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Energy Efficiency and the Principal-Agent Problem: Measuring the effect of split incentives on the Austrian residential sector

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Energy Efficiency and the Principal-Agent Problem: Measuring the effect of split incentives on the Austrian residential sector

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Thesis

Master of Science in Socio-Ecological Economics and Policy
Vienna University of Economics and Business

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Vienna, October 2014

This is dedicated to my late grandfather, Herbet M. Guyett. He always saw great things in my future and helped – in many different ways – make them possible. Sorry you didn't get the chance to see this one completed, Baback.

Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections. Three elements of policy are required for an effective global response. The first is the pricing of carbon, implemented through tax, trading or regulation. The second is policy to support innovation and the deployment of low-carbon technologies. And the third is action to <u>remove barriers to energy efficiency</u>, and to inform, educate and persuade individuals about what they can do to respond to climate change.

—Stern Review on the Economics of Climate Change, 2006 (author's own emphasis)

Acknowledgements

There were, as with every thesis, a number of people who helped me along the way and deserve acknowledgement. First and foremost: my supervisor and professor, Univ.Prof. Dr. Gunther Maier. Not only did he help me with the subject matter and methodology – including making sense of the results – he is genuinely a nice guy. Even though he’s an extremely busy man, he seemed to always have time to discuss – again and again – the complications or tribulation of my thesis. I had the added bonus to also work with him on a separate but related, EU-sponsored research project. In fact, had it not been for the opportunity he gave me to work on the Transnational Cooperation for the Improvement of Building Energy Performance and Efficiency (TRACE) project, this topic may never have materialized as a focus in my research. I’m grateful for the opportunities and support he provided because it has led to a genuine interest and (hopefully) interesting career path.

Second, I would like to thank and acknowledge my two office and work colleagues, Ann H. and Kateryna K., for listening (often, at length) to my concerns, frustrations, and sudden bursts of insight on a regular basis. Their feedback and advice in other areas of economics were helped to keep me level-headed with the final goal in sight. Also, I would like to thank some of my university colleagues. I had a fantastic opportunity to study with a group of extremely smart individuals from all areas of the social sciences. In particular: Matthias K., Florentin G., Harald W., Martha E., and Elisabeth R. for feedback, advice, SPSS tips, and method-talk.

And, last but not least, my friends and family should be acknowledged for their understanding, compassion, and unwavering support. Even though most of them didn’t quite understand what the topic of my research was about – or they possessed only a mild interest in hearing about it – they each offered something only friends and family can: a distraction. I especially thank my parents, Vivian and Dan H., for their encouragement and support, even from all the way on the other side of the Atlantic. Encouragement goes a long way.

Abstract

Concern about climate change and greenhouse gas (GHG) emissions has brought about renewed attention to energy conservation, with a particular focus on energy efficiency of buildings. Economic literature of the past 30 years has identified both market and non-market barriers concerning energy efficiency, with one in particular affecting the residential sector: the principal-agent (PA) problem. Involving transaction costs, asymmetrical information, and split incentives, PA problems are thought to keep economically sound investments in energy efficiency from being realized. This problem is prevalent within the landlord-tenant relationship in the private rental housing segment. And 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 magnitude of PA problems that keep economically sound investments from being realized. The aim of this study, therefore, is to quantify the effect of the PA problem on the residential sector in Austria. A conditional demand model is regressed whereby annual energy expenditure per square meter is estimated as a function of occupancy type, housing characteristics, location and socio-economic variables using household-level micro-data from the European Union Statistics on Income and Living Conditions. The analysis indicates that PA problems are unimportant or irrelevant to energy efficiency in the Austrian residential sector and concludes with some explanations as to why that may be the case.

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1 Introduction

Concern about climate change and greenhouse gas (GHG) emissions has brought about renewed attention to energy conservation, with a particular focus on energy efficiency of buildings. According to Price *et al.* (2006), the buildings sector contributes about a third of all energy-related CO_2 emissions worldwide. What is more, in a 2007 Intergovernmental Panel on Climate Change (IPCC) report, a 30 percent reduction in global, building-related GHG emissions could be expected by the year 2020 if cost-effective mitigation measures are implemented (IPCC, 2007). That would equate to a savings of approximately 1.6 billion tons of CO_2 in the global residential sector, indicating that this segment of buildings is important to achieving international climate change goals. Increasing energy efficiency and promoting conservation measures in private households are therefore important goals in energy policy development.

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 magnitude of the market failures which keep economically sound investments from being realized. Economic literature of the past 30 years has identified both market failures and non-market barriers concerning efficiency, including imperfect information, positive externalities, hidden costs, and misplaced or split incentives. These barriers are potential factors that deter adoption of efficient technology in all three segments of the building sector: residential, industry and tertiary. Of these barriers, however, information problems and split incentives – typically referred to as the principal-agent (PA) problem – have a prevailing effect in the residential sector and, in particular, the private rental market.

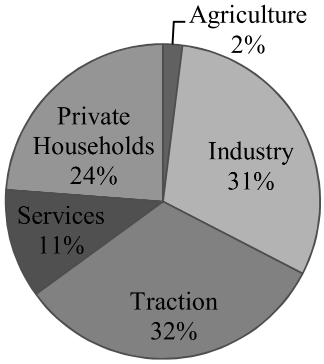
1.1 Statement of the problem

Energy-related economic theory posits that a PA problem exists whenever an agent acts on behalf of a principal, such as managing property that is owned by the principal, but the interests of the two parties are not aligned and information is asymmetric and costly to obtain. In the present context, for example, the landlord is the agent and is generally responsible for the selection of energy-using technology in the property, while the tenant or principal is responsible for the payment of the energy costs. The landlord lacks the incentive to invest in energy efficient technology because she does not immediately realize the benefits of lower energy bills; homeowners, on the other hand, are both the principal and the agent, and therefore have a higher incentive to invest in technology improvements. Likewise, tenants may not have the right to make structural improvements to their homes without landlord consent, and any increase in asset value due to improvements is realized by the landlord. The PA problem therefore prevents economically sound investments in energy efficiency from being undertaken in the private rental housing market. It is thought that this results in tenant-occupied households paying higher energy bills for inefficient dwellings than those which are owner-occupied. The literature reviewed for this study extensively refers to ownership as a major barrier to energy efficiency investment decisions (see, e.g. Blumstein *et al.*, 1980; Jaffe & Stavins, 1994a, 1994b; Murtishaw & Sathaye, 2006).

1.2 Background

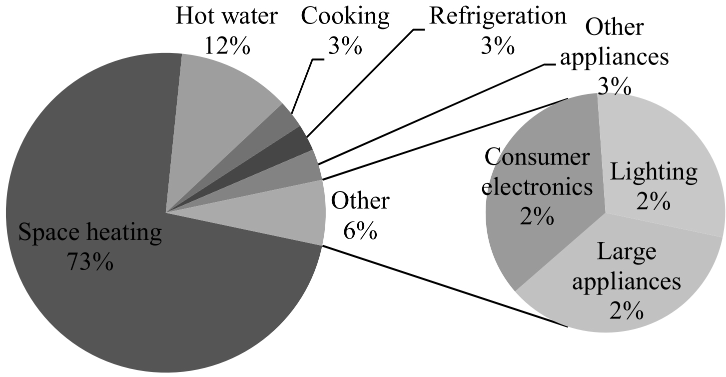
As Figures 1-1 and 1-2 illustrate, the private household sector in Austria was responsible for 24 percent of final energy consumption (FEC) in 2011 – 87 percent of which was attributed to space heating, water heating and cooking (author's own calculations using data from Statistik Austria, 2013a). Given their large share of residential energy consumption, these three energy uses serve as important indicators for energy efficiency performance in Austria and a potential focus area for studying the existence of a PA problem. Take space-heating as an example, where an estimated 40 to 48 percent of Austrian households (mostly tenant-occupied) and their corresponding energy use were potentially affected by at least one type of PA problem in 2011 (author's own calculations, 2014, see Appendix). The method employed to obtain these estimates was developed for an exhaustive investigation by the International Energy Agency (IEA, 2007) covering five countries. It utilized descriptive housing and energy consumption statistics to calculate the percentage of the housing stock (and therefore also the share of energy consumption) potentially affected by a PA problem. The estimates reported for Austria are consistent with the findings of the report, in which an estimated 46 to 48 percent of space-heating energy use was potentially affected in the United States and the Netherlands by the same type of PA problems. Furthermore, Figure 1-3 illustrates that space-heating in the Austrian residential sector was

Figure 1-1. Overall energy balance in Austria, 2011.



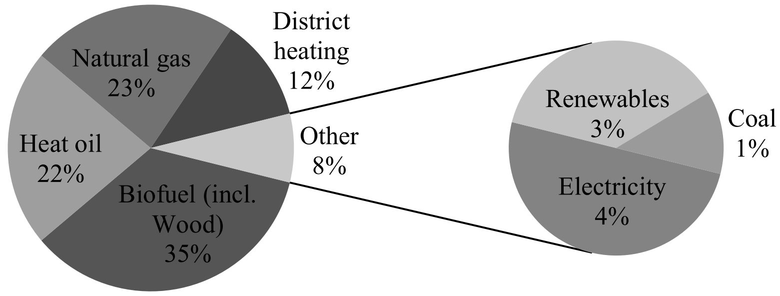
Source: Statistik Austria, 2013

Figure 1-2. Share of residential energy use in Austria, 2011.



Source: Statistik Austria, 2013

Figure 1-3. Share of fuel sources for residential space heating in Austria, 2011.



Source: Statistik Austria, 2013

highly dependent on fossil fuels in 2011, with 45 percent coming from natural gas and oil (author's own calculations using data from Statistik Austria, 2013a). If a PA problem is actually affecting these households in Austria, appropriate, market-correcting policy measures may be necessary to mitigate its effect.

1.3 Objective, research question and methodology

The aim of this study, therefore, is to conduct an empirical inquiry that attempts to identify and measure the effect of split incentives, i.e. PA problems, on energy expenditures in Austria. The focus of the study is on energy consumption attributed to space heating, water heating and cooking in the private, residential sector, where PA problems are thought to be most prevalent. Following the description of the landlord-tenant relationship above, and the PA problems attributed to it, this study will specifically examine differences between the energy expenditures of owners and renters. In other words, does market failure due to the PA problem contribute to higher energy expenditures for renters than for owner-occupied households in Austria?

This research question helps guide the design of the empirical analysis. A log-linear regression model is developed using a large number of housing and socio-economic characteristics at the household level extracted from the EU Statistics on Income and Living Conditions (EU-SILC) dataset for Austria. Annual energy expenditure per square meter is used as a proxy for energy consumption and therefore an indication of the efficiency of the dwelling. A critical explanatory variable, indicating occupancy type (e.g. renter-occupied), is used in the model to identify the existence of the PA problem and measure its significance and magnitude. The hypothesis is that owners pay less in energy expenditures because they inhabit more efficient dwellings than renters.

1.4 Scientific contribution

Previous studies are mainly concerned with analyzing the determinants of energy efficiency investments, or obtaining price and income elasticities, using household-level data from national surveys. They mostly differ in method application, time frame, location, and aggregation level of the data employed, and – perhaps more importantly – few focus directly on PA problems. To the best of the author's knowledge, the present study goes beyond the current literature by being the first empirical investigation of the PA problem relating to energy efficiency in Austria using household-level micro-data from the EU-SILC survey. While cross-national comparison of results from studies such as this is often difficult, due to the formerly listed differences, the present study contributes to the growing literature in energy efficiency of buildings.

1.5 Structure of the thesis

The thesis is organized as follows. Chapter 2 discusses the theoretical background of energy efficiency and the PA problem within economic theory. Chapter 3 provides an overview of the relevant literature reviewed in preparation of the study, concentrating on econometric analyses pertinent to the research question. In chapter 4, the empirical design of the study is outlined, including the data source employed and structure of the econometric analysis. The results of the analysis are presented in chapter 5 and discussed in relation to the theoretical background and literature review in chapter 6. In the final chapter, some conclusions are drawn. Additionally, there is an appendix.

2 Theoretical Background

2.1 Energy efficiency in economics

Prior to the first energy crisis in the 1970s, there was little public policy discussion of the efficient use of energy. Following the crisis, however, governments and analysts around the world became acutely aware of the fact that the resources upon which we had become dependent were both limited and largely under the control of foreign interests. This prompted a new intellectual trend, propelled by the pioneering book *Limits to Growth* (Meadows *et al.*, 1972), which postulated that global ecological constraints, e.g. fossil fuel reserves, growing CO_2 emissions, would have significant influence on global developments in the twenty-first century. Proponents of this new vision realized that current energy policies and consumption behavior would lead to rising energy prices and future shortages, suggesting that a new policy strategy was needed.

From the onset of this new vision, some analysts contended that efforts should be made to moderate the demand for energy through the adoption of efficiency measures. The implications of these measures were articulated in Lovins (1976), whose main argument was the basis for the concept of energy efficiency: using less energy would lead to more economic growth. Researchers of the time came to the conclusion that the market alone was not working efficiently to correct the energy crisis, nor would it for future crises. Consequently, ideas about energy efficiency began having a significant effect on public policy, leading to the concept of the "energy efficiency gap" or "energy efficiency paradox". The term was coined by Hirst and Brown (1990), but the concept was developed years before using bottom-up, engineering-economic models to study the technical and economic potential for energy efficiency.

2.1.1 The energy efficiency gap

The energy efficiency gap (in short: efficiency gap), refers to the difference between levels of investment in technically feasible energy efficiency measures that appear to be cost effective and the levels actually occurring (Golove & Eto, 1996, p. 6; Hirst & Brown, 1990; Sorrell *et al.*, 2004). In other words, it is the existence of unexploited investment opportunities that appear economically sound at current prices. The concept posits that there is an implicit discount rate for energy efficiency investments which can be compared to the interest rates offered by other, non-energy-efficiency investments that consumers are purchasing. The difference between these rates is offered as evidence of inadequacies in the function of the markets for energy efficiency (Golove & Eto, 1996; Koopmans & te Velde, 2001; Ruderman *et al.*, 1987).

The evidence, according to Ruderman *et al.* (1987), rests on the theory that consumers are willing to invest in non-energy-efficiency options offering a certain level of return on investment but unwilling to invest in energy efficiency without receiving substantially higher returns. More simply, investors apply a higher discount rate to energy efficiency investments than to other options.[1,2] This is in contradiction to orthodox (i.e. neo-classical) economic theory, wherein investors should be equally willing to invest in options offering the same expected return for the same levels of risk and liquidity (Golove & Eto, 1996). The observation that investments with a very high rate of return were being neglected led researchers to postulate that such investments were being inhibited by various "barriers" and that such barriers justified government intervention.

2.1.2 Market barriers to energy efficiency

The term "market barrier" was introduced by researchers to explain the existence of the efficiency gap. Several taxonomies of these barriers have been developed over the decades, sparking intense debates concerning the economic theories applied to conceptualize them. Blumstein *et al.* (1980) were the first to systematically analyze the causes for the efficiency gap. In their study, six market barriers were identified as features of the energy services market: 1) misplaced incentives, 2) lack of access to financing, 3) flaws in market structure, 4) mispricing imposed by regulation, 5) decision influenced by custom, and 6) lack of information or misinformation. Subsequent studies, such as Hirst and Brown (1990), were mostly conducted by energy efficiency practitioners and researchers, rather than academic economists, and were selective in their use of economic theory (Golove & Eto, 1996;

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[1] Hausman (1979) presents a model of individual behavior in the purchase and utilization of energy-using household appliances, examining the tradeoff between capital costs for more energy efficient technology and operating costs for the appliances. His results show relatively low price elasticity, evidence that consumers do trade off capital costs and expected operating costs, and an individual discount rate of about 20 percent which varies inversely with income.

[2] Ruderman *et al.* (1987) focused on sales of residential appliances and heating/cooling equipment and found estimated, implicit discount rates ranging from 20 to 800 percent per year. These were found to be significantly higher than the returns available on other investments.

Sorrell *et al.*, 2004). These studies generally focused on three basic propositions concerning energy efficiency: 1) market barriers exist and discourage investments in energy efficiency, 2) these barriers cause an efficiency gap that should be closed, and 3) energy efficiency investments should be encouraged by government policy and utility programs (Sutherland, 1996). Research studies proposing these propositions attracted criticism from orthodox economists, especially Sutherland (1991, 1996), who pointed out that the term "barrier" was too ambiguous, was not being used in a consistent way, and that many of the proposed barriers could be benign characteristics of well-functioning markets.

Over the past three decades, the debate has mostly concentrated on the size and magnitude of the efficiency gap as well as criticisms on the approaches used to explain its existence. Recent studies suggest that the bottom-up, engineering-based approach used to identify the efficiency gap does not provide a true estimate of its size. Specifically, researchers point out that they typically fail to account for all costs and neglect particular types of economic behavior. Many other critics of the engineering-based approach suggest that the efficiency gap is overestimated and misconstrued because it does not account for possible alternative explanations. These include 1) the heterogeneity of consumers, 2) the natural diffusion rate of any new technology, 3) risk and uncertainty, 4) hidden costs, and 5) other, non-economic variables (for further reading, see Gillingham & Palmer, 2013; Golove & Eto, 1996; Jaffe *et al.*, 2004; Sorrell *et al.*, 2004, Chapter 2). Gillingham and Palmer further argue that, interestingly, engineering approaches may also underestimate the size of the gap "by assuming a constant energy service demand before and after the efficiency investment" (2013, p. 5). In other words, they neglect to account for the rebound effect. Still others criticize the "barrier" explanation of the efficiency gap. Orthodox economists argue that economic theory has long recognized concepts known as "market failures" that inhibit the efficient functioning of a market and justify public intervention (Jaffe & Stavins, 1994a, 1994b; Sutherland, 1991, 1996). In the context of energy efficiency, these market failures include environmental externalities, imperfect competition, public goods, and imperfect information (for further discussion see Sorrell *et al.*, 2004). Here again, Sutherland (1991) reiterates his argument that market barriers in general do not discourage investment in energy efficiency and should not be considered market failures. Subsequent discussions by efficiency proponents and practitioners such as Jaffe and Stavins (1994a, 1994b) and

Levine *et al.* (1994) incorporate the concept of market failures into their literature by redesigning the taxonomy to be more "orthodox-friendly". The concept posited that market barriers may refer to any factor which explains why economically sound investments are not undertaken, but only a subset of these may correspond to recognized market failures.

This idea was characterized in a framework developed by Jaffe and Stavins (1994b), where a distinction was drawn between non-market failures, which do not necessarily warrant policy intervention, and market failures, which may. The framework also identifies which of these market and non-market failures can explain the efficiency gap. Table 2-1 summarizes the Jaffe–Stavins framework that helped propel the energy efficiency discussion into more mainstream economic literature. However, Sorrell *et al.* (2004), as well as a growing number of other researchers, criticize a purely orthodox approach. They argue that, given the broad range of non-market failures involved in the efficiency gap debate, orthodox economic theory may be necessary but is insufficient to fully explain the gap. In order to properly explain all the barriers to energy efficiency, some of the literature suggests a synthesis of economic theories, including neo-classical economics (including agency theory and the economics of information), transaction cost economics, and behavioral economics (for further reading, see Gillingham & Palmer, 2013; Gillingham *et al.*, 2009; Golove & Eto, 1996; Sorrell *et al.*, 2004).

2.1.3 Theory in relation to this thesis

A full discussion on the debate surrounding the efficiency gap hypothesis and the causal market barriers is beyond the scope of the present study, however interesting it may be. It is, nevertheless, important to understand where the concepts and theories used in this study stand within energy efficiency literature and broader economic theories. Moreover, it is important to keep in mind that other theories exist which may be used to approach the problem presented here. Given the narrow focus of the study, limited time frame and resources, the present research question relies on the economic theory of rational choice to define the market barrier of interest: split incentives, also referred to as the principal-agent problem in the literature. The concept of principal-agent problems used here derives from agency theory and, within the context of the above theoretical discussion, is a market

Table 2-1. Barriers to energy efficiency.

	Explains efficiency gap	Does not explain efficiency gap
Barriers that are market failures	- Public good attributes of information - Positive externalities of technology adoption - Asymmetric information in energy services market – leading to problems of adverse selection, moral hazard and **split incentives**	- Distortions in energy pricing - Environmental externalities
Barriers that are not market failures	- Hidden costs - Reduced product performance - Option value of delaying investment	

Source: Based on Jaffe and Stavins (1994b) in Sorrell *et al.* (2004)

failure in the orthodox framework because it involves imperfect information (Golove & Eto, 1996; Jaffe & Stavins, 1994b). It is also a market barrier, as defined by Blumstein *et al.* (1980) and Hirst and Brown (1990), because it involves misplaced/split incentives. In the following section, the PA problem and the theory behind it is placed within the context of this study.

2.2 The principal-agent problem

According to Ross (1973), a principal-agent relationship exists whenever there is a contractual arrangement between two or more parties in which one party (the agent) acts for, on behalf of, or as representative for the other party (the principal).[3] PA relationships can be described between an employer (principal) and employee (agent), bank (principal) and barrower (agent), or any other relationship where one party hires another to perform a specific task. Bannock *et al.* state that a PA problem arises when

> the principal cannot ensure that the agent performs [the tasks described in the agreement] in exactly the way the principal would like. The efforts of the agent are impossible or expensive to monitor and the incentives of the agent differ from those of the principal (1992).

[3] Note that no physical contract is necessary to define this relationship; verbal agreements and other social interrelations can be defined as a PA relationship.

Murtishaw and Sathaye (2006) note three important economic components present in this definition. First, the principal has imperfect information concerning the actions of the agent (i.e. cannot monitor or control the effort of the agent). Second, the principal can incur transaction costs or disutility due to the actions of the agent, such as attempting to monitor or obtain information on the effort of the agent. Third, the principal and the agent have different incentives for entering the contractual arrangement (split incentives). When asymmetric information problems exist and the agent's interests are not perfectly aligned with those of the principal, adverse selection or moral hazard scenarios can arise. In these scenarios, the agent can take "advantage" of the principal with the additional information she possesses, either before or after the contract is agreed upon (for discussions on adverse selection and moral hazard, see Gillingham *et al.*, 2012; Laffont & Martimort, 2002, Chapters 3–5; Sorrell *et al.*, 2004, pp. 39–42; Wilkerson, 2012).

2.2.1 Principal-agent problems and energy efficiency

PA problems are often cited in energy efficiency literature, especially in connection with the residential sector. Murtishaw and Sathaye note however that "the conceptualization of principal and agent must be stretched beyond a strictly literal definition" (2006, p. 3) when examining the PA problem in the residential sector. Recall that, in the literal definition given above, the agent is hired by the principal to perform a specific task. In the residential sector, a PA relationship can exist between a home buyer and a seller, building owner and builder, tenant and landlord, among several other scenarios. The tenant-landlord relationship and the resulting PA problem can manifest itself in several ways, depending on who pays the energy bills and who makes the decision relating to the efficiency level of a device or dwelling.

Table 2-2 illustrates the four possible scenarios relating to PA problems. In the first case, no PA problem exists because the end-user of the device or dwelling and the person who pays the energy bill are the same. Homeowners typically fall within this category; no split incentives exist because the homeowner has perfect information. In the second case, the end-user pays the energy bill but cannot choose the efficiency level of the dwelling. This is the typical scenario for the landlord-tenant relationship, resulting in split incentives and

Table 2-2. Principal-agent scenario matrix.

	End-user can choose	End-user can't choose
End-user pays energy costs	*Case 1*: No problem	*Case 2*: Efficiency problem
End-user doesn't pay energy costs	*Case 4*: Both	*Case 3*: Usage problem

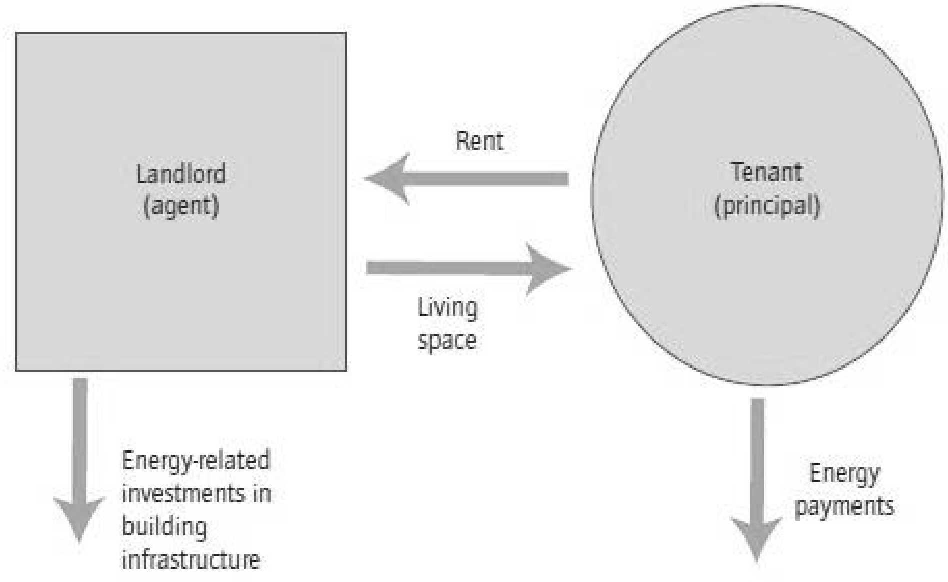
Source: IEA (2007)

asymmetric information problems. This is referred to as an *efficiency* problem. A *usage* problem occurs in the third case, where the end-user does not pay energy costs and cannot choose the efficiency level. This case typically affects rent-free tenants and landlord-tenant relationships where energy costs are included in the rent. The fourth case is extremely rare. The current analysis focuses on the efficiency problem, i.e. Case 2. See Murtishaw and Sathaye (2006), IEA (2007), and Wilkerson (2012) for quantitative studies on the various PA problems.

The tenant-landlord relationship of Case 2 and the associated transactions involved with the efficiency problem are graphically represented in Figure 2-1. As described by A. Meier and Eide (2007), the tenant/principal pays rent to the landlord/agent in exchange for use of the dwelling. 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 way, it can be said that the energy consumption is somewhat "insulated" from energy prices and cost-effective opportunities may be ignored, i.e. an efficiency gap arises (IEA, 2007; A. Meier & Eide, 2007; Sorrell *et al.*, 2004).

In the context of the market barrier discussion in Section 2.1.2, the PA problem in the rental housing market suffers a great deal from imperfect information, transaction costs and, especially, split incentives. Market forces may have some impact on this barrier, but the

Figure 2-1. Energy-related transactions between landlord and tenant.



Source: IEA (2007, p. 34)

essential conflict of interest between landlords and tenants is not altered by these forces. Blumstein *et al.* (1980) provide an example where market forces do not correct the problem: where one might expect rising energy prices will cause tenants to be willing to pay more for energy-efficiency dwellings, one would also expect there to be some incentive for landlords to make efficiency upgrades. This market correction, however, does not occur naturally. They argue this is due to a challenging information barrier because it is both difficult and expensive to determine the energy efficiency of a dwelling, and owners of inefficient units are unlikely to provide much assistance to renters seeking efficient units. Sutherland (1991), however, argues that landlords who invest in energy efficiency would simply increase the rent in order to recover investment costs, but remains silent on the issue of the transaction costs involved.

2.3 Summary of theoretical background

In this chapter, the theoretical background on energy efficiency was discussed. The efficiency gap and the (much debated) barriers which are theorized to cause this gap were also presented, in order to provide a theoretical framework for the principal-agent problem. Likewise, the PA problem and split incentives were defined in order to frame the problem being investigated in the current study. In the next chapter, a literature review of previous econometric studies is presented as the state of the art in energy efficiency literature. A rich source of previous studies was reviewed in order to develop an appropriate methodological approach to investigate the PA problem in the Austrian rental housing market.

3 Literature Review

3.1 Empirical studies on energy efficiency

So far, much of the literature already discussed focuses on identifying and defining the various market barriers and failures affecting investments in energy efficiency, but do not attempt to quantify their effects on energy use. Murtishaw and Sathaye (2006), on the other hand, focus specifically on PA problems. They provide quantitative estimates of their potential importance on residential energy use. Specifically, they examine the number of dwellings that may be affected by at least one PA problem, and use this number to calculate the theoretical upper bound of energy savings possible if policies could be implemented to entirely address the issue. A report by the IEA (2007) looks at case studies to provide a sense of where PA problems may be most important. Wilkerson (2012) expands on the above studies by creating a bottom-up model of explicit appliance energy usage and applying that to different housing and ownership types to quantify the PA problem and potential savings. These three studies discuss the differing ways that the PA problem may manifest itself in energy consumption, but do not provide empirical evidence of the extent to which the problem may exist using individual household-level data.

Econometric analyses of residential energy consumption based on individual household-level data have been relatively rare due to data availability. The focus of most of the studies available is on price and income elasticities to estimate changes in energy demand, mainly for electricity. They differ with respect to model application, time period, location and the aggregation level of the data chosen. Dubin and McFadden (1984) were among the first to investigate the choice of energy-using equipment and energy use using a discrete/continuous modelling framework on micro-level data for the U.S. More recent studies inspired by this approach include Bernard *et al.* (1996), Lee and Singh (1994), and Liao and Chang (2002) for the U.S. and Canada. Liao and Chang (2002), for example, investigate the space and water heating demands of the aged in the U.S. They find that space heating energy demand increases with the age of the household, but water heating energy demand decreases as the aged become older. In Europe, most of the studies were conducted for Norway (Nesbakken, 2001; Vaage, 2000), the Netherlands (Berkhout *et al.*, 2004; Brounen *et al.*, 2012; van Raaij & Verhallen, 1983), the UK (Baker *et al.*, 1989), and Germany (Braun, 2010; Schuler *et al.*, 2000). They were among the first to expand the discrete/continuous model with additional socio-economic characteristics of the household, including occupancy type. In Braun (2010), for example, the inclusion of a large number of variables representing socio-economic, housing and regional characteristics is found to have a significant influence on energy-related behavior of households. Baker *et al.* (1989) investigate the determinants of electricity and gas demand for households during the period 1972 to 1983, accounting for socio-economic characteristics such as ownership, household size and income, as well as details of the dwelling such as the number of rooms. They find that energy consumption increases with income and that the price sensitivity of households is higher for families with children and lower income. Other studies which provide important contributions to residential energy efficiency literature include Branch (1993), Garbacz (1983), Brounen *et al.* (2012), Green (1987), and Hirst *et al.* (1982).

Other studies by Bird and Hernández (2012), Leth-Petersen and Togeby (2001), Linares and Labandeira (2010) and Schaefer *et al.* (2000) investigate the effects of policy intervention to correct energy efficiency market failures. Schaefer *et al.* (2000), for example, analyze energy efficiency policy instruments within the residential sectors of the Netherlands, France, Denmark, Sweden and Germany, investigating the effectiveness of those policies based on survey data. They find that future policies aiming toward energy conservation in the residential sector should combine a bundle of instruments to achieve substantial emissions reductions at low costs. Specifically, their analysis finds that emission taxes play an important role in this case, but also flexible standards, subsidies and information measures are particularly important. Leth-Petersen and Togeby (2001) investigate the effects of policy measures aimed at reducing the consumption of energy for space heating in Danish apartment blocks in a panel data analysis covering the period 1984-1995 on energy consumption and technical characteristics of heating systems. Their results indicate building regulations have been very important policy measures in the pursuit of improving energy efficiency in new buildings in Denmark, while estimation results indicate that policy measures affecting the price of oil or district heating (i.e. taxes) have very limited effects on the consumption of energy in apartment blocks in the short run. Bird and Hernández (2012) provide an overview of the PA problem for low-income tenants and propose a specific policy approach which combines the success of on-bill financing with improvements for landlord incentives.

3.2 Studies relating to the principal-agent problem

There are several relevant empirical studies investigating the determinants of residential energy consumption focusing more directly on the PA problem. Davis (2010) compares appliance ownership patterns between homeowners and renters using household-level data from a nationally-representative survey. His results show that, controlling for household income and other household characteristics, renters are significantly less likely to have energy efficient refrigerators, clothes washers and dishwashers. Gillingham *et al.* (2012) investigate two types of PA problems between owners and tenants of residential dwellings for the State of California: heating or cooling incentives are suboptimal when the occupant does *not* pay for energy use, and insulation incentives are suboptimal when the occupant *cannot* perfectly observe the owner's insulation choice. They find that those who pay are 16 percent more likely to change the heating setting at night and owner-occupied dwellings are 20 percent more likely to be insulated in the attic or ceiling. Three recent studies in particular, however, have provided insight on an appropriate model design to analyze the present research question. These include Rehdanz (2007), Meier and Rehdanz (2010) and Wood *et al.* (2012).

Rehdanz (2007) examines the determinants of household expenditures on space heating and hot water supply in Germany, revealing differences in the characteristics of owners and renters. The analysis includes a number of socio-economic characteristics along with building characteristics on more than 12,000 households in Germany for the years 1998 and 2003. A conditional demand model is employed to investigate whether different kinds of households are affected differently by increases in energy prices.[4] She finds a significant difference between the effects of energy price increases for owners and tenants, and concludes that owners are more likely to have installed energy-efficient heating and hot water supply systems. Meier and Rehdanz (2010) conduct a similar study for Great Britain. Employing a conditional demand model on panel data, they examine the determinants affecting heating expenditure, controlling additionally for weather conditions (i.e. heating degree days), on 64,000 households over a 15 year period (1991–2005). The aim of the

[4] Conditional demand model: the decision for consuming energy is not determined by adjustments in technologies but by adjustments in consumption of energy given the available technology. This is the same modelling choice of the current study.

study is to derive price and income elasticities both for Britain as a whole and for different types of household. Their results suggest that differences exist between owner-occupied and renter households in their reactions to changes in income and price. More specifically, they find that homeowners pay more for energy than tenants in Great Britain.

Wood *et al.* (2012) focus their investigation more directly on the PA problem for Australia. Their analysis quantifies the magnitude of the PA problem in the Australian private rental housing market with a modelling approach whereby energy expenditure is estimated as a function of housing tenure, dwelling type, location, climate and other socio-demographic variables. They fail to find evidence in support of the PA problem hypothesis in Australia since homeowners had higher energy outlays than those of renters. Their conclusions suggest that, contrary to other study areas such as Germany and the United States, powerful tax incentives and a relatively unregulated rental market perhaps eliminate the effects of PA problems in Australia. The current analysis differs from the above studies mainly in location and restrictions on the dataset (discussed further in the next chapter). Moreover, this study is the first to employ EU Statistics on Income and Living Conditions data as a source for energy consumption data on an EU Member State.

4 Empirical Design

4.1 EU-SILC Data

The European Union Statistics on Income and Living Conditions (EU-SILC) is an instrument which collects comparable cross-sectional and longitudinal multidimensional micro-data on income, poverty, social exclusion and living conditions in Member States. The EU-SILC instrument was selected because it provides descriptive variables on housing, demographic, socio-economic and financial characteristics on individuals and households in Austria. Micro-data for Austria have been collected through panel surveys by Statistik Austria since 2003. Around 6000 households participate annually in the Austrian EU-SILC survey, drawn at random from addresses in the Central Register of Residents (Statistik Austria, 2014). It is therefore a nationally representative dataset which, 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 heating fuel.

4.2 Variable definition

The structure of the model includes variables which describe housing, socio-economic and regional characteristics of the household, as well as occupancy type. Housing characteristics are especially important as control variables because they typically have the largest effect on energy consumption. Therefore, 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, and fuel source for space heating, water heating and cooking. Also based on previous studies, socio-economic and demographic characteristics are expected to have an impact on energy consumption, including income, age of the household members, and size of the household. Regional characteristics control for weather and possible differences in fuel prices.

4.2.1 Critical explanatory variables

The occupancy type, i.e. tenure relationship, is the critical explanatory variable and its sign, size and statistical significance is used to determine if a PA problem exists and to what extent it affects energy expenditures. The different types of occupancy include owner-occupied of an apartment or house, renter-occupied (main renter or subtenant), renter with a co-operative agreement, council or social-housing tenant, and other (i.e. rent-free tenants). Recall that the primary interest of this study is whether owners pay more in energy expenditures than renters; therefore, the analysis excludes council- and other-occupancy types. House- and apartment-owners are grouped together, while main renters, subtenants, and renters with co-operative agreements are grouped into one category.

4.2.2 Control variables

The types of heating system recorded in the survey include district, central or electric heating, as well as gas convector, detached system (e.g. electric radiator, hot-air heater), or other (e.g. single oil or wood ovens).[5] For the purpose of this analysis, the model only controls for the presence of a central heating system (i.e. district, central, electric or gas) rather than the specific type of technology. The types of fuel include natural gas, heating oil, wood (e.g. pellets, wood chips, firewood), and coal (including coke and other solid fuels). Households may have more than one fuel source (i.e. fuel stacking) or none at all (i.e. electricity only). Therefore, since fuel stacking is allowed in the model, the fuel variables are not dummy variables, i.e. there is no reference category. The model also controls for the presence of renewable energy technology, usually used in combination with other fuels. Fourteen percent (588 households) of the sample reported that at least one or more fuels were not paid for by the household; seventeen percent of those were owner-occupied. Since it was unclear from the EU-SILC questionnaire and code book whether these households were receiving subsidies for the respective fuel(s), or if the costs of the fuel(s) were recorded elsewhere, a special control variable was used to capture any possible effect this may have on energy expenditures.[6,7]

[5] Central heating (*Zentralheizung*), as defined by the survey, is a central heating system within the building/apartment, such as a central boiler; district heating (*Fernwärme*) is located outside of the house/building.

[6] The exception being households with district heating; the survey allowed respondents to indicate if the cost of district heating was included in the running costs of the building. These observations were excluded from the analysis because their inclusion could bias the results.

[7] Wood fuel was the main fuel reported with zero cost (571 households, or 12 percent of total dataset). Possible explanations could be that the cost for wood fuels (pellets, fire wood, etc.) is included in the running costs of the building, or the household is collecting the fuel wood free of charge (such as in rural or farm areas). In total, 1282 households reported both using wood as an energy source *and* living in a thinly populated area.

The type of building is expected to have a significant effect on energy expenditures. Numerous studies, for example, have concluded that free-standing, detached houses are less energy efficiency than residential apartment buildings. The types of building identified in the Austrian EU-SILC survey are based on the number of apartments, or dwellings, in the building. There is a further distinction for buildings with one or two apartments, either as a detached house or a semi-detached house (row house or townhouse). For the present study, the following five distinctions are made in the model: 1) single-family house (SF) with one or two apartments, 2) semi-detached (RH) 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, whether any structural problems exist in the dwelling (e.g. moisture, rot, leaky roof or windows, etc.), and whether the unit has a bath or shower inside the dwelling.

The socio-economic variables control for household characteristics which 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, net household income, and age of the oldest household member. Baker *et al.* (1989) found a positive relationship between energy consumption and the number of children in the household, as well as the income-level of the household. Liao and Chang (2002) found a positive relationship to the average age of the household concerning space heating, and a negative relationship to water heating. Additionally, the model controls for the number of household members registered as unemployed or on pension. Both Rehdanz (2007) and Wood *et al.* (2012) utilized models with the same controls in order to estimate the potential number of people at 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. Price variations in different states are due to the reliance on diverse energy sources in different parts of the country which have different costs of production and therefore prices. The state variable serves as a crude proxy for these price variations. 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; H. Meier & Rehdanz, 2010, p. 951, fn. 4). In order to more accurately control for meteorological conditions across the country, however, it would be preferable to match the EU-SILC data with time series data on regional heating degree-days (see, e.g., H. Meier & Rehdanz, 2010; Wood *et al.*, 2012). Unfortunately, data on heating degree-days at the regional level for Austria were difficult to obtain; but, on the other hand, the Austrian climate is mostly temperate, and the necessity for this control is not as high as in other studies. Nevertheless, a combination of the state and urbanization variables is used as a crude proxy for possible differences in weather conditions which would otherwise be measureable with heating-degree-day statistics (Rehdanz, 2007). The definition of variables included in the analysis is shown in Table 4-1.

4.2.3 Limitations

One 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 heating system or water heater, the presence of double glazing, or other forms 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, recall that energy expenditure is used as a proxy for energy consumption in this model with a broad assumption that expenditures are perfectly correlated with consumption. While this is not a perfect solution, it is a common work-around within the literature reviewed for this study.

Another limitation occurs in the variables which capture the size of the dwelling and age of the individuals. The 2012 survey allows respondents to enter the exact size of the dwelling in square meters; in the resulting dataset, however, the variable is truncated to 200 as the maximum value (indicating 200 m^2 or more). It was unclear how to handle this, since dwelling size is expected to have a significant effect on energy expenditures, but the variance in the size of dwellings above 200 m^2 would not be measured accurately. After experimenting with model specifications which included or excluded these observations, the results indicate that the estimated coefficients are similar. A similar limitation exists for the age of the individual household members, with a maximum value of 80 (indicated 80 years or older). In the end, the number of households affected by these limitations (296 for the size, and 289 for age) is minimal and they remain in the analysis.

Table 4-1. Description of variables included in the regression.

Variable	Definition
L_EXP_SM	Log of annual expenditure for energy per m^2 (dependent)
RENTER	Unity if renter-occupied, zero otherwise
TYPE	Type of building: Detached house (SFH), semi-detached (RH), MFH with 3-9 flats, MFH with 10-19 flats, MFH 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
PROBLEM	Unity if dwelling has structural problems (i.e. rot, moisture, leaky roof or windows), zero otherwise
HEAT_CENTRAL	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: Gas, oil, wood, coal, 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
SUBSIDIZED	Unity if household does not pay for one or more fuel, zero otherwise
STATE	Austrian Federal State: Burgenland, Carinthia, Lower Austria, Upper Austria, Styria, Salzburg, Tirol, Vorarlberg, Vienna; unity or zero
URBAN	Level of urbanization: Densely populated area, intermediate area, thinly populated area; unity or zero
L_INCOME	Log of household annual net income
HH_ADULT	Number of adults older than 16
HH_CHILD	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

Source: European Union Statistics on Income and Living Conditions, 2012, Austria.

4.2.4 Exclusions

A number of exclusions to the dataset are necessary:

- Households receiving social benefits, living rent free or paying a reduced rent, and those living in council or social housing. For most of these households, expenditures for energy are included in the monthly rent, or partially paid for by the government, and are independent of consumption.

- Buildings which are non-residential, such as school housing, hospitals or nursing homes. In most of these cases, it is difficult to separate energy expenditure from the cost of room and board.

- Households who reported less than one year of occupancy in the dwelling. The total yearly energy expenditure in these households is not captured in the survey.

- Households who reported district heating costs were included in the running costs of the building. The true annual cost of energy is not captured in the survey. Likewise, those households who reported less than €100 in energy costs are also excluded, because it is unclear from the survey if some of those costs are recorded elsewhere.

- Finally, households without a water connection (very rare in Austria) and those who reported income from rental property. The latter are excluded because it is unclear from the survey if the landlord reported energy expenses from properties where the energy bills are included in the rent.

The final sample size is 4,164: 2,745 (66 percent) of which are owners, and 1,419 (34 percent) are renters (including co-operative arrangements).

4.3 Model specification

The model specifies the annual household energy expenditures per square meter as a function of the type of tenure, characteristics of the building in question, type of fuel, socio-economic characteristics, and regional characteristics of individual households:

$$E_i = \alpha + \beta_T T_i + \beta_B B_i + \beta_F F_i + \beta_R S_i + \beta_S R_i + \varepsilon,$$

where

E_i	annual energy expenditure per square meter (of ith household),
T_i	tenure type (critical explanatory variable),
B_i	building characteristics,
F_i	fuel type used for space heating, water heating and cooking,
S_i	socio-economic characteristics,
R_i	location and urbanization,
α	constant (intercept), and
ε	error term.

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). Under the Box-Cox transformation procedure written for SPSS by Raynald Levesque (see Osborne, 2010), the energy expenditure per-square-meter variable was estimated using 32 different lambdas simultaneously. The original variables had a skewness = 4.449. The best result (i.e. a skew closest to 0) produced a log-transformed dependent variable with a skewness = -0.141, $\lambda = 0.1$). This lambda remains in the neighborhood of logarithmic transformation. A log-linear form is also in line with earlier studies. The size of the dwelling, annual disposable income, and the age of the oldest household member are transformed into natural logarithmic form following the same tests for functional form and indicate elasticities. In the case of income elasticity, for example, values exceeding (less than) one indicate an elastic (inelastic) demand because a 10 percent increase in income results in an increase in energy consumption that is greater than (less than) 10 percent. The remaining continuous variables, indicating the number of adults and children, unemployed and retired household members, were left as untransformed continuous variables. In order to ensure homoscedasticity, the `hcreg()` macro, authored by Hayes and Cai (2007), was used in SPSS® to obtain heteroscedasticity-consistent standard errors (HCSE), i.e. robust standard errors. Given the large sample size of the analysis, the HC0 method, or the Huber-White heteroscedasticity-consistent estimator, was used to obtain the HCSE (for further reading, see Hayes & Cai, 2007; MacKinnon & White, 1985; White, 1980).

5 Results

5.1 Descriptive statistics

Table 5-1. Mean annual energy expenditures of owners and renters, by dwelling type.

	Mean (€)		
Building type	Owner	Renter	All
Annual energy expenditures			
Detached house	2419	1973	2396
Semi-detached house	2270	1846	2173
MFH with 3 to 9 flats	1569	1316	1406
MFH with 10 to 19 flats	1366	1266	1297
MFH with 20 or more flats	1308	1246	1265
All building types	*2190*	*1357*	*1907*
Annual energy expenditures / m²			
Detached house	19.52	21.25	19.60
Semi-detached house	20.15	21.60	20.49
MFH with 3 to 9 flats	17.96	19.84	19.17
MFH with 10 to 19 flats	17.60	19.26	18.74
MFH with 20 or more flats	17.02	19.67	18.88
All building types	*19.15*	*19.83*	*19.38*

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

As it turns out, when examining the descriptive statistics of the sample, owners pay more in energy expenditures than renters. In fact, the typical owner in the sample spends on average €833 (61 percent) more per year in energy bills than the €1357 spent by a typical renter. Assuming no differences in the price per unit of energy paid by these two groups, it appears that, contrary to expectations, owners consume more energy despite PA problems that are expected to deter landlord/tenant investment in energy efficiency. These averages, however, reflect differences in building type and size that could obscure tenure-related differences in energy consumption (Wood *et al.*, 2012). Table 5-1 presents average energy expenditure comparisons by building type, size and tenure. The figures illustrate the importance to control for dwelling characteristics. Disregarding dwelling size for the moment (i.e. top-half of Table 5-1), single-family, detached buildings are, as expected, more costly and less energy efficient than multi-family apartment buildings. Average annual (2012) expenditures by occupants of detached housing with one or two apartments is €2396, €223 (10 percent) more than for occupants of semi-detached housing, and an even larger €1131 (89 percent) more than the average outlays incurred by residents of apartment buildings of 20 or more flats. Only 6 percent of detached housing in the sample is occupied by renters, yet they occupy 34 percent of buildings with 3 to 9 flats, 27 percent of buildings with 10 to 19 flats, and 28 percent of buildings with 20 or more flats. Owners, on the other hand, occupy 66 percent of detached housing and only 25 percent of buildings with 3 or more flats.

What is interesting, however, is when dwelling size is taken into consideration (i.e. bottom-half of Table 5-1). Per square meter, occupants of detached housing spend €19.60 per year, €0.43 (2 percent) more per year than occupants of multi-family buildings with 3 to 9 flats. The size differential continues among the various types of building, with an extreme outlier occurring in the semi-detached housing category. On closer inspection, it appears that the number of apartments in semi-detached housing has some influence on energy expenditures per square meter. Occupants of semi-detached buildings with one apartment spend on average €18.54 per square meter per year, while those with two apartments spend €24.57 (33 percent higher). What is more, owner-occupiers in semi-detached with two apartments spend €25.15 per square meter per year, €3.18 (14 percent) more than renters, while owner-occupiers in a semi-detached with one apartment spend €17.82, €3.52 (16 percent) less than renters, and €7.33 (29 percent) less than owner-occupiers with two apartments. The differentials within this category of buildings indicate that a detached house is less demanding on energy than semi-detached, which cannot be explained in the model or data.

When comparing owners to renters, occupying the same type of building equal in size, the statistics become even more interesting. The average owner-occupied dwelling is 121 square meters, while renter-occupied dwellings are on average 73 square meters. The typical owner pays €19.15 per square meter per year, €0.68 (4 percent) less than the €19.93 paid by a typical renter. The differential increases significantly when building type is taken into account. The typical renter in a detached house pays €1.73 (9 percent) more in annual energy outlays per square meter than the typical owner; renters of a flat in multi-family buildings of 20 or more flats pay an even larger €2.65 (16 percent) more than owners of a flat of the same size. At first glance, it would appear that, when dwelling size is taken into consideration, a PA problem does exist in the Austrian rental market, as expected in the hypothesis. Upon closer examination, however, it turns out that the size of the dwelling has a negative relationship to energy costs. In other words, energy costs decrease with every additional square meter of living space. Again, these findings could obscure other tenure-related differences in energy consumption.

Other key points from the descriptive statistics include (see Table 5-2):

- The distributions of owner- and renter-occupied dwellings by state are relatively similar, with the exception of Vienna.
- As already mentioned above, owners are more likely to occupy detached housing and have larger dwellings (7 percent reported dwellings 200 square meters or more).
- A third of renters live in a building built before 1945.
- A large majority of owner-occupied households use central heating (this is most likely due to the large number of detached housing they occupy); also, households of both groups report mostly district or central heating.
- Wood (or biofuels) is used by the majority of households as a fuel source, followed by natural gas, electricity (indicated by the "None" category), and oil; wood is used by over half of owner-occupied households, most likely due to their higher propensity to have central heating, live in detached housing, and live in rural or suburban areas.
- Owners have larger households, including more children, which corresponds to the larger dwellings.
- The oldest responding household member of owner-occupied households tends to be older than their renter counterparts, but only 3.2 years older than the mean of the sample.
- Annual net income of owners and renters are significantly different. Furthermore, fewer owners are officially registered as unemployed, but represent a larger percentage of pensioners.

Table 5-2. Descriptive statistics; column percentage or mean.

Variables	Owner	Renter	All
State (%)			
Burgenland	5.3	1.4	4.0
Carinthia	7.3	5.3	6.6
Lower Austria	23.5	10.9	19.2
Upper Austria	18.1	16.7	17.6
Salzburg	6.2	7.0	6.5
Styria	15.7	10.1	13.8
Tirol	9.0	6.3	8.1
Vorarlberg	5.1	2.6	4.2
Vienna	9.9	39.5	20.0
Building type (%)			
Detached house	66.1	6.2	44.1
Semi-detached house	9.2	4.9	7.6
Multi-family with 3 to 9 flats	10.6	33.8	19.1
Multi-family with 10 to 19 flats	7.2	27.4	14.6
Multi-family with 20 or more flats	7.0	27.7	14.6
Building vintage (%)			
Before 1919	10.5	22.3	14.5
From 1919 to 1944	4.8	9.4	6.4
From 1945 to 1960	11.7	11.1	11.5
From 1961 to 1970	13.8	13.2	13.6
From 1971 to 1980	17.6	9.7	14.9
From 1981 to 1990	13.5	8.9	11.9
From 1991 to 2000	16.2	13.4	15.3
From 2001 to 2005	6.8	6.7	6.7
From 2006 to 2010	5.0	5.3	5.1
Heating system (%)			
District heating	11.5	37.6	20.4
Central heating	78.7	46.7	67.8
Electric heating	4.4	5.5	4.8
Gas convector	1.2	5.4	2.6
Total with central heating system [a]	95.8	95.1	95.6

Variables	Owner	Renter	All
Single oven system (wood- or coke-oven, single oil-oven)	3.9	4.0	3.9
Other detached system (electric radiator, air heater)	0.1	0.8	0.4
Fuel source (%)[b]			
Natural gas	30.6	41.2	34.2
Heat oil	25.9	10.0	20.5
Wood (firewood, pellets or wood chips)	53.6	12.1	39.4
Coal (incl. coke or briquettes)	4.0	2.2	3.4
None (uses electricity only)	15.0	42.1	24.2
Renewable energy source	21.2	3.5	15.2
Degree of Urbanization (%)			
Densely populated area	17.4	55.6	30.4
Intermediate area	29.3	29.6	29.4
Thinly populated area	53.2	14.8	40.1
Other building characteristics			
Mean dwelling size in square meters	121	73	104
Mean annual energy expenditure (€)	2190	1357	1907
Mean annual energy expenditure per m^2 (€)	19.15	19.83	19.38
Households reporting one or more fuels not paid for directly (%)	17.5	7.5	14.1
Households reporting use of more than one fuel source (%)	28.1	6.9	20.9
Dwellings reported as 200 m^2 or more in size (%)	7.6	0.2	5.1
Other household personal characteristics			
Mean number of adults aged over 16 years	2.1	1.6	1.9
Mean number of children aged 16 years and under	0.5	0.3	0.4
Mean age of oldest responding household member (years)	56.0	49.4	53.8
Mean annual net household income (€)	62 953	45 714	57 079
Mean number of adults registered as unemployed	0.04	0.08	0.05
Mean number of adults registered as pensioner	0.61	0.38	0.53

Source: Author's calculations using the 2012 EU-SILC data.
Notes: a. 'Central heating system' is defined as either having a district heating connection, central heating present in the building or unit, electric heating or gas convector. b. Households may use more than one fuel source, therefore percentages may not add up to 100.

5.2 Empirical findings

Regression results were obtained from three log-linear models corresponding to sample designs that differ in terms of their geographical coverage and two models restricted by occupancy type, for a total of five specifications. Model A included all households that met the criteria outlined in Chapter 4, i.e. the entire sample size of 4164 households. From this model specification, the net effect of being a renter can be measured. In other words, the presence of a PA problem can be identified and its effect on energy expenditures can be quantified. Furthermore, important determinants of energy expenditures can be investigated. Model B was restricted in specification to households located in Vienna, the largest and most populous city and state in Austria, while Model C included all other households outside of Vienna. By narrowing the analysis to Vienna only, and then comparing those results to the rest of Austria, it can be judged whether the large share of renters (39.5 percent) in Vienna bias the results found in Model A.

After obtaining and analyzing the regression results from the three models just described, it was apparent that owners and renters may have different characteristics that determine their annual energy expenditure that could be obscured by the binary variable RENTER. In order to examine these differences, regression results were then obtained from two additional log-linear models restricted in specification to the two groups based on occupancy type. Consequently, Models D and E examine the determinants of residential energy expenditures of owners and renters, separately. Tables 5-3 and 5-4 report OLS regression results for the five model specifications described here, including the coefficients, robust standard errors, and significance levels. Sample sizes are healthy for each specification, i.e. all are above 800 observations.

Consider the estimates of Model A, for the moment, and the building characteristics in particular. Building type and vintage have their expected impact on annual energy expenditure. Single-family, detached housing (SF) is 29 percent more costly in energy per square meter than multi-family apartment housing (MF) in buildings with 20 or more flats. Apartment units in buildings of 10–19 flats are not significantly different than those in buildings with 20 or more. These results are comparable to previous studies conducted in

Table 5-3. Log-linear annual energy expenditures per square meter model results.

	Model A: All			Model B: Vienna only			Model C: Excluding Vienna		
Explanatory variables	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.
RENTER	–0.041	0.021	0.053	0.067	0.046	0.142	–0.085	0.024	0.000
TYPE_SF	0.285	0.035	0.000	0.375	0.067	0.000	0.275	0.046	0.000
TYPE_RH	0.269	0.036	0.000	0.299	0.081	0.000	0.268	0.046	0.000
TYPE_MF3	0.076	0.029	0.008	0.104	0.053	0.047	0.085	0.039	0.030
TYPE_MF10	0.017	0.029	0.557	–0.004	0.040	0.922	0.035	0.043	0.412
TYPE_MF20	—	—	—	—	—	—	—	—	—
VINTAGE1 (<1919)	0.142	0.036	0.000	0.113	0.091	0.215	0.126	0.041	0.002
VINTAGE2 (1919-1944)	0.143	0.043	0.001	0.101	0.108	0.351	0.140	0.047	0.003
VINTAGE3 (1945-1960)	0.122	0.037	0.001	0.030	0.105	0.772	0.132	0.040	0.001
VINTAGE4 (1961-1970)	0.091	0.036	0.011	0.090	0.092	0.325	0.091	0.039	0.020
VINTAGE5 (1971-1980)	0.118	0.035	0.001	0.010	0.093	0.910	0.137	0.038	0.000
VINTAGE6 (1981-1990)	0.137	0.034	0.000	0.048	0.089	0.590	0.148	0.037	0.000
VINTAGE7 (1991-2000)	0.055	0.033	0.093	0.086	0.086	0.319	0.048	0.035	0.175
VINTAGE8 (2001-2005)	0.049	0.036	0.172	0.054	0.100	0.588	0.053	0.038	0.167
VINTAGE9 (2006-2010)	—	—	—	—	—	—	—	—	—
L_SIZE	–0.618	0.027	0.000	–0.629	0.054	0.000	–0.619	0.030	0.000
BATH	0.067	0.088	0.446	0.158	0.200	0.428	0.056	0.090	0.531
PROBLEM	0.031	0.023	0.182	0.030	0.045	0.504	0.038	0.026	0.153
HEAT_CENTRAL	0.208	0.043	0.000	0.177	0.103	0.085	0.216	0.048	0.000
FUEL_GAS	0.283	0.027	0.000	0.347	0.137	0.011	0.272	0.027	0.000
FUEL_OIL	0.560	0.025	0.000	0.572	0.130	0.000	0.561	0.026	0.000
FUEL_WOOD	0.120	0.022	0.000	0.076	0.073	0.297	0.133	0.023	0.000
FUEL_COAL	0.253	0.041	0.000	0.186	0.282	0.510	0.257	0.041	0.000
FUEL_NONE	0.132	0.031	0.000	0.167	0.137	0.224	0.145	0.033	0.000
RENEW	–0.110	0.021	0.000	–0.134	0.090	0.138	–0.112	0.022	0.000
NOTPAID	–0.335	0.026	0.000	–0.088	0.064	0.171	–0.375	0.027	0.000

	Model A: All			Model B: Vienna only			Model C: Excluding Vienna		
Explanatory variables	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.
L_INCOME	0.032	0.011	0.003	0.013	0.020	0.503	0.038	0.013	0.003
ADULTS	0.084	0.010	0.000	0.131	0.025	0.000	0.074	0.011	0.000
CHILDREN	0.054	0.009	0.000	0.032	0.023	0.157	0.060	0.010	0.000
L_AGE	0.035	0.034	0.296	0.018	0.066	0.791	0.050	0.040	0.209
UNEMPL	0.076	0.029	0.008	0.106	0.055	0.053	0.055	0.032	0.088
PENSION	0.021	0.013	0.101	0.009	0.031	0.783	0.021	0.014	0.126
STATE1 (BU)	—	—	—				—	—	—
STATE2 (KA)	0.111	0.043	0.010				0.109	0.043	0.011
STATE3 (NO)	0.094	0.036	0.008				0.094	0.036	0.009
STATE4 (OO)	0.041	0.036	0.252				0.042	0.036	0.237
STATE5 (ST)	0.111	0.037	0.002				0.108	0.037	0.003
STATE6 (SZ)	0.097	0.044	0.029				0.094	0.044	0.032
STATE7 (TR)	–0.037	0.041	0.361				–0.040	0.041	0.331
STATE8 (VO)	–0.186	0.051	0.000				–0.187	0.051	0.000
STATE9 (WIE)	0.113	0.044	0.009						
URBAN_DENSE	—	—	—				—	—	—
URBAN_INTER	0.043	0.026	0.104				0.045	0.027	0.090
URBAN_THIN	0.021	0.028	0.454				0.023	0.029	0.426
Constant	4.117	0.210	0.000	4.299	0.396	0.000	4.021	0.246	0.000
F-stat	45.119		0.000	9.563		0.000	40.875		0.000
R^2	0.34			0.27			0.37		
Sample	4164			832			3332		

Source: Author's own calculations using the 2012 EU-SILC data.
Notes: a. Heteroscadasticity-consistent standard errors obtained using the HC0 method option in the SPSS macro; while heteroscedasticity was not present according to graphical tests, most economic literature recommends using robust standard errors in every situation.. — indicates omitted category.

Table 5-4. Log-linear annual energy expenditures per square meter, owners and renters

	Model A: All			Model D: Owners			Model E: Renters		
Explanatory variables	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.
RENTER	–0.041	0.021	0.053						
TYPE_SF	0.285	0.035	0.000	0.416	0.049	0.000	0.110	0.066	0.099
TYPE_RH	0.269	0.036	0.000	0.376	0.052	0.000	0.225	0.055	0.000
TYPE_MF3	0.076	0.029	0.008	0.208	0.049	0.000	0.022	0.036	0.556
TYPE_MF10	0.017	0.029	0.557	0.081	0.055	0.143	–0.001	0.033	0.976
TYPE_MF20	—	—	—	—	—	—	—	—	—
VINTAGE1 (<1919)	0.142	0.036	0.000	0.208	0.046	0.000	0.073	0.064	0.252
VINTAGE2 (1919-1944)	0.143	0.043	0.001	0.178	0.053	0.001	0.114	0.074	0.124
VINTAGE3 (1945-1960)	0.122	0.037	0.001	0.171	0.046	0.000	0.068	0.066	0.300
VINTAGE4 (1961-1970)	0.091	0.036	0.011	0.165	0.043	0.000	0.005	0.064	0.941
VINTAGE5 (1971-1980)	0.118	0.035	0.001	0.185	0.042	0.000	0.062	0.069	0.364
VINTAGE6 (1981-1990)	0.137	0.034	0.000	0.201	0.041	0.000	0.036	0.063	0.569
VINTAGE7 (1991-2000)	0.055	0.033	0.093	0.075	0.040	0.060	0.039	0.058	0.507
VINTAGE8 (2001-2005)	0.049	0.036	0.172	0.084	0.041	0.042	0.007	0.069	0.923
VINTAGE9 (2006-2010)	—	—	—	—	—	—	—	—	—
L_SIZE	–0.618	0.027	0.000	–0.652	0.032	0.000	–0.609	0.044	0.000
BATH	0.067	0.088	0.446	0.130	0.098	0.182	0.034	0.143	0.811
PROBLEM	0.031	0.023	0.182	–0.012	0.033	0.710	0.086	0.031	0.006
HEAT_CENTRAL	0.208	0.043	0.000	0.199	0.055	0.000	0.244	0.069	0.000
FUEL_GAS	0.283	0.027	0.000	0.281	0.027	0.000	0.258	0.089	0.004
FUEL_OIL	0.560	0.025	0.000	0.577	0.026	0.000	0.408	0.084	0.000
FUEL_WOOD	0.120	0.022	0.000	0.090	0.022	0.000	0.184	0.071	0.010
FUEL_COAL	0.253	0.041	0.000	0.224	0.044	0.000	0.351	0.102	0.001
FUEL_NONE	0.132	0.031	0.000	0.092	0.036	0.010	0.133	0.089	0.136
RENEW	–0.110	0.021	0.000	–0.099	0.022	0.000	–0.135	0.079	0.090
NOTPAID	–0.335	0.026	0.000	–0.334	0.029	0.000	–0.312	0.055	0.000

	Model A: All			Model D: Owners			Model E: Renters		
Explanatory variables	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.	Coeff.	HCSE[a]	Sig.
L_INCOME	0.032	0.011	0.003	0.055	0.015	0.000	0.006	0.018	0.726
ADULTS	0.084	0.010	0.000	0.059	0.012	0.000	0.147	0.019	0.000
CHILDREN	0.054	0.009	0.000	0.049	0.011	0.000	0.058	0.016	0.000
L_AGE	0.035	0.034	0.296	–0.045	0.051	0.382	0.110	0.046	0.016
UNEMPL	0.076	0.029	0.008	–0.026	0.038	0.493	0.132	0.041	0.001
PENSION	0.021	0.013	0.101	0.028	0.015	0.064	–0.013	0.024	0.587
STATE1 (BU)	—	—	—	—	—	—	—	—	—
STATE2 (KA)	0.111	0.043	0.010	0.079	0.049	0.104	0.184	0.089	0.038
STATE3 (NO)	0.094	0.036	0.008	0.090	0.039	0.022	0.117	0.080	0.145
STATE4 (OO)	0.041	0.036	0.252	0.045	0.040	0.259	0.059	0.077	0.447
STATE5 (ST)	0.111	0.037	0.002	0.117	0.051	0.022	0.087	0.088	0.323
STATE6 (SZ)	0.097	0.044	0.029	0.104	0.041	0.011	0.158	0.080	0.048
STATE7 (TR)	–0.037	0.041	0.361	–0.025	0.046	0.588	0.003	0.088	0.976
STATE8 (VO)	–0.186	0.051	0.000	–0.134	0.052	0.010	–0.344	0.133	0.010
STATE9 (WIE)	0.113	0.044	0.009	0.023	0.057	0.685	0.190	0.082	0.021
URBAN_DENSE	—	—	—	—	—	—	—	—	—
URBAN_INTER	0.043	0.026	0.104	–0.014	0.036	0.701	0.087	0.038	0.024
URBAN_THIN	0.021	0.028	0.454	–0.032	0.037	0.382	0.058	0.048	0.225
Constant	4.117	0.210	0.000	4.259	0.301	0.000	3.960	0.313	0.000
F-stat	45.119		0.000	42.810		0.000	12.735		0.000
R^2	0.34			0.40			0.28		
Sample	4164			2745			1419		

Source: Author's own calculations using the 2012 EU-SILC data.
Notes: a. Heteroscadasticity-consistent standard errors obtained using the HC0 method option in the SPSS macro; while heteroscedasticity was not present according to graphical tests, most economic literature recommends using robust standard errors in every situation. — indicates omitted category.

Europe (see, e.g. Baker *et al.*, 1989; Berkhout *et al.*, 2004; H. Meier & Rehdanz, 2010; Nesbakken, 2001; Rehdanz, 2007). Older buildings, especially those built prior to World War II, are also less energy efficient. Buildings built before 1919 are 14 percent more costly per square meter compared to those built between 2006–2010. Similar results were found in Germany (Rehdanz, 2007). For each newer period of construction, the impact on energy expenditures decreases. That is, except during periods 1971–1980 and 1981–1990, where there is evidence of a significant reduction in energy efficiency. This spike in energy costs could possibly be related to changes in building materials used during those periods or poor building codes and standards. There is no significant difference in the impact on energy expenditures between buildings built in 2001–2005 and 2006–2010.

Fuel types also have their expected signs and significance levels. For Model A, gas and oil add 28 and 56 percent, respectively, to annual energy expenditures per square meter, while wood and coal add only 12 and 25 percent, respectively. Households which reported no fuel usage are assumed to rely solely on electricity for cooking and/or water heating, increasing energy outlays by 13 percent. The presence of a renewable energy source reduces energy costs by 11 percent. 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.[8]

The estimates for building characteristics and fuel type are comparable across models A, B and C. Building type remains a significant factor across all three models, while building vintage appears to be less significant for households located in Vienna only. This is interesting because 40 percent of Viennese renters live in a building built before 1919 (Statistik Austria, 2014); expectation would be that this would have a significant impact on energy expenditures for renters. Energy costs decrease per square meter with the size of the dwelling at relatively the same rate in all three models. The presence of a bath or shower, or of structural problems in the dwelling, is not statistically significant in any of the specifications. A central heating system, as expected, is a significant factor in energy expenditures, increasing costs by 18 to 22 percent, depending on the specification. The

[8] A similar analysis which excluded this variable indicates a possible interaction with FUEL_WOOD (i.e. FUEL_WOOD became statistically insignificant). As mentioned in the previous chapter, most of the respondents who fall into this category indicated wood was not paid for by the household.

variables controlling for fuel type, including renewable energy and non-payment, are nearly identical in Models A and C. For households in Vienna, however, only gas and oil remain statistically significant.

Turning now to socio-economic characteristics, income elasticity ranges from 0.01 to 0.04 in the analysis, but is statistically insignificant for households in Vienna. Meier and Rehdanz (2010) also found income elasticities in Great Britain between 0.01 and 0.04 at the 5 percent confidence level. The major difference here being the income variable itself: they used real annual income, while in the current study, annual disposable income is used. In Germany, Rehdanz (2007) found elasticities that ranged from 0.01 to 0.10 and Wood *et al.* (2012) reported a range from 0.07 and 0.14 in Australia. Other studies based on household energy consumption estimated income elasticities between 0.08 and 0.17 (Baker *et al.*, 1989; Bernard *et al.*, 1996; Garbacz, 1983; Hirst *et al.*, 1982; Nesbakken, 2001). Berkhout *et al.* (2004) and Vaage (2000) found negative income elasticities for the Netherlands and Norway, respectively. The number of adults over the age of 16 is highly significant in all three specifications. Except for households in Vienna, there is a positive and significant relationship between the number of children and the dependent variable. This is similar to other studies (Baker *et al.*, 1989; Hirst *et al.*, 1982; H. Meier & Rehdanz, 2010). Rehdanz (2007) found a negative relationship, while Nesbakken (2001) found no relationship. Contrary to other studies (Baker *et al.*, 1989; Liao & Chang, 2002; Rehdanz, 2007), however, there is no significant relationship between age and energy expenditures in Austria. Additionally, the share of household members registered as pensioners is insignificant in the current results; as with Meier and Rehdanz (2010), age and pension-status may be related. On the other hand, the number of officially registered unemployed household members has a positive relationship to the dependent variable in all three models, as expected and is in line with other studies (H. Meier & Rehdanz, 2010; Rehdanz, 2007). Wood *et al.* (2012), however, found a negative relationship to energy expenditures.

As for the regional characteristics, annual energy expenditures for households in Upper Austria (OO) and Tyrol (TR) are not significantly different than those in Burgenland (BU). Households in Vienna (WIE) and Styria (ST) pay 11 percent more in energy outlays, while those in Vorarlberg (VO) pay 19 percent less, than in Burgenland. These estimates are nearly identical in Models A and C, as expected. The estimates for the state-dummies are an indication of energy market segmentation and price variation in Austria. It is difficult to interpret from these estimates if weather conditions have been appropriately captured in the model. There also appears to be no relationship between the level of urbanization and energy expenditures, discounting the theory of an urban heat-island for Austria. Rehdanz (2007) used a similar categorization to measure community size and found comparatively insignificant results, while Wood *et al.* (2012) found mixed results.

Contrary to expectations, *ceteris paribus*, the net effect of being a renter in Austria actually lowers annual energy expenditures per square meter by 4 percent, significant at the 5 percent confidence level. There is an even greater 9 percent decrease in energy outlays per square meter in the Vienna-excluded model for renters, significant at 1 percent. In Vienna, the effect is positive but not statistically significant. Meier and Rehdanz (2010) found that renters paid between 3 to 4 percent less in energy bills per room than owners in Great Britain. Likewise, Wood *et al.* (2012) found that renters paid between 14 to 19 percent less than owners in Australia (dwelling size was not considered in their analysis). Owners were also found to consume more energy in other studies (e.g. Baker *et al.*, 1989; Berkhout *et al.*, 2004; Vaage, 2000). In contrast, Rehdanz (2007) found that owners paid between 5 and 18 percent less in energy expenditures per square meter than renters in Germany.

According to the estimates for the critical explanatory variable RENTER, a PA problem concerning energy efficiency appears unimportant in the Austrian residential sector, even after controlling for confounding influences on energy expenditures. It is conceivable, however, that owners and renters may have different characteristics that determine annual energy expenditure, and the binary variables RENTER fails to detect these differences. Following a similar approach as Rehdanz (2007) and Meier and Rehdanz (2010), the model specification was restricted by occupancy type in order to investigate the determinants of energy expenditures for owners and renters, separately.

The regression results in Table 5-4 show, for example, that the type of building and its vintage are (significantly) more important for owners than for renters. Detached housing, for example, increases energy outlays per square meter by 42 percent for owners, significant at the 1 percent level, versus 11 percent for renters, significant only at the 10 percent level. Similar results were found in Great Britain (H. Meier & Rehdanz, 2010), the Netherlands (Berkhout *et al.*, 2004) and Norway (Vaage, 2000), while the opposite was found in Germany (Rehdanz, 2007). Further, household disposable income appears to be significant only for owners, with an elasticity of 0.06. Similar conditions exist for Great Britain (H. 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 owners. Based on these observations, there is the possibility that PA problems only exist among particular subgroups of owners and renters. That is to say, certain subgroups of owners may consume less energy than their renter counterparts, and vice versa. An example of such a situation includes different income groups of owners, where low-income owners may not have as much capital outlay available to make energy efficient improvements as wealthier owners. PA problems would then only be observable, in this case, when high-income owners are compared to renters with similar incomes.

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 on the Model A specification. Table 5-5 indicates 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 at the 5 percent confidence level, confirming the findings in Model D. On the other hand, while the vintage of the building was shown to be more important for owners, only two of the vintage categories, e.g. periods 1961–1970 and 1981–1990, are significant at the 5 percent level. Nevertheless, building type appears to have significant interactions on energy expenditures for owners; specifically, interaction with detached housing was significant at the 1 percent level and semi-detached at the 5 percent. The significance level of the interaction variables measure to what extent the effect is different for owners, compared to renters. In this case, detached housing, semi-detached housing, and an increase in disposable income have a higher impact on energy expenditures per square meter for owners than renters. These interactions may have an influence on the estimates presented previously.

Table 5-5. Log-linear model showing selected interaction variables.

Explanatory variables[a]	Coeff.	HCSE[b]	*Interaction variables*[a]	Coeff.	HCSE[b]
RENTER	–0.300	0.435			
TYPE_SF	0.110	0.066	i_TYPE_SF	0.307***	0.082
TYPE_RH	0.225***	0.055	i_TYPE_RH	0.151**	0.076
TYPE_MF3	0.022	0.036	i_TYPE_MF3	0.186***	0.061
TYPE_MF10	–0.001	0.033	i_TYPE_MF10	0.082	0.065
TYPE_MF20	—	—	i_TYPE_MF20	—	—
VINTAGE1	0.073	0.064	i_VINTAGE1	0.135*	0.078
VINTAGE2	0.114	0.074	i_VINTAGE2	0.064	0.091
VINTAGE3	0.068	0.066	i_VINTAGE3	0.103	0.080
VINTAGE4	0.005	0.064	i_VINTAGE4	0.160**	0.078
VINTAGE5	0.062	0.069	i_VINTAGE5	0.122	0.080
VINTAGE6	0.036	0.063	i_VINTAGE6	0.165**	0.075
VINTAGE7	0.039	0.058	i_VINTAGE7	0.036	0.071
VINTAGE8	0.007	0.069	i_VINTAGE8	0.077	0.080
VINTAGE9	—	—	i_VINTAGE9	—	—
L_INCOME	0.006	0.018	i_L_INCOME	0.049**	0.024
ADULTS	0.147***	0.019	i_ADULTS	–0.088***	0.022
CHILDREN	0.058***	0.016	i_CHILDREN	–0.009	0.019
L_AGE	0.110**	0.046	i_L_AGE	–0.155**	0.068
UNEMPL	0.132***	0.041	i_UNEMPL	–0.158***	0.056
PENSION	–0.013	0.024	i_PENSION	0.041	0.028
Constant	3.960***	0.313			
F–stat	27.422				
R^2	0.36				
Sample	4164				

Source: Author's own calculations using the 2012 EU-SILC data.
Notes: a. Due to space constraints, only variables of interest to the discussion were included in the table.
b. Heteroscadasticity-consistent standard errors obtained using the HC0 method option in the SPSS macro; while heteroscedasticity was not present according to graphical tests, most economic literature recommends using robust standard errors in every situation.
— indicates omitted category. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

6 Discussion

The estimates reported for Model A indicate that annual energy expenditures per square meter for renters tend to be 4 percent lower compared to owners in Austria. One interpretation of this result is that renters consume less energy, and therefore occupy dwellings which are more energy efficient, than owners. That is to say, the landlord-tenant PA problem presented in the introduction of this study does not exist or is unimportant to energy efficiency in the Austrian rental housing sector. This interpretation may be an oversimplification, however, because of the conflicting results found in the descriptive statistics. As presented in Table 5-1, the total effect of being a renter indicates that tenants consistently pay more in energy outlays per square meter than owners. This discrepancy is more difficult to interpret. Since the model controls for observable variables, such as building, socio-economic, and regional characteristics, which are thought to have confounding influences on energy outlays, what explanations might be offered for the higher expenditures of owners? Earlier studies presented in Chapter 3 indicate there is a precedence where PA problems do not exist, or at least are unimportant, in residential energy efficiency. While direct comparison to other studies is difficult due to important differences in study area, data source, and methodology, they do offer possible insights as to why, contrary to the theories presented in Chapter 2, PA problems do not always have an effect on energy efficiency investments.

Meier and Rehdanz (2010), for example, conclude that, while price and income elasticities are higher for owners than renters in Great Britain, differences between owner and renter heating expenditures are mainly due to differences in the type of dwelling they occupy. In their study, owners tend to live in detached or semi-detached houses, which have higher levels of heat loss than flats located in multi-family buildings. These conditions are very similar to those found in Austria. Recall that, in the separate regression results for owners and renters (see Table 5-4), building type and vintage were more important to owners than to renters. These findings were confirmed through similar regressions that included interaction effects, where detached housing is found to have a more significant impact on annual energy outlays per square meter for owners than for renters (see Table 5-5). This is an expected outcome since, in the current sample, 66 percent of owners live in detached housing and 9 percent in semi-detached; conversely, only 6 percent of renters live in detached housing and 5 percent in semi-detached (see Table 5-2, Building Type). More to this point, Nair *et al.* (2010) find evidence in Sweden that owners in detached housing are less likely to invest in energy efficiency improvements to the building envelope. Their study indicates that 43 percent of homeowners prefer to adopt non-investment measures, e.g. turning off lights and appliances, while only 21 percent invested in improving the building envelope, e.g. installing an efficient heating system. This suggests that owners in detached housing may not be taking advantage of cost-effective improvements to energy efficiency, resulting in owners paying more in energy expenditures than renters. Interestingly, Rehdanz (2007) reports that, while the demographics of the housing stock in Germany are similar to those found in Austria and Great Britain, a PA problem is evident in the residential sector. Her analysis concludes that this may be the result of strict rental regulation, where landlords are responsible for introducing energy related technology, while tenants have to pay the energy bill. This, however, is also the case in Austria.

Wood *et al.* (2012) offer alternative reasoning. They suggest that the energy-efficiency policy framework and rental housing regulations of a country are potentially important factors in the existence of PA problems. Australia, they report, has powerful tax incentives to motivate Australian landlords to invest in rental buildings. Moreover, the rental market is for the most part unregulated, possibly creating even more incentives for landlords to invest in the energy efficiency of their rental properties. They note that this latter point differs dramatically from other studies areas, such as in Germany or the United States, where rental market regulation is strict and PA problems are found to be prevalent (see, e.g. Davis, 2010; Rehdanz, 2007). In Austria, the rental market is highly regulated, similar to that of Germany, making it difficult in some cases for landlords to recover the costs on improvements to their property through rental increases. The Austrian Government does, however, provide about €2.4 billion per year in incentives – through tax reductions, grants and subsidies – to encourage homeowners and landlords to renovate and invest in energy efficiency improvements (ABB Group, 2011; Austrian Energy Agency, 2011). Moreover, energy policy implementation in Austria has been relatively successful in the last 25 years. A recent energy efficiency profile from the Austrian Energy Agency (2012) reports that energy efficiency in the Austrian residential sector has improved by 34 percent over the period 1990 to 2010, compared to 25 percent for the EU. More specifically, over the same period, energy efficiency of space heating improved by 37 percent, water heating by 11 percent, and cooking by 42 percent.

In the residential building sector, these policy measures include information campaigns, reinforced building standards and codes, along with the tax incentives and subsidies previously mentioned, all aiming to enhance investment in energy efficiency. The Second National Energy Efficiency Action Plan (NEEAP) of the Republic of Austria, published by the Austrian Energy Agency (2011), reports the current policies and their estimated (national) energy savings. Since 1982, the Austrian Government has supplied expansive subsidies and grants for the renovation of residential buildings and the construction of efficient new buildings, targeting both the shell of the building and the installation of efficient heating systems. The national recovery and renovation voucher plan was an extension to the original subsidy program between 2009 and 2011, targeting private households. The aim of the program was to provide subsidies for measures to improve the thermal insulation and to improve the weather generation systems of residential buildings erected before 1999 or which were at least 20 years old. In 2008, the Government passed into law the EU-related Energy Performance of Buildings Directive (2002/91/EC) an energy certificate program (German: *Energieausweise für Gebäude*). The program requires an energy performance certificate to be issued for a building or building unit, detailing the quality of the thermal insulation and energy consumption requirements. The certificate, according to EU law, is required to be presented at the time of purchase or when the unit or building is rented. Information campaigns and energy advice centers, which provide unbiased information concerning energy efficiency and conservation measures to consumers, have also been available since 1990 and informative billing measures since 2008. Similar policy mixes in other countries were found to significantly enhance energy efficiency in buildings (see, e.g. Gillingham *et al.*, 2009; Leth-Petersen & Togeby, 2001; Schaefer *et al.*, 2000).

7 Conclusion

The aim of this study was to identify and measure the effect of split incentives on energy expenditures in the Austrian residential sector. The hypothesis was that, based on the economic literature reviewed, renters pay more in energy expenditures than owners due to a PA problem in Austria. Estimates derived from the regressions suggest that, using energy expenditure as a proxy for energy consumption, household energy outlays are actually lower for renters than owners. Therefore, the PA problem within the landlord-tenant relationship is, according to these estimates, unimportant or non-existent, in the residential sector in Austria. Moreover, additional restrictions to the sample according to geographical area confirmed this finding. Restricting the sample according to occupancy type indicated that building and socio-economic characteristics do not impact energy expenditures for owners to the same extent as renters. Further investigations into possible interaction effects between occupancy type and the explanatory variables provided marginal evidence to support those findings, indicating that subgroups of owners and renters should be compared when investigating a PA problem. Specifically, there is significant evidence of an important interaction between the type of building and ownership, which results in owners who reside in detached and semi-detached housing paying more in energy outlays than renters.

What does this mean for the energy efficiency gap and principal-agent theories presented in Chapter 2? In a way, the results of the study do little to (dis-)prove those theories. In one form or another, the efficiency gap does exist in Austria: owners may not be investing in the energy efficiency of their dwellings, despite cost effective measures available to them. While further research is needed to determine if other, more intrusive market failures are at play, what can be concluded from the results is that the energy efficiency gap is not broadened by a PA problem in the landlord-tenant relationship in Austria. Still, this analysis could be extended in several ways. First, given the limitations of the EU-SILC dataset, this investigation was confined to analyzing *combined* space heating, water heating, and cooking expenses. A separate analysis for these types of expenditures could be expected to produce more precise results and farther-reaching conclusions. Second, also owing to data limitations, the study was restricted to household energy expenditure, rather than actual energy consumption. It would be interesting to compare the present results to those that used energy consumption in physical units as the dependent variable instead.

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. All of these points could be expected to yield more insight into the discrepancy between what the descriptive statistics on energy expenditures for owners and renters suggest and the estimates from the analysis.

Nevertheless, since this study was able to identify some of the most important determinants in residential energy consumption for owners and renters, policy implications can still be deduced from the results. Future energy policy in Austria could focus on these specific determinates in order to achieve the ultimate goal of further increasing energy efficiency and decreasing GHG emissions. These policy measures could include broader information campaigns targeting homeowners; tax reductions, grants or subsidies aimed towards renovating detached housing; and reinforcing and promoting the use of energy performance certificates, as required by the EU Directive, as suggested by Schaefer *et al.* (2000), Leth-Petersen and Togeby (2001), and Bird and Hernández (2012).

Appendix

Quantifying the Principal-Agent Problem in Austria

The methodology used to quantify the principal-agent (PA) problem in Austria follows the approach used in the International Energy Agency (IEA, 2007) report and relies on the concept of "affected energy use", i.e. energy use that is insulated from the marginal price of energy. The calculations below focus specifically on space-heating energy use and follow a four-step method:

1. Identifying and categorizing the housing stock in Austria into segments based on housing characteristics, e.g. type of building, occupancy type;
2. Identifying the final energy consumption of the Austrian residential sector and extracting energy use relating to space heating;
3. Estimating the number of end users affected by a PA problem; and,
4. Estimating the affected energy use for each of the affected end users.

Table 1 summarizes the four possible cases discussed in Chapter 2 of this thesis and works as a descriptive tool once the principal and the agent are identified in the relationship. Before the analysis can begin, the following questions must be asked to determine exactly who is the principal and who is the agent (IEA, 2007; A. Meier & Eide, 2007):

- Who selects, purchases, and owns the energy-using device (in this case, heating system)?
- Who pays the energy bill?
- Who controls operation of the energy-using device?

Housing data from the 2011 Register-based Census from Statistik Austria (2012) was used to compile the descriptive statistics on the housing stock in Austria. Table 2 reports these statistics based on building type and occupancy type. Building vintage data has been excluded from this appendix. Energy consumption data were taken from Statistik Austria's

Table 1. The principal-agent matrix.

	End-user can choose device	End-user can't choose device
End-user pays energy costs	*Case 1*: No problem	*Case 2*: Efficiency problem
End-user doesn't pay energy costs	*Case 3*: Both	*Case 4*: Usage problem

Source: IEA (2007)

Table 2. Building stock segmentation in Austria, by occupancy type, 2011.

Number of Residences in 2011		Housing Segment (millions)		
Building Type	Total (millions)	Owner	Renter	Other
Detached , semi-detached	1.2 (34%)	1.08 (30%)	0.06 (2%)	0.06 (2%)
Multi-family	2.3 (66%)	0.8 (22%)	1.4 (38%)	0.2 (6%)
Total	3.6 (100%)	1.8 (52%)	1.4 (40%)	0.3 (8%)

Source: Statistik Austria (2012)
Note: Absolute values include rounding.

Table 3. Share of household energy consumption by energy use in Austria, 2011.

Energy Use	Terajoule	Percent
Space heating	**190,720**	**72.5**
Hot water	30,836	11.7
Cooking	7,579	2.9
Cooling & freezing	7,389	2.8
Large appliances	6,375	2.4
Small appliances	2,215	0.8
Consumer electronics	6,295	2.4
Illumination	5,169	2.0
Other	6,315	2.4
Total	*262,894*	*100*

Source: Statistik Austria (2013b)
Note: Percentages may not add up to total due to rounding.

1993 to 2012 Useful Energy Analysis (Statistik Austria, 2013b). Table 3 summarizes the share of household energy consumption by energy use; the focus here, however, is only on space heating.

The census data and energy use data were cross referenced using the PA matrix introduced in Table 4. Using the broad assumption that each household consumes an equal share of energy, the number of household in each segment of the housing stock was used as the decisive factor in the share of energy affected by a PA problem. The results reported in Table 4 suggest that, if all renters are assumed to pay for their heating costs directly, 40 percent of the rental segment may suffer from an efficiency principal-agent problem, i.e. the focus of this thesis. Additionally, some or all of the rent-free households suffer from a usage PA problem. Similar results were found in the United States and the Netherlands (see IEA, 2007; Murtishaw & Sathaye, 2006). The results do not confirm or disprove the existence of a PA problem in the Austrian residential sector; they simply estimate the potential number of households, and their corresponding energy, which may be affected by one or more PA problems.

Table 4. Estimated share of households and energy consumption per PA problem in Austria, 2011.

	End-user can choose device	End-user can't choose device
End-user pays energy costs	***Case 1*: No problem** No. of HH: 1.8M, 52% Amt. of Energy: 99,174 TJ Mostly owner-occupied dwellings	***Case 2*: Efficiency problem** No. of HH: 1.4M, 40% Amt. of Energy: 76,288 TJ Mostly renter-occupied dwellings; may be lower due to unknown number of HH that have energy costs included in rent
End-user doesn't pay energy costs	***Case 3*:** Both Negligible	***Case 4*: Usage problem** No. of HH: 281,800, 8% Amt. of Energy: 15,258 TJ Mostly rent-free households; may be higher due to unknown number of HH that have energy costs included in rent

Source: Author's own calculations

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