6967

The expectation is that, for owners, this variable will be both negative and statistically significant, indicating the existence of the PA problem in Austria. The scope of the study is limited to the private, residential building sector in Austria, where PA problems are thought to be most prevalent, and where regional differences are more easily detected.

The remainder of this paper is as follows: the next section gives an overview of the relevant literature; the third and fourth sections describe the data and model specifications used for the analysis; the fifth section presents and discusses the regression results, and the final section provides some concluding remarks.

2 Previous studies

Dubin, McFadden (1984) were among the first to investigate the choice of energy-using equipment and energy use using a discrete-continuous modeling framework on micro-level data for the US. Other studies in the US and Canada include Bernard et al. (1996), Lee, Singh (1994), and Liao, Chang (2002). In Europe, most of the studies were conducted for Norway (Nesbakken 2001), the Netherlands (Brounen et al. 2012, Van Raaij, Verhallen 1983), the UK (Baker et al. 1989), and Germany (Braun 2010, Schuler et al. 2000). They expanded the discrete continuous model with additional socioeconomic characteristics of households, including occupancy type. Other studies that provide important contributions to residential energy efficiency literature include Branch (1993), Garbacz (1983), Brounen et al. (2012), Green (1987), and Hirst et al. (1982). Most of these studies investigate price and income elasticities to estimate changes in energy demand and differ in methodology, location, and data aggregation. There is also a rich literature concerning policy measures and their effectiveness in enhancing energy efficiency (see, e.g. Bird, Hernández 2012, Brown 2001, Linares, Labandeira 2010, Schaefer et al. 2000).

Murtishaw, Sathaye (2006), Wilkerson, Sweeney (2015), and a study published by the International Energy Agency (IEA 2007) focus more directly on PA problems in residential and commercial energy use. Specifically, these studies relied on descriptive statistics of housing stocks and energy consumption to provide quantitative estimates of the potential importance of PA problems in different countries. More recent econometric analyses use individual household data to measure the extent to which a PA problem may exist, several of which use a conditional demand model (see, e.g. Baker et al. 1989, Charlier 2012, Davis 2010, Gillingham et al. 2012, Leth-Petersen, Togeby 2001). Three relevant studies, however, provide insight on an appropriate model design for this paper. Rehdanz (2007) examines the determinants of household expenditures on space heating and hot water supply in Germany on more than 12,000 households for the years 1998 and 2003. She finds significant evidence that owners pay less in heating bills than renters, and regional differences between East and West Germany. Meier, Rehdanz (2010) conducted a similar study for Great Britain, employing a conditional demand model on panel data on 64,000 households over a 15-year period (1991–2005). They find that owners pay more in heating bills than renters in that country do. Finally, Wood et al. (2012) focus their investigation more directly on the PA problem for Australia in order to quantify its magnitude in the private rental housing market. They fail to find evidence of a PA problem for the Australian market. All three of these studies modeled energy expenditures as a function of building, socioeconomic, and regional characteristics.

The following analysis is in line with previous research with the inclusion of a large number of building and socioeconomic characteristics as determinants of household energy demand. It differs from the above studies mainly in location and restrictions to the dataset, but also in its focus on the PA problem and regional differences. To the best of the author's knowledge, this paper is the first empirical investigation of a PA problem relating to energy efficiency in Austria using household-level microdata from the EU-SILC. Additionally, it is the first examination of the determinants of residential energy expenditure on a regional level in Austria.

3 Data employed

The European Union Statistics on Income and Living Conditions (EU-SILC) is an instrument that collects comparable cross-sectional and longitudinal multidimensional microdata on income, poverty, social exclusion, and living conditions in Member States. The EU-SILC dataset was selected because it provides descriptive variables on housing, demographic, socioeconomic, and financial characteristics on individuals and households in Austria. Around 6,000 households participate annually in the Austrian EU-SILC. It is therefore a nationally representative dataset that, since 2012, contains information on the annual energy expenditure of households. While it would be preferable and more informative to utilize the time-series feature of the Austrian EU-SILC panel data, the current study is restricted to the survey year 2012 because it is the first year in which respondents were asked about their annual expenditure on electricity, gas, and other fuel.

The structure of the model includes variables that describe housing, socioeconomic, and regional characteristics of the household. Following a similar approach as previous studies, the model includes a large number of dummy variables describing the dwelling's period of construction, type of heating system (central system or single stove), and fuel source for space heating, water heating, and cooking. Households may have more than one fuel source (i.e. fuel stacking) or none at all (i.e. electricity only). The model also controls for the presence of renewable energy technology and whether one or more of the fuels are not paid for directly by the household. The type of building is expected to have a significant effect on energy expenditures. There are five classifications of buildings: 1) detached housing with one or two apartments, 2) semi-detached with one or two apartments, 3) multi-family house (MF) with 3–9 apartments, 4) MF with 10–19 apartments, and 5) MF with 20 or more apartments. Other controls include the size of the dwelling in square meters, presence of any structural problems (e.g. moisture, rot, leaky roof or windows, etc.), presence of a bath or shower, and whether a central heating system is present (e.g. district heating, central heating, gas convector, or electric heating).

The occupancy type, i.e. tenure relationship, is the critical explanatory variable for detecting the PA problem. Its sign, size, and statistical significance are used to determine if the problem exists and to what extent it affects energy expenditures. A binary variable controls for the tenure status of the dwelling in question, indicating if the occupants are renters or owners. The group "renters" includes main renters, subtenants, and co-operative agreements of either an apartment or house; "owners" includes both house and apartment owners. The socio-economic variables control for household characteristics that may affect energy consumption per household. These include the number of adult occupants over the age of 16, number of children aged 16 and under, household disposable income, and age of the oldest household member. Additionally, the model controls for the number of household members registered as unemployed or retired in order to account for the number of people possibly home during the day.

Finally, the model includes regional control variables: a state dummy variable, indicating which of the nine federal states of Austria the dwelling is located; and an urbanization dummy variable, indicating the level of urbanization, or population density. The state variable controls for possible variations in the price for fuel and electricity. The urbanization variables may similarly capture price variations, but also energy-demand variations due to the urban "heat island" effect, which can influence the demand for heat energy. This effect causes urban areas to be warmer than rural ones under similar weather conditions (see also Gartland 2008, Meier, Rehdanz 2010, p. 951, fn. 4). A combination of the state and urbanization variables is also used as a crude proxy for possible differences in weather conditions. The definition of variables included in the analysis is shown in Table 1.

A limitation to the dataset used in the analysis is that no information is offered on energy consumption; instead, expenditures on energy consumption are recorded. Additionally, no information is available on the efficiency or age of the appliances or the presence and efficiency of insulation. As far as the latter issue is concerned, the variables indicating the age of the building, presence of any structural damage, and type of tenure might capture some of this information. Concerning the former, household

Table 1: Description of variables included in the regression

Variable	Definition
L_EXP_SM	***Log of annual expenditures for energy per m^2 (dependent)***
OWNER	Unity if owner-occupied, zero otherwise
TYPE	Type of building: Detached house (SF), semi-detached (RH), multi-family with 3-9 flats, MF with 10-19 flats, MF with 20 or more flats; unity or zero
VINTAGE	Period of construction: Before 1919; 1919-1944; 1945-1970; 1971-1980; 1981-1990; 1991-2000; 2001-2005; 2006-2010; unity or zero
L_SIZE	Log of size of dwelling in square meter
BATH	Unity if dwelling has bath or shower, zero otherwise
PROB	Unity if dwelling has structural problems (i.e. rot, moisture, leaky roof or windows), zero otherwise
HEAT_C	Unity if dwelling has a central heating system (i.e. district heating, central heating, electric heating, or gas convector heating), zero otherwise
FUEL	Type of fuel source: (G) Gas, (O) oil, (W) wood, (C) coal, (N) none (i.e. electricity only); unity or zero (fuels are not mutually exclusive, fuel stacking allowed in model)
RENEW	Unity if dwelling is using renewable energy, zero otherwise
NOTPAID	Unity if household does not pay for one or more fuel, zero otherwise
L_INC	Log of household disposable income in euros
ADULTS	Number of adults older than 16
CHILDREN	Number of children 16 and younger
L_AGE	Log of age of oldest household member
UNEMPL	Number of officially registered unemployed members of the household
PENSION	Number of officially registered retired members of the household
STATE	Austrian Federal State: (BU) Burgenland, (KA) Carinthia, (NO) Lower Austria, (OO) Upper Austria, (ST) Styria, (SZ) Salzburg, (TR) Tirol, (VO) Vorarlberg, (W) Vienna; unity or zero
URBAN	Level of urbanization: (1) Densely populated area, (2) intermediate area, (3) thinly populated area; unity or zero

Source: European Union Statistics on Income and Living Conditions, 2012, Austria.
Descriptive statistics for the dataset are available in Table 5-2 on page 30 of the thesis.

energy expenditure is used as a crude proxy for energy consumption in this model with a broad assumption that expenditures are perfectly correlated with consumption. Another limitation is that both the variables that capture the size of the dwelling and age of the oldest household member are truncated variables (the upper limits being $200m^2$ and 80 years, respectively). Since the size of the dwelling is expected to have a significant effect on energy expenditures, and the number of observations above $200m^2$ was relatively small, this limitation was ignored. The result is that the variance in the size of dwellings above $200m^2$ is not measured accurately. The same is true of the age variable.

Excluded from the analysis are households receiving social benefits, living rent-free or paying a reduced rent, and those living in council or social housing. Also excluded are buildings that are non-residential, such as school housing, hospitals, or nursing homes. For most of these households, expenditures for energy are included in the monthly rent, room, and board, or partially paid for by the government, and are independent of consumption. Also excluded are households that reported less than one year of occupancy, since the total yearly energy costs were not captured in the survey; households with district heating costs included in the running costs of the building; and those that reported less than €100 in energy costs, because it was unclear from the survey if some of those costs were recorded elsewhere. Finally, households without a water connection and those that reported income from rental property were also excluded. The final sample size is 4,164: 2,745 (66%) of which are owners, and 1,419 (34%) are renters.

4 Model specification

The model specifies the annual household energy expenditures per square meter as a function of the occupancy type, characteristics of the building in question, type of fuel, socioeconomic characteristics, and regional characteristics of individual households. The multiple-linear regression model is estimated using ordinary least squares (OLS) with a logarithmic functional form. Different transformations of the dependent variable were considered but the log-linear model provided the most consistent results judging from tests for functional form (Wooldridge 2012) and the Box-Cox transformation procedure written for SPSS® by Raynald Levesque (see Osborne 2010). Moreover, a log-linear form is in line with earlier studies. Heteroscedasticity was not detected judging from both Breusch-Pagan and residual plot tests; therefore, heteroscedasticity-consistent standard errors, i.e. robust standard errors, were not necessary in the analysis (Hayes, Cai 2007, White 1980).

Regression results were obtained from seven log-linear models corresponding to sample designs that differ in terms of their geographical coverage or occupancy type. The first model included all households that met the criteria outlined in the previous section, i.e. the entire sample size of 4,164 households. The second model was restricted to households in Vienna only, while the third, fourth and fifth models were restricted according to the three, EU-NUTS Level 1 regions in Austria. These included: Eastern Austria (NUTS-AT1), comprised of Burgenland and Lower Austria, but excluding Vienna; Southern Austria (NUTS-AT2), Carinthia and Styria; and Western Austria (NUTS-AT3), Upper Austria, Salzburg, Tyrol and Vorarlberg. Narrowing the analysis to geographical regions allows for judging whether there are regional differences in determinant factors for energy expenditures in Austria. Moreover, the presence of the PA problem and its magnitude can be tested in the different regions. Lastly, it became apparent that the OWNER variable may be obscuring differences in characteristics between owners and renters. Therefore, the sixth and seventh models examine the determinants of energy expenditures for owners and renters, separately.

5 Empirical results

Tables 2 and 3 report OLS regression results for the seven model specifications, including the coefficients, standard errors, and significance levels. Sample sizes are healthy for each specification, i.e. all are above 800 observations.

Consider the estimates of the Austria-wide model, for the moment, and the building characteristics and fuel sources in particular. Except for the critical occupancy-type variable, all other building variables have their expected impact on the dependent variable. Detached and semi-detached housing, for example, are found to be more energy intensive than other types of building. Compared to multi-family housing with 20 or more flats, detached housing is 33% more costly in energy per square meter, and semi-detached housing is 31% more.[2] Older buildings, especially those built prior to World War II, are also less efficient. Buildings built before 1919 are 15% more costly per square meter compared to those built between 2006 and 2010. There is a noticeable increase in energy efficiency in newer buildings, with those built after 1991 being the most efficient. The fuel variables also have their expected signs and significance levels. For all households in the sample, gas and oil add 33–75% to annual energy expenditures per square meter, respectively, while wood and coal add 13–29%, respectively. Households that reported no fuel usage are assumed to rely solely on electricity for cooking and/or water heating, increasing energy outlays by 14%. The presence of a renewable energy source reduces energy costs by 10%. Recall that the variable NOTPAID indicates when a household does not pay for one or more of the fuels, including electricity and/or district heating. It has the expected negative and statistically significant impact on energy expenditures.

[2] Following Halvorsen, Palmquist (1980), in the case of dummy variables, percentage change values were computed as $\exp(c) - 1$ from the OLS results, where c is the respective OLS coefficient.

Table 2: Log-linear estimates of annual energy expenditures per square meter[a]

Explanatory variables	All Coeff.	All Std. Err.	Vienna Coeff.	Vienna Std. Err.	Eastern[b,c] Coeff.	Eastern[b,c] Std. Err.	Western Coeff.	Western Std. Err.	Southern Coeff.	Southern Std. Err.
OWNER	0.041**	0.021	-0.067	0.046	0.013	0.051	0.116***	0.033	0.075*	0.044
TYPE_SF	0.285***	0.035	0.375***	0.067	0.299***	0.088	0.278***	0.061	0.256***	0.075
TYPE_RH	0.269***	0.036	0.299***	0.081	0.299***	0.096	0.246***	0.065	0.302***	0.083
TYPE_MF3	0.076***	0.029	0.104**	0.053	0.094	0.088	0.054	0.052	0.149**	0.068
TYPE_MF10	0.017	0.029	-0.004	0.04	-0.031	0.094	0.063	0.057	0.019	0.07
TYPE_MF20	–	–	–	–	–	–	–	–	–	–
VINTAGE19	0.142***	0.036	0.113	0.091	0.177**	0.079	0.051	0.063	0.176**	0.087
VINTAGE44	0.143***	0.043	0.101	0.108	0.148*	0.087	0.096	0.073	0.210**	0.09
VINTAGE60	0.122***	0.037	0.03	0.105	0.195**	0.083	0.062	0.06	0.200**	0.083
VINTAGE70	0.091***	0.036	0.09	0.092	0.111	0.08	0.043	0.059	0.156**	0.081
VINTAGE80	0.118***	0.035	0.01	0.093	0.178**	0.075	0.071	0.057	0.214***	0.08
VINTAGE90	0.137***	0.034	0.048	0.089	0.168**	0.078	0.101*	0.058	0.213**	0.084
VINTAGE00	0.055	0.033	0.086	0.086	0.101	0.073	-0.004	0.055	0.095	0.081
VINTAGE05	0.049	0.036	0.054	0.1	0.003	0.081	0.041	0.062	0.163*	0.087
VINTAGE10	–	–	–	–	–	–	–	–	–	–
L_SIZE	-0.618***	0.027	-0.629***	0.054	-0.611***	0.053	-0.669***	0.041	-0.575***	0.052
BATH	0.067	0.088	0.158	0.2	0.104	0.12	0.148	0.25	-0.123	0.192
PROB	0.031	0.023	0.03	0.045	0.051	0.045	0.039	0.041	-0.010	0.051
HEAT_C	0.208***	0.043	0.177*	0.103	0.175**	0.068	0.288***	0.06	0.226***	0.07
FUEL_G	0.283***	0.027	0.347**	0.137	0.303***	0.042	0.243***	0.041	0.281***	0.062
FUEL_O	0.560***	0.025	0.572***	0.13	0.650***	0.047	0.515***	0.036	0.528***	0.047
FUEL_W	0.120***	0.022	0.076	0.073	0.142***	0.04	0.139***	0.035	0.105**	0.051
FUEL_C	0.253***	0.041	0.186	0.282	0.108	0.067	0.358***	0.071	0.322***	0.07
FUEL_N	0.132***	0.031	0.167	0.137	0.172***	0.062	0.088*	0.048	0.163**	0.063
RENEW	-0.110***	0.021	-0.134	0.09	0.004	0.041	-0.172***	0.031	-0.147***	0.042
NOTPAID	-0.335***	0.026	-0.088	0.064	-0.350***	0.043	-0.369***	0.034	-0.393***	0.044
L_INC	0.032***	0.011	0.013	0.02	0.006	0.025	0.064***	0.02	0.049**	0.022

Table 2: Log-linear estimates of annual energy expenditures per square meter (continued)[a]

Explanatory variables	All Coeff.	All Std. Err.	Vienna Coeff.	Vienna Std. Err.	Eastern[b,c] Coeff.	Eastern[b,c] Std. Err.	Western Coeff.	Western Std. Err.	Southern Coeff.	Southern Std. Err.
ADULTS	0.084***	0.01	0.131***	0.025	0.068***	0.022	0.076***	0.017	0.070***	0.02
CHILDREN	0.054***	0.009	0.032	0.023	0.029	0.02	0.081***	0.015	0.048**	0.021
L_AGE	0.035	0.034	0.018	0.066	-0.011	0.077	0.169***	0.057	-0.111	0.075
UNEMPL	0.076***	0.029	0.106*	0.055	0.129**	0.064	0.02	0.05	0.051	0.064
PENSION	0.021	0.013	0.009	0.031	0.011	0.026	0.011	0.022	0.055**	0.028
STATE_BU	–	–			–	–				
STATE_NO	0.094**	0.036			0.098**	0.038				
STATE_W	0.113**	0.044								
STATE_VO	-0.186***	0.051					–	–		
STATE_OO	0.041	0.037					0.240***	0.039		
STATE_SZ	0.111**	0.044					0.289***	0.045		
STATE_TR	-0.037	0.041					0.156***	0.042		
STATE_KA	0.111**	0.043							–	–
STATE_ST	0.097***	0.037							-0.007	0.031
URBAN_1	–	–					–	–	–	–
URBAN_2	0.043	0.026					0.068*	0.036	0.025	0.045
URBAN_3	0.021	0.028					0.037	0.041	0.008	0.045
Constant	4.117***	0.21	4.299***	0.396	4.495***	0.436	3.137***	0.405	4.523***	0.454
F-stat	45.119		9.563		17.774		26.481		15.709	
R^2	0.34		0.27		0.37		0.38		0.4	
Sample	4164		832		965		1519		848	

Source: Author's own calculations using 2012 EU-SILC data.
Notes: a. Heteroscedasticity-consistent standard errors were not used in the analysis since none was present according to graphical tests.
b. Regional division was based on EU-NUTS 1 geocode standard for referencing subdivisions in Austria.
c. Vienna was excluded from this specification for comparison purposes. – indicates omitted category. *** p <0.01, ** p <0.05, * p <0.10.

Table 3: Log-linear estimates of annual energy expenditures per square meter, owners and renters[a]

Explanatory variables	All [b] Coeff.	Std. Err.	Owners Coeff.	Std. Err.	Renters Coeff.	Std. Err.
OWNER	0.041**	0.021				
TYPE_SF	0.285***	0.035	0.416***	0.049	0.110*	0.066
TYPE_RH	0.269***	0.036	0.376***	0.052	0.225***	0.055
TYPE_MF3	0.076***	0.029	0.208***	0.049	0.022	0.036
TYPE_MF10	0.017	0.029	0.081	0.055	-0.001	0.033
TYPE_MF20	–	–	–	–	–	–
VINTAGE19	0.142***	0.036	0.208***	0.046	0.073	0.064
VINTAGE44	0.143***	0.043	0.178***	0.053	0.114	0.074
VINTAGE60	0.122***	0.037	0.171***	0.046	0.068	0.066
VINTAGE70	0.091***	0.036	0.165***	0.043	0.005	0.064
VINTAGE80	0.118***	0.035	0.185***	0.042	0.062	0.069
VINTAGE90	0.137***	0.034	0.201***	0.041	0.036	0.063
VINTAGE00	0.055	0.033	0.075*	0.04	0.039	0.058
VINTAGE05	0.049	0.036	0.084**	0.041	0.007	0.069
VINTAGE10	–	–	–	–	–	–
L_SIZE	-0.618***	0.027	-0.652***	0.032	-0.609***	0.044
BATH	0.067	0.088	0.13	0.098	0.034	0.143
PROB	0.031	0.023	-0.012	0.033	0.086**	0.031
HEAT_C	0.208***	0.043	0.199***	0.055	0.244***	0.069
FUEL_G	0.283***	0.027	0.281***	0.027	0.258***	0.089
FUEL_O	0.560***	0.025	0.577***	0.026	0.408***	0.084
FUEL_W	0.120***	0.022	0.090***	0.022	0.184**	0.071
FUEL_C	0.253***	0.041	0.224***	0.044	0.351***	0.102
FUEL_N	0.132***	0.031	0.092**	0.036	0.133	0.089
RENEW	-0.110***	0.021	-0.099***	0.022	-0.135*	0.079
NOTPAID	-0.335***	0.026	-0.334***	0.029	-0.312***	0.055
L_INC	0.032***	0.011	0.055***	0.015	0.006	0.018
ADULTS	0.084***	0.01	0.059***	0.012	0.147***	0.019
CHILDREN	0.054***	0.009	0.049***	0.011	0.058***	0.016
L_AGE	0.035	0.034	-0.045	0.051	0.110**	0.046
UNEMPL	0.076***	0.029	-0.026	0.038	0.132***	0.041
PENSION	0.021	0.013	0.028*	0.015	-0.013	0.024
STATE_BU	–	–	–	–	–	–
STATE_NO	0.094**	0.036	0.090**	0.039	0.117	0.08
STATE_W	0.113**	0.044	0.023	0.057	0.190**	0.082
STATE_VO	-0.186***	0.051	-0.134**	0.052	-0.344**	0.133
STATE_OO	0.041	0.037	0.045	0.04	0.059	0.077
STATE_SZ	0.111**	0.044	0.104**	0.041	0.158*	0.08
STATE_TR	-0.037	0.041	-0.025	0.046	0.003	0.088
STATE_KA	0.111**	0.043	0.079	0.049	0.184**	0.089
STATE_ST	0.097***	0.037	0.117**	0.051	0.087	0.088
URBAN_1	–	–	–	–	–	–
URBAN_2	0.043	0.026	-0.014	0.036	0.087**	0.038
URBAN_3	0.021	0.028	-0.032	0.037	0.058	0.048
Constant	4.117***	0.21	4.259***	0.301	3.960***	0.313
F-stat	45.119		42.81		12.735	
R^2	0.34		0.4		0.28	
Sample	4164		2745		1419	

Source: Author's own calculations using 2012 EU-SILC data.

Notes: a. Heteroscedasticity-consistent standard errors were not used in the analysis since none was present according to graphical tests.

b. Included for comparison. – indicates omitted category. *** p <0.01, ** p <0.05, * p <0.1

The remaining estimates for the regional and socioeconomic variables provide interesting results in the general model specification. The state variables, for example, indicate price variation and energy market segmentation in Austria. Households located in Lower Austria, Vienna, Salzburg, Carinthia, and Styria all pay between 10–12% more in energy outlays than those in Burgenland, while in Upper Austria and Tyrol they pay relatively the same as in Burgenland. Vorarlberg households pay 17% less in energy expenditures than the reference group, Burgenland. The results here provide a sound reasoning to examine regional differences even closer in the subsequent model specifications. None of the urbanization variables are statistically significant, indicating that there is no heat island effect in Austria. The model also estimates income elasticity (based on disposable income) of 0.03. This is comparable to other studies in which income elasticities ranged from 0.01–0.17 (Baker et al. 1989, Bernard et al. 1996, Garbacz 1983, Hirst et al. 1982, Meier, Rehdanz 2010, Nesbakken 2001, Rehdanz 2007, Wood et al. 2012). The number of adults and children in the household is found to have a positive and significant relationship to energy expenditures, as well as the number of unemployed household members. Contrary to other studies (Baker et al. 1989, Liao, Chang 2002), age is not an important factor in Austria.

At the start of this study, renters were expected to spend more on annual energy outlays than owners do. Contrary to that expectation, however, owners pay more in expenditures per square meter than renters do, even after controlling for factors predicted to have an impact on energy consumption. In other words, ceteris paribus, the net effect of being an owner in Austria actually increases annual energy expenditures per square meter by 4%, significant at the 5% confidence level. Examining the variable OWNER, it appears that the PA problem either does not exist or is unimportant in the Austrian residential sector. Since the PA problem could not be identified, the magnitude of the problem cannot be measured in this analysis.

5.1 Regional determinants of residential energy expenditures in Austria

Comparison to the geographical model specifications reveals potentially important patterns. As expected, building type remains a significant factor in all three regions and Vienna. Building vintage, however, does not remain consistent across the regions; rather, it appears to be more important only in Eastern and Southern Austria, and not at all in Western Austria or Vienna. These significance levels are interesting because, when comparing Vienna to Eastern Austria, the region to which it belongs, there is a noticeable difference between Vienna and its two neighboring states, Lower Austria and Burgenland. The vintage dummy variables, therefore, may be detecting energy efficient improvements to the older building stock in Vienna, compared to the rest of Eastern Austria. Energy costs decrease per square meter with the size of the dwelling at relatively the same rate in each region. Neither the presence of a bath nor structural problems in the dwelling are statistically significant. A central heating system, as expected, is an important factor in all regions, increasing energy costs by 19–33% compared to a single-stove heating system. The variables controlling for fuel type maintain their expected signs and significance levels, except in Vienna, where only gas and oil remain significant. Renewable energy source, however, appears unimportant in Eastern Austria, including Vienna.

Continuing with the other variables, income elasticity ranges from 0.01–0.06 in the analysis, based on geographical differences, but is not statistically significant for households in Vienna or Eastern Austria. Again, except for households in Vienna and Eastern Austria, there is a positive and significant relationship between the number of children and the dependent variable; this is similar to other studies (e.g. Baker et al. 1989, Hirst et al. 1982, Meier, Rehdanz 2010). The age of the oldest household member is significant only in Western Austria. These results reveal that socioeconomic factors vary in their significance across Austria, especially income elasticity. The regional variables also indicate variations in energy prices within the EU-NUTS Level 1 regions. This is especially the case in Western Austria, where households in Salzburg pay 34% more in energy outlays than in Vorarlberg, and in Eastern Austria, where Lower Austria pays 10% more than households in Burgenland.[3] Due to multicollinearity, urbanization variables were excluded from the regional models except in Western and Southern Austria; however, they remain mostly insignificant. Rehdanz (2007) used a similar categorization to measure community size and found comparatively insignificant results in Germany, while Wood et al. (2012) found mixed results in Australia.

Aside from Vienna and Eastern Austria, the critical explanatory variable OWNER remains both positive and significant. There is an even greater 12% increase in energy outlays per square meter in Western Austria, significant at 1%. In Vienna, the effect is negative, but positive in Eastern Austria; both, however, are statistically insignificant. These results demonstrate that, similar to the findings of the Austria-wide model, the PA problem does not exist in Austria even at the regional level. In comparison to similar studies, Meier, Rehdanz (2010) found that owners paid between 3–4% more in energy bills per room than renters in Great Britain; likewise, Wood et al. (2012) found a range between 14–19% (size of the dwelling was not considered in their analysis) more in outlays by owners in Australia. In contrast, Rehdanz (2007) found owners paid between 5–18% less in energy expenditures per square meter than renters in Germany, depending on model specification.

These regional differences may also be due to climatic variations, differences in regional energy sources, energy strategies, or energy providers that go undetected in the model. The mountainous, Alpine states in the west tend to have lower temperatures and more snowfall during winter than the flat, Pannonian Plains of the eastern states. This may explain why households in the Western model pay higher energy outlays than those in the Eastern or Southern models. Climatic differences aside, energy sources and regional policies have a large impact on residential energy expenditures. Energy outlays for households in Vorarlberg, for example, in both the Austria-wide and the Western models, are significantly lower than for other households. This is likely due to a heavy reliance on hydropower (an arguably inexpensive and renewable energy source) in that state, where electricity is even exported to Germany during peak times. In general, Austria's energy efficiency policy is influenced by EU law and the goals therein are to be reached by stipulations on the efficiency of new construction, implementation of Energy Performance Certificates, increases in comprehensive thermal refurbishments, passive house standards, and the enforcement of new heating systems. According to Amann et al. (2012), these goals are heavily funded by subsidy laws that are designed to enhance the investment in energy efficiency measures. Since 2009, the nine federal states of Austria must decide on the funds allocated to housing policy out of their own budgets. This autonomy in policy implementation is likely to create differing rates of investment across the regions, creating variations in energy expenditures for comparable households. Furthermore, alongside the National Energy Efficiency Action Plan (Nationaler Energieeffizienzaktionplan), each state develops their own Action Plan, which set individual goals and measurements that may differ from state to state.

5.2 Differences in the determinants of energy expenditures between owners and renters

According to the regional and Austria-wide estimates, a PA problem concerning energy efficiency appears unimportant or does not exist in the Austrian residential sector. It is conceivable, however, that owners and renters may have different characteristics that determine annual energy expenditure, and the binary variable OWNER fails to detect these differences. The regression results shown in Table 3, for example, indicate that the type of building and its vintage are (significantly) more important for owners than renters. Detached housing, for instance, increases energy outlays per square meter by 52% for owners, versus 12% for renters. Further, household disposable income appears to be more important to owners than renters, with an income elasticity of 0.05. Similar conditions also exist in Great Britain (Meier, Rehdanz 2010) and Germany (Rehdanz 2007). The age of the oldest household member, the number of household members unemployed, and the presence of structural problems are, on the other hand, more important for renters than

[3] A separate model specification for Eastern Austria, which included Vienna (not shown here), reveals that households in Vienna also pay 10% more in energy outlays compared to Burgenland.

owners. Based on these observations, there is the possibility that PA problems only exist among particular subgroups of owners and renters. In other words, certain subgroups of owners may consume less energy than their renter counterparts due to non-investment in energy efficiency, and vice versa.

In order to test whether this is the case in the analysis, a log-linear specification that adds interaction effects between the household characteristic variables and the binary OWNER variable was regressed.[4] The results indicate that the addition of interaction variables offers some supporting evidence of differences between subgroups of owners. For example, interaction effects between disposable income and owner-status are significant (i.e. have a higher impact) at the 5% confidence level. In contrast, Wood et al. (2012) conducted a similar regression that included interaction variables but found no significant interaction between owner-status and income for Australia. On the other hand, while the vintage of the building is shown to be more of a determinant factor for owners in the Owners model, only two of the vintage categories were significant at the 5% level. Perhaps more important in the context of this paper, building type appears to have significant interaction effects on energy expenditures for owners. Specifically, interaction with detached housing was significant at the 1% level and semi-detached at the 5%. The significance level of the interaction variables measure to what extent the effect is different for owners; in this case, detached housing has a higher impact on energy expenditures per square meter for owners than renters.

These interactions may have an influence on the estimates presented previously. Recall that detached housing, for example, is known to be less energy efficient than apartment units in multi-family buildings are. In this sample, 66% of owners live in detached housing, while only 14% live in a building with 10 or more flats. In contrast, only 6% of renters live in detached housing, while 55% live in a building with 10 or more flats (Author's own calculations 2014). Therefore, the large number of owners living in detached housing may be obscuring any detection of a PA problem.

6 Concluding Remarks

The aims of this paper were to examine the determinants of energy consumption patterns in Austria, identify any regional differences, and investigate if market failures due to PA problems contribute to higher energy outlays for renters than for owners. Regional characteristics in the determinants of household energy expenditure were identified, as expected. These characteristic differences in what affects energy outlays include the building type, annual disposable income elasticity, and the type of fuel used. These findings could potentially affect policy implementation. While the source of these differences could not be identified with this dataset (e.g. climatic variation, federal state energy policies, energy sources; as discussed in 5.2), the analysis does bring to light the types of building and the income groups of homeowners or renters that regional governments should target with future energy efficiency policies or programs.

As to the latter aim, the estimates derived from the regressions suggest that, using energy expenditure as a proxy for energy consumption, household energy expenditures per square meter are actually higher for owners than renters. Therefore, it appears that PA problems within the landlord-tenant relationship are nonexistent or unimportant in the residential sector in Austria, when efficiency investments are the only mechanism considered. Restricting the sample according to occupancy type also indicated that building and socioeconomic characteristics do not impact energy expenditures for owners to the same extent as renters. Further investigation into the interaction effects between occupancy type and the other explanatory variables provided significant evidence of an important interaction between the type of building and ownership. This interaction may result in owners who reside in detached and semi-detached housing paying more in energy outlays than renters – who reside mostly in multi-family housing – do. This possibly obscures any PA problems for renters in the analysis.

On the other hand, the estimates found regarding the PA problem could be the result

[4] The full results of the interaction analysis are available in the master's thesis; they were excluded due to space constraints.

of successful energy policy implementation in Austria. A recent report from the AEA (2012b) indicates that energy efficiency in the Austrian residential sector has improved by 34% over the period 1990 to 2010, compared to 25% for the EU. More specifically, over the same period, energy efficiency of space heating improved by 37%, water heating by 11%, and cooking by 42%. Austria's National Energy Efficiency Action Plan outlines a number of ambitious initiatives, including the thermal renovation of all buildings constructed between 1950 and 1980 by the year 2020 (AEA 2011, 2012a). Furthermore, Austria currently provides approximately €2.4 billion per year in funding for housing support programs, including building renovations and subsidies for energy-efficient or renewable heating systems (ABB Group 2011, AEA 2012a). These energy efficiency policy measures, put in place during last decade, are likely the driving force behind the increase in efficiency. More importantly, they may be an indication that PA problems have already been addressed. An analysis that includes a time-series dimension and variables indicating implementation of particular energy policies is necessary to determine if this is actually the case (for an example of this in Denmark, see Leth-Petersen, Togeby 2001).

This analysis could be expanded in several ways. Specifically, there were a number of limitations to the dataset, which if properly addressed, could be expected to produce results that are more precise. First, this study was confined to analyzing combined energy-use expenses, i.e. space heating, water heating, and cooking. A separate analysis for these types of expenditures may reveal more accurate results concerning the determinants of energy outlays. Second, the analysis was also restricted to household energy expenditures, rather than actual energy consumption. A comparison of the present results to those that used energy consumption in physical units as the dependent variable could provide farther-reaching conclusions. Third, the dataset offered no information on the level and quality of insulation, or the age and efficiency of the heating or hot water systems, installed in the dwellings. This would be expected to have a significant impact on energy consumption and expenditures. Lastly, the study could only rely on cross-section modeling for the survey year 2012 because energy expenditure data was unavailable in previous waves. Subsequent waves of the EU-SILC in Austria, however, are expected to continue capturing energy expenditure data; therefore, longitudinal analysis is a potential future direction for research.

Still, since this study was able to identify some of the determinants in residential energy consumption at a regional level, as well as for owners and renters, policy implications can nevertheless be deduced from the results. Future energy policy in Austria could focus on these specific determinants in order to achieve the ultimate goal of further increasing energy efficiency and decreasing greenhouse gas emissions. These policy measures could include information campaigns, tax reductions, or grants and subsidies, as suggested by Schaefer et al. (2000), Leth-Petersen, Togeby (2001), and Bird, Hernández (2012). In Austria, it would be more fruitful if those policies targeted detached and semi-detached housing or owner-occupied households in Western Austria.

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