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Abstract

Institutional structures may cause considerable inefficiencies in the use of energy. In this paper, we investigate the energy efficiency of multi-dwelling buildings in Sweden to find out whether the type of ownership matters. More specifically, we investigate whether rental apartment buildings are less efficient than cooperative apartment buildings and whether public ownership has a negative impact on energy efficiency. A conceptual framework is presented to illustrate that such differences could be explained by the split incentive problem and deviations from profit maximizing interests. The empirical analysis is based on a unique dataset that combines data from energy performance certificates with ownership data on residential units. The results indicate that cooperative apartment buildings are significantly more energy efficient than buildings with rental apartments. The results also indicate that publicly owned buildings have lower energy performance than privately owned ones.

Keywords: Energy efficiency; Energy performance certificates; Multi-dwelling buildings; Split incentives; Public versus private management; Profit satisficing.

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Highlights

- A conceptual framework connecting ownership to the energy efficiency gap is presented.
- The empirical results suggest that ownership matters for the energy performance of multi-dwelling buildings.
- On average, tenant-owned buildings have higher energy performance than buildings managed by private and public rental companies.
- Privatization of multi-dwelling buildings may improve their management and result in better energy performance, especially if the new owner is the tenant.

1 Introduction

Several studies argue that there is a potential to cost-effectively reduce energy demand by investing more in energy-efficient technologies or incentivizing behavioral change. The argument is typically supported by bottom-up calculations of negative life-cycle costs for measures to improve energy efficiency. Although the magnitude of the so-called energy efficiency gap may be debated, such a gap can be explained by economic theory. It is well known that markets under certain conditions fail to deliver an economically efficient outcome. Several papers have listed a number of market failures and behavioral anomalies explaining why there likely exists an energy efficiency gap (for reviews see Broberg and Kazukauskas, 2015; Gillingham and Palmer, 2014; Allcott and Greenstone, 2012; Linares and Labandeira, 2010). The listed failures include institutional structures that cause misaligned incentives among stakeholders in the residential sector. In this paper, we study the role of ownership structures to investigate to what extent the energy performance of multi-dwelling buildings in Sweden is affected by institutional failures in the form of principal-agent problems and deviations from profit maximizing interests.

Split incentives arise from institutional structures where the benefits of certain actions do not accrue to the agent who pays for these actions. Concerning residential energy use, split incentives cause either a usage or an efficiency problem. In Sweden the usage problem is potentially relatively large as heat is usually included in the apartment rent and therefore the tenants have no economic incentives to actively manage their indoor temperature to save energy. To deal with the usage problem and the its economic consequences, landlords must increase the rents and/or invest in better insulation or control equipment to regulate the indoor temperature. The efficiency problem occurs when the landlord decides the level of energy efficiency by controlling appliances and installations in the apartment/building. This causes a problem of misaligned incentives in cases where the tenants are the ones paying the energy bill. Under these conditions, the landlord has incentives to minimize investment costs rather than life-cycle costs (or maximize cost-effectiveness). The outcome of this situation is that the tenants will pay too much for the energy they consume. Of course, well-functioning markets should punish such behavior, but asymmetric information and mistrust creates a dynamic that is expected to result in adverse selection and a "market of lemons" (Akerlof, 1970). Under such circumstances, the market will supply cheap inefficient buildings with too little insulation and equipped with wasteful appliances. In Sweden, the policy response to the efficiency part of the spilt incentive problem has consisted of the introduction of energy performance standards for new buildings and an energy performance certification system. The objective of the latter is to provide tenants and buyers with trustworthy information.

In this paper, we first present a conceptual framework linking ownership structures to institutional failures and inefficient use of energy in the residential sector. We then empirically compare the energy performance of buildings managed under different ownership structures using data based on energy performance certificates covering the population of multi-dwelling buildings in Sweden. Our ultimate objective is to quantify inefficiencies caused by institutional failures in the residential sector. We hypothesize that the energy performance is higher in buildings where the owner has a clear economic incentive to manage the building in an efficient manner and where the incentives of the property owner and the tenants are aligned. In our study, the average energy performance of cooperative apartment buildings is used as the benchmark with which rental apartments are compared. Cooperative apartments are owner-occupied and, therefore, the incentives of the owner and the tenants are more aligned compared with the case with rental apartments. Members of a cooperative apartments association (COAA) are part-owners of the property with the right to use common areas and an exclusive right to use a specific apartment in the building. COAAs own approximately 40 percent of the total number of apartments in Sweden. Many of these apartments were built as rental apartments but have been sold to its tenants over time. From 1991 to 2012, around 180,000 rental apartments were sold to COAAs. About 60 percent of all apartments in Sweden are rental apartments, and 50 percent of these are owned and managed by municipal companies (Statistics Sweden, 2016). The hypotheses tested in this paper is whether cooperative apartment buildings have better energy performance than private and municipal rental apartment buildings, respectively.

Public ownership of residential buildings causes additional management problems. First, in contrast to public managers, private owners have property rights and personally benefit from cost reductions from energy savings. Hence, the incentives to accomplish cost-reductions are stronger in the private sector (Shleifer and Vishny, 1994). Second, compared with private owners, public managers may focus more on potential quality erosions associated with cost savings (Hart et al., 1997). Adjustments of the quality level of services may be more difficult to accomplish for public rental companies which are under the control of a political leadership. The services of public rental companies affect many voters in the form of tenants and employees and, therefore, any dissatisfaction with these services may spill over to the political arena. As an example, if landlords want to avoid dissatisfaction, they will not control the indoor temperature even if doing so would be motivated in the second best context of split incentive problems. Finally, more than 80 percent of the multi-dwelling buildings in Sweden are heated by district heating produced in facilities owned by the municipalities. This means that improvements in energy efficiency have a negative effect on the municipal revenues from energy sales (Lind, 2012).

The rest of the paper is structured as follows. In Section 2, we present a conceptual framework to illustrate the impact of split incentives and different ownership structures on energy efficiency. In Section 3, we review previous literature on the split incentive problem. We also briefly review empirical research on the efficiency of private ownership compared with that of public ownership. In Section 4, we highlight some features of the housing market in Sweden and describe our data. In Section 5, we describe our econometric models and present empirical results. In Sections 6 and 7, we conclude the paper with discussions about the results and their policy implications.

2 Conceptual framework

In order to describe the links between ownership types and energy efficiency, we apply a simple theoretical framework to describe the energy efficiency level of a building managed under different ownership structures. We first assume that the landlord can only improve the energy efficiency of the building by investing in better weatherization, control equipment, or energy-efficient appliances and installations. The landlord cannot influence the tenant's behavior. Next, we assume that the marginal cost of energy efficiency increases with the energy efficiency level of the building. The higher the energy performance, the more costly it is to incrementally improve the energy efficiency level. Given this setting, the landlord's profit level can be illustrated with a bell-shaped curve as illustrated in Figure 1. Points B, C, and D represent the profit and energy efficiency levels of a cooperative apartment association, a private rental company, and a public rental company, respectively. Under this framework, the energy efficiency level from under all three ownership structures to a different degree deviate from point A, which represents the profit-maximizing energy efficiency level.

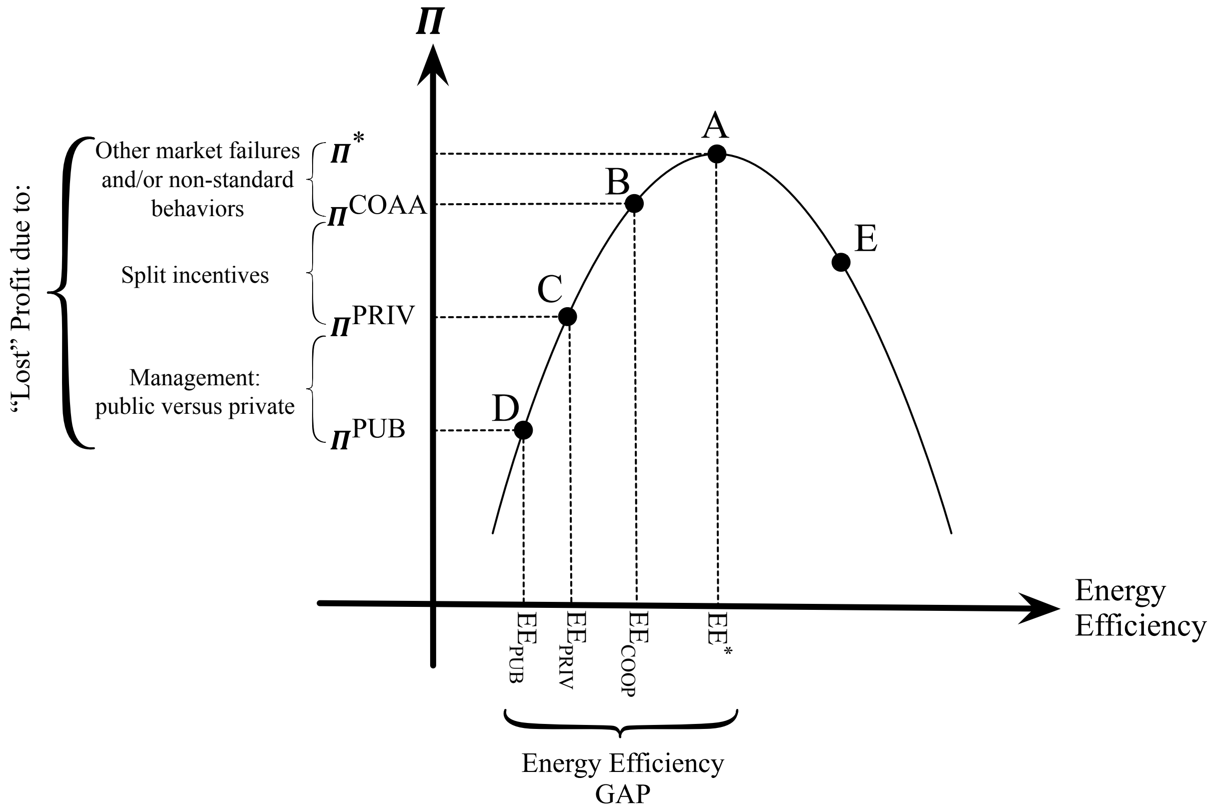
If the owner of the building is a cooperative apartment association (B), the building is owner-occupied and we therefore assume that the tenants waste less energy. We also assume that all cost-effective measures to deal with the split incentive problem are completed. However, the split incentive problem is difficult to solve completely. Regardless of owner, heat and hot water are typically subject to average pricing. This incentivizes free-riding behavior, which has a negative impact on the energy performance of the building as a whole. This inefficiency is expected to increase with the size of the cooperative because the tenants who cause extra costs have to pay a smaller share of this cost if they are part of a large cooperative. Also, one could expect the social pressure to act in the interest of the cooperative to be larger in small cooperatives.

In the case of private rental companies (C), the incentives of the owner and the tenants are misaligned and, thus, tenants will waste more energy compared with the case where they are part of a cooperative apartment association. However, we expect private rental companies to be profit seeking and therefore complete all cost-effective measures to deal with the split incentive problem.

Public rental companies (D) may not have profit maximization as their ultimate objective but may instead be profit satisficing. Under profit satisficing, agents settle for a satisfactory outcome rather than the best attainable outcome (Kaufman, 1990). Public rental companies may also to some degree be reluctant to invest in energy efficiency improvements regardless of the cost savings, especially if doing so may cause complaints that spill over to the political arena. Politicians may respond to this threat by lowering the expected return from the public rental company. In this context, a public rental company's energy efficiency investments may have lower priority than, for example, improvements in the social environment of the buildings (e.g., accessibility).

Point E represents situations of "overinvestment", where the level of energy efficiency is inefficiently high. For example, rental companies may choose to improve weatherization to compensate for the tenant's inefficient use of energy due to split incentives. A landlord can also end up in E if she wants to signal environmental awareness to improve her public image or reputation of being pro-environmental. For example, environmental signaling could be part of the objective function of a profit-satisficing public company.

Figure 1: Conceptual framework describing the relationship between ownership, profits, and energy efficiency



3 Previous literature

The split incentive problem is widely acknowledged in the energy efficiency literature, but few papers verify its existence and quantify it. There are essentially two types of empirical studies in the literature. The first assesses the potential size of the split incentive problem based on the number of dwellings affected by misaligned incentives. Murtishaw and Sathaye (2006) estimate that as much as 35 percent of residential energy use in the U.S. is potentially affected by split incentive problems.

The second type of studies aims to empirically verify and to some extent quantify the split incentive problem by studying household behavior using survey data. Levinson and Niemann (2004) use survey data on U.S. households and find support for the hypothesis that the indoor temperature is higher in households that do not pay for heating directly. Davis (2012) also uses survey data on U.S. households and finds support for the hypothesis that landlords who do not pay for energy use are less likely to choose energy star rated appliances.

Maruejols and Young (2011) analyze split incentive problems in Canadian multi-family dwellings (semi-detached houses, row houses, and low-rise apartment buildings). They conduct an econometric analysis of survey data from 2003 and conclude that households that do not pay for heat directly tend to keep a higher indoor temperature than others. In old buildings, the difference tends to be as much as 4°C. They also find that households that do not pay for heat directly are less prone to turn down the thermostat when being out of the dwelling.

Gillingham et al. (2012) use survey data on Californian households to study split incentives related to both insulation of buildings and heating and cooling settings. The study finds some support for the hypothesis that owners who pay for heating and cooling are more prone to adjust their thermostat setting. The study also finds support for the hypothesis that the presence of wall and attic insulation is more likely in dwellings where the landlord pays for heating. Back-of-the-envelope calculations are presented to assess how relevant it is to address split incentive problems in energy and climate policy. The results of these calculations point at modest energy savings and CO_2 reductions (1 and 2 percent potential reduction of the total use of electricity and gas, respectively). The largest potential lies in addressing the efficiency problem of insufficient insulation levels.

Krishnamurthy and Kriström (2015) use survey data on 11 OECD countries (including Sweden) and run binary regression models to study differences between owners and tenants in access to energy efficient appliances, energy efficient light bulbs, thermal insulation, energy efficient windows, heat thermostats, solar power, wind turbines, and ground source heat pumps. That someone have access to a specific equipment means it is present in the person's residence. The authors argue that they do a better job than previous studies addressing agency problems by controlling for whether owners inherited energy efficient appliances or invested in energy efficiency themselves. The results point at a higher owner-renter divide than the one found in Davis (2012) and Gillingham et al. (2012): owners are 45 and 51 percent more likely than renters to have access to energy efficient appliances and light bulbs, respectively. When running the conventional "have access to" model, the marginal effects are 0.12 and 0.05 for energy efficient appliances and light bulbs. These figures are of the same magnitude as those found in previous studies. The study also finds a sizable owner-renter divide concerning thermal insulation and insulated windows, and also a statistically significant divide for heat thermostats.

It should be noted that it is difficult to generalize results from empirical studies at the national level, as there are important country- and region-specific circumstances. For example, countries may differ in climate, culture, incentive structures, and regulatory framework. In Sweden, the apartment rent typically includes heat and water, but not electricity. Landlords provide an oven, a refrigerator, a freezer, and a laundry room with washing machines and dryers. In other countries, tenants often pay for heating, and the appliances and services (e.g., laundry rooms) the landlord provides may differ. There might also be important differences in the regulatory frameworks for apartment rents. Countries may have direct or indirect rent controls that influence the incentives to invest in energy efficiency. The regulatory framework in Sweden stipulates that rents should be centrally negotiated and based on general user values (e.g., standard and location). Based on the user value principle, comparable apartments should have the same rent. As a result of the regulatory framework and how it has been interpreted and implemented, apartment rents in major cities in Sweden are commonly believed to be well below their market-clearing levels, reducing investments in new rental apartments. However, there is no clear evidence that the framework in Sweden has a negative impact on investments in old buildings, as is commonly believed to be the case when direct rent controls are applied (Boverket, 2014).

Few studies explicitly explore split incentives and energy efficiency of buildings in Sweden or countries with similar structures in the residential sector. There exist some bottom-up calculations of potentials to increase the energy efficiency in the residential and service sector. The part of the potentials that is related to split incentives has been estimated to 2–2.4 TWh (Boverket, 2013).[2]

The debate on the relative effectiveness of public and private companies has been widely discussed in the economics literature. One common view is that privatization of public services incentivizes cost reductions due to improved efficiency and quality deterioration (Hart et al., 1997). Another argument in favor of privatization is based on property rights and corporate management theory (Pommerehne and Frey, 1976; Shleifer, 1998). According to the property rights argument, a principal in the form of a private owner is likely to have better control over the manager (agent) compared with when the principal is a public company and therefore is less likely to personally benefit from higher profits. A third argument focuses on the role of bureaucratic restrictions that impede cost efficiency in public companies. These restrictions may concern a company's labour policy or capital and debt management. For example, Swedish municipal companies cannot borrow money in the capital market directly but must go through a common municipal company that controls the debts of the municipality as a whole. Many Swedish municipalities and counties cooperate within the framework of an association (*Kommuninvest*) to improve their loan terms in the capital market. The association keeps track of each member's debts to secure that its own credit rating remains at the highest possible level. This structure adds administrative work to municipal companies and may hold back large-scale investments in some companies as it is the debt of the municipality as a whole that matters for the credit rating.

[2] According to statistics from the Swedish Energy Agency, the final energy use in Sweden amounted to 375.37 TWh in 2013, of which the residential and services sectors accounted for 39% (146.6 TWh). The households alone used 86.24 TWh, including household electricity.

4 The data and descriptive statistics

Directive 2002/91/EC (European Parliament, 2002) on the energy efficiency of buildings stipulates that all buildings in the residential sector must have an energy performance certificate. The directive was implemented in Sweden through a specific law (Law 2006:985) and a complementary ordinance regulating the certification procedure (Ordinance 2006:1592). An energy performance certificate typically includes a temperature-adjusted estimate of the building's energy performance (kWh per m^2), an energy performance labeling, related energy statistics, and suggestions on how to cost-effectively improve the building's energy performance. The certificates concern the energy use of the whole building rather than the households in it. The energy measured is for heating, hot water, and the landlord's use of electricity. Thus, the tenants' electricity use is neither measured nor included in the energy performance indicator. The energy performance certification in Sweden started in 2007 and the aim was for all relevant buildings to be certified by December 30, 2008. For various reasons, the process was delayed and a majority of the buildings were instead certified 2009–2015.

The energy use data analyzed in this paper comes from the energy performance certificates register administrated by the National Board of Housing, Building and Planning (*Boverket*). By August 1, 2015, the register included 124,224 energy certificates for multi-dwelling buildings, of which 90,044 are for buildings mainly consisting of residence units and for which the data quality is high.[3] These certificates cover about 1.8 million apartments in total[4]. According to public statistics, there were 2.4 million apartments in Sweden at the end of 2015 (Statistics Sweden, 2016). Thus, our data covers about 75 percent of all multi-dwelling buildings in Sweden. The energy performance certificate register does not include any information about the owners and the tenants. The information about owner type, average family size, and

[3] The base unit of the register is certificates. One certificate can include several buildings if they share the same heating source. Thus, the number of certificates is lower than the number of existing buildings in the official statistics. The 90,044 observations exclude certificates lacking relevant information or containing unrealistic numbers or that are for extraordinary buildings. Also, all certification units where non-residential activities constituted 10% or more of the building's area were excluded from the analysis.

[4] 1,784,498 apartments (40% COAAs, 32% public rental companies, 16% private rental companies, 6% private person, and 6% other).

average household income comes from central registers administered by Statistics Sweden (SCB). The registers were matched on the real estate number and the year of certification.

In theory, it should be possible to determine a building's energy performance by looking at all relevant facts, including characteristics of the building and the people living in it. Our matched data focuses on the characteristics of the buildings available in the energy performance certification data and includes only aggregated information about family size and disposable income of households. Table 1 presents the mean values or shares for key variables used in our analysis. The descriptive statistics are categorized by ownership structure. Here we are mainly interested in comparing public vs. private owners and buildings with rental apartments vs. cooperative apartment buildings. To ease the presentation of our data and results, we use the term *energy use intensity* to describe the kWh/m^2 energy performance indicator. If the energy use intensity is low, energy performance is high and vice versa.

When comparing the average energy use intensity for buildings with different types of ownership, it can be observed that residence units owned by private persons and cooperatives use less energy per square meter (137 and 138, respectively) than do other buildings, e.g., publicly owned buildings (153 kWh per m^2). See also Appendix A.

Table 1: Mean of selected variables by type of ownership

Variable	Private person	Private rental company	Cooperative (COAA)	Public rental company	Other	Total
Energy use intensity (kWh/m2)	136.72	144.96	138.17	153.22	146.08	144.33
Energy consumption (kWh - year)	124,595	214,431	282,399	257,628	268,987	244,781
Construction year	1943	1960	1964	1970	1960	1963
Heated area (m2)	873	1,454	2,065	1,717	1,842	1,706
Apartments by building	10	17	23	20	24	20
Average size of apartments (m2)	91	86	92	84	84	88
Total apartments by owner	60	621	122	7,123	796	2,429
Has basement (Yes 1 No 0)	0.80	0.68	0.59	0.51	0.67	0.61
Has heated garage (Yes 1 No 0)	0.13	0.10	0.11	0.05	0.09	0.09
Floors	3	3	4	3	4	3
Residential share (%)	99	99	99	99	99	99
Average family size	1.45	1.50	1.54	1.59	1.50	1.54
Average income	232,939	143,821	188,815	128,491	148,220	164,558
Location: Middle of building (Yes 1 No 0)	0.10	0.07	0.08	0.03	0.09	0.06
Location: End of building (Yes 1 No 0)	0.09	0.07	0.06	0.04	0.08	0.06
Complex building (Yes 1 No 0)	0.01	0.02	0.02	0.02	0.03	0.02
Natural ventilation: (Yes 1 No 0)	0.71	0.48	0.43	0.33	0.43	0.44
Mechanical ventilation out (Yes 1 No 0)	0.26	0.45	0.51	0.61	0.47	0.50
Mechanical ventilation: out /in (Yes 1 No 0)	0.02	0.03	0.02	0.03	0.07	0.03
Ventilation with recycling (Yes 1 No 0)	0.06	0.16	0.17	0.19	0.18	0.16
Main use: district heating (Yes 1 No 0)	0.64	0.74	0.85	0.85	0.80	0.80
Main use: combustion (Yes 1 No 0)	0.09	0.07	0.03	0.05	0.06	0.05
Main use: electricity heating (Yes 1 No 0)	0.06	0.06	0.04	0.04	0.04	0.05
Main use: heat pumps (Yes 1 No 0)	0.21	0.14	0.08	0.06	0.10	0.10
Secondary use: heat pumps (Yes 1 No 0)	0.22	0.14	0.11	0.07	0.10	0.11

There may be several explanations to the differences in energy use intensity. Our ultimate objective is to find out whether any differences are caused by the split incentive problem or the management practices characterizing each ownership type. To this end, we need to conduct an analysis where we control for cofounding effects, e.g., size, age, heating, and ventilation systems, and other characteristics of the buildings as well as the average size and income of the households residing in them. The econometric models we estimate are based on the following expression:

$$kWh/m^2 = \alpha + \sum \beta_j Own_j + \sum \beta_i X_i + \varepsilon$$

where the energy performance (kWh/m^2) is the dependent variable, which is regressed on different types of ownership ($\sum \beta_j Own_j$) and other control variables ($\sum \beta_i X_i$).

Table 1 presents the variables included in the models (see also Appendix B). As can be seen, most multi-dwelling buildings are heated by district heating and use mechanical ventilation. As the data are for certified units, one observation could correspond to one or more detached buildings or to part of a building. In the latter case, which is rather unusual, it is important to control for the effect of heat waste from other parts of the building. Essentially, it matters whether a unit is located in the middle of or the ends of a building.

It is also important to note that an owner can own several buildings that have been certified on different occasions. As most municipalities have only one public rental company, these companies tend to own relatively many buildings. Only a few private rental companies operate at the national level. According to our data, the largest private company owns 8,489 apartments covered by 324 certificates. The largest public company operates in Stockholm and owns 33,633 apartments covered by 1,097 certificates. In the empirical analysis, we control for the economic size of the owners as we expect that large owners are more likely to manage their buildings more professionally. We control for size effects that are unique to cooperative apartment associations, private persons, and private rental companies by including interaction effects between ownership type and size of the apartment stock of each owner. As mentioned above, we expect average pricing of energy to cause more inefficiency in large cooperatives.

The model also includes the year of certification and a dummy indicating whether the heated area of a certification unit has been estimated rather than metered. In the best of all possible worlds, these factors should not turn out to be significant but may actually be so because of imperfect temperature adjustment based on heating degree days or changing/differing practices over time in the way the energy use or area of the buildings has been measured.[5]

The model also includes dummies for Sweden's 290 municipalities, which are important for at least two reasons. First, Sweden is a relatively large country with higher heat requirements in the north due to a longer heating season and lower winter temperatures. Accordingly, on average the energy use intensity increases the further north the municipality is located, *ceteris paribus*. Second, parts of the building code differ across municipalities. The minimum energy performance standards for new buildings are stricter in the south than in the north and municipalities are allowed to adopt even stricter standards regarding energy performance than stipulated in the national building code. As we control for the average temperature at the regional level, we expect the municipality dummies to mainly capture other aspects.

5 The results

In order to sort out whether type of ownership matters for the energy efficiency of multi-dwelling buildings, we run a number of linear regression models centered on our reference model (Model 1). Most of the models concern sub-samples and are estimated to check the robustness of our main results. The differences between the models are described in Table 2. As we work with close to population data, we focus on the economic significance of the coefficients rather than their statistical significance. All coefficients in the regression models are associated with a small standard error and, thus, are statistically significant at the 1 percent level. However, regression analysis on population data has no clear statistical interpretation as the coefficients reflect population rather than sample averages. The method applied is in practice a matching procedure where certification (building) units are compared based on differences in specific characteristics.

[5] The temperature adjustment is made by certified energy consultants in line with Ordinance 2006:1592.

Table 2: Description of models

Model	Description
0	Energy use intensity regressed on type of property
1 (main model)	Model 0 plus control variables including socio economic variables (family size and income), certification year, selected interactions, temperature, municipality, main sources of heating, ventilation system, and building characteristics.
2	Model 1 (main model) without main sources of heating
Restricted models	
3	Model 1 (main model) if district heating is main heating source
4	Model 3 (if district heating is main heating source) plus if climate zone[6] = 3
5	Model 4 (if district heating is main heating source and climate zone = 3) plus only buildings built earlier than 1981
Stockholm	
6	Model 1 (main model) for Stockholm
7	Model 2 for Stockholm
8	Model 5 (but without climate zone) for Stockholm

Table 3 presents the results for the building characteristics included in our baseline model. The ownership coefficients are presented separately in Table 4, which includes results for all estimated models. The effects of the building characteristics are in line with our expectations. The energy use intensity is on average higher in older buildings and decreases non-linearly with the number of square meters and floors of the certification unit. The energy use intensity is lower for certification units that only constitute parts of a building, in particular if they are between two other units. The energy use intensity increases with the number of apartments and decreases with average apartment size. The energy use intensity also increases with family size and household income. When interpreting the coefficients for different types of heating systems, heat pumps are more efficient than district heating, which in turn is more efficient than domestic combustion. Having a heat pump as a secondary heat source further decreases the energy use intensity.

Surprisingly, as can be seen in Table 3, the variables associated with the practices applied when conducting the certification have a significant impact on the energy performance. The energy use intensity is on average lower for certification units whose heated area was metered instead of estimated. Also buildings certified in 2008 have significantly lower energy use intensity. The reason for this is unclear. Potential explanations could be biases in the temperature adjustment or changes over time in

[6] Sweden is formally divided into four climate zones numbered from north to south. Climate zone 3 includes both Stockholm and Gothenburg.

the certification practices and methods. For example, in the beginning of the certification period, it was unclear how to treat heated garages when calculating the energy performance indicator. The winter of 2010 was exceptionally cold.

The results for the municipality dummies, not presented in Table 3, reveal that buildings in Stockholm on average display relatively high energy use intensity compared with most other municipalities when differences in building characteristics are controlled for.[7]

Table 3: Results for housing characteristics

Variable	Coefficient (St.d.)
Construction year (Ref: 1981–1990)	
1800–1900	22.23073 (1.025927)
1901–1949	19.68066 (0.4618323)
1950–1973	19.25434 (0.4003827)
1974–1980	13.48239 (0.50928)
1991–2007	-5.26799 (0.4050512)
2008–2014	-19.70041 (0.8810589)
Heated area (Log of m^2)	-8.70756 (0.2785163)
Apartments	0.0548738 (0.0073096)
Avg. apartment's size (m^2)	-.2821433 (0.0072226)
Floors	
2 floors	-3.959485 (0.7481812)
3 to 11 floors	-6.903422 (0.7945465)
11 or more floors	-8.547108 (1.576489)
Temperature	-1.600455 (0.8872402)
Family size	5.210579 (0.3589316)
Income	0.000000165 (9.15x10^{-9})
Basement	-6.135481 (0.2747494)
Heated garage	5.556707 (0.3703453)
Part of building	
Middle	-9.1352 (0.4728869)
End	-3.525769 (0.4510945)

[7] Stockholm is used as reference for the municipality dummies.

Table 3: cont.

Variable	Coefficient (St.d.)
Ventilation system (Ref: Natural)	
Mechanical ventilation out	2.87037 (0.2858328)
Mechanical ventilation out/in	6.133799 (0.6500384)
Ventilation with recycling	-2.158018 (0.4200658)
Heating system (main) (Ref: district heating)	
Combustion	17.1564 (0.7441063)
Electric heating (direct)	-31.70276 (0.6179306)
Heat pump (water pipes)	-34.91493 (0.6353662)
Secondary: heat pump	-34.31251 (0.5659462)
Complex building	1.259517 (0.7514359)
Residence share (%)	0.1004098 (0.0469923)
Size of owner (Ref: Size public rental)	
Size COAA owners	0.0030947 (0.0006224)
Size Private person owners	0.0333514 (0.002608)
Size Private rental owners	-0.000444 (0.0001827)
Size other owners	-0.0012214 (0.0002813)
Heated area measured	-5.801695 (0.2321737)
Certificate year (Ref: 2008)	
2009	2.936628 (0.2533937)
2010	3.727685 (0.3424139)
2011	2.865466 (0.5420368)
2012 - 2016	1.352983 (0.5124093)

Table 4 presents the results for the ownership dummies in all models estimated for Sweden and selected models for Stockholm. Model 0 only includes the ownership variables and as such reflects the relative difference in average energy use intensity between public rental companies and other ownership types. Model 1 (our reference model presented in Table 3 and Appendix B) includes all control variables including average family size and income, main heating system, and other relevant building characteristics. In Model 2, the certification units' heating systems, which are assumed to be fixed in the short run, are excluded. The results from Model 1 show that buildings owned by private and public rental companies on average have higher energy use intensity compared with buildings owned by private owners and cooperative apartment associations.[8] Compared with the average sized cooperative apartment association, publicly owned residential buildings use approximately 8.18 kWh/m^2 more energy per square meter. It can also be seen that publicly owned rental buildings have higher energy use intensity than their private counterparts. On average, the difference is 1.66 kWh/m^2.

Comparing the results of Model 1 and Model 2 shows that the difference between public owners and others decreases when we control for heating system. This result reflects that heat pumps are less frequently used in buildings owned by public rental companies than in other buildings. Differences in heating systems increase the difference in energy use intensity between cooperative buildings and public rental companies by around 38 percent. The difference between private and public rental companies more than doubles. The results for Model 2 can be interpreted as a long-run potential to improve the energy performance of multi-dwelling buildings.

As a first robustness check, Model 3 only concerns buildings with district heating. The general pattern of the parameters describing the relation between different ownership structures remains the same. This is also true for the results from estimation of Models 4 and 5, where the sample is further restricted and includes only buildings in climate zone 3 and those built pre-1981. Model 5 is of particular interest in the Swedish policy context as the apartment stock expanded rapidly during the period 1960–1980 as a result of a central policy program that has become known as "the million program." The buildings constructed during this period focused on functionality and costs rather than quality. The standard of these buildings now necessitates renovations. The results of Model 5 points at a wider dispersion between privately and publicly owned rental apartment buildings in this age segment (2.79 kWh/m^2).

[8] The differences between different ownership structures are evaluated based on the ownership dummies and the owner size coefficients evaluated at the average size of the owner types.

Table 4: Coefficients of type of property on models for Sweden

	Model	N	adj R^2	Adjusted* Coefficients (Reference: Public rental)			
				Private person	Private rental	Cooperative (COAA)	Other
	0	90044	0.0242	-16.51	-8.27	-15.06	-7.14
Main model	1	89437	0.4723	-8.31	-1.66	-8.18	-3.14
	2	89437	0.2727	-17.94	-6.73	-11.26	-5.56
Restricted	3	72189	0.3287	-7.67	-0.92	-7.22	-2.81
	4	43380	0.3191	-8.81	-1.87	-7.36	-4.22
	5	34112	0.28	-10.38	-2.79	-8.36	-5.99
Stockholm	6	9124	0.2728	-9.12	-7.80	-15.14	-9.37
	7	9124	0.4996	-20.28	-13.95	-22.76	-13.13
	8	6714	0.3518	-11.21	-10.71	-15.63	-10.39

* Evaluated for the average number of apartments taking the size/ownership interaction effects into account

Judging from descriptive statistics, buildings in Stockholm on average display relatively high energy use intensity (158 kWh/m^2). The average for buildings owned by municipal housing companies is even higher (177 kWh/m^2). To see what factors determine the difference between different ownership structures, we estimated Models 1 (our reference model), 2, and 5 on energy efficiency certificates for buildings in Stockholm. The results, presented as Models 6–8 in Table 4, show that the differences in energy use intensity between buildings owned by public rental companies and private buildings cannot be explained by the building and household characteristics we control for. As can be seen, buildings owned by private rental companies seem to display noticeably higher energy use intensity than cooperative apartment buildings.

6 Discussion

In this paper, we have compared the energy use intensity of multi-dwelling buildings managed under different ownership structures. It is important to note that we only study the energy used for heating, hot water, and electrical appliances in common areas. Almost all rental and cooperative apartment contracts in Sweden are for heated apartments. Thus, the costs of energy for heating have to be covered by the apartment rents/fees, which implies that tenants lack incentives to save energy by turning down the indoor temperature or reducing their consumption of hot water. Under *ceteris paribus* assumptions, we find evidence of inefficient management of both privately and publicly owned residential rental buildings. The inefficiency discussed here is relative to the energy performance of cooperative apartment buildings. We argue that as cooperative apartment buildings are owner occupied, the principal agent problems are mitigated since the benefits from improving the energy efficiency of these buildings go directly back to the tenants in the form of lower monthly fees and higher property values.

On average, we estimate that public rental companies could reduce their energy use by at least 8.2 kWh per m^2 (or 5.3 percent). In total, this annual inefficiency amounts to 0.4 TWh, implying a potential reduction in annual energy costs of approximately SEK 0.4 billion (€ 40 million). If we also consider that the heating system in a long run perspective can be changed and improved, the cost reduction potential increases by around 38 percent. This potential is calculated based on the energy efficiency levels of cooperative apartment buildings. It should be noted that this is by no means the total potential, since the management of cooperative buildings may be inefficient as well. Therefore, the above mentioned estimate of the potential is conservative.

Private rental companies also on average exhibit higher energy use intensity values than co-operative apartment buildings when controlling for differences in building characteristics. The difference is mainly attributed to the split incentive problem and amounts to 7 kWh/m^2 (or 4.5 percent). In total, the inefficiency amounts to approximately 0.2 TWh. For buildings owned by private persons, we find no substantial difference compared with the energy use intensity of cooperative apartment buildings.

It should be pointed out that the results presented are subject to some uncertainty. The data includes no information about some technical details of the buildings, such as the age of the heating and ventilation systems, the amount of wall and attic insulation, and their shape, height, and exact geographical coordinates. Any systematic differences in the above mentioned factors between different owner types will make our results biased.

7 Policy recommendations

When designing energy efficiency policies, policy makers have to consider the benefits and costs involved. From a strict economic perspective, only cost-effective measures should be undertaken. We believe that the inefficiency pointed out in this paper can be eliminated cost-effectively as it obviously does not exist in the unregulated part of the residential sector (co-operatives). It has been suggested that in order to accomplish greater savings and effectively get rid of the principal agent problem in the residential sector, individual metering and debiting of heat, water, and electricity use are needed. One problem with this strategy is that installment of such a metering system in the existing building stock has proven to be quite expensive. Maybe more important, the introduction of individual metering and debiting solves one principal agent problem, but creates another. Landlords who do not pay for the energy used in the buildings lack proper incentives to invest cost-effectively in their buildings. For Sweden, our results suggest that it would be a better idea from an energy efficiency perspective to transform public rental apartments to cooperative apartments. Such a strategy would provide tenants with economic incentives not to waste energy and manage the buildings more effectively, e.g., by installing thermostats to control the energy used for heating.

Inventive informational policy measures may also be effective. It has been proven in several papers that information alluding to social norms significantly reduces energy use (see review in Broberg and Kazukauskas, 2015). A recent study finds that peer-comparisons of water consumption also significantly reduce the use of electricity (Jaime Torres and Carlsson, 2016). The electricity consumption of Swedish households in apartment buildings is typically individually metered and debited. Thus, peer comparisons of electricity use might be an effective measure to deal with the split incentive problem as such comparisons may reduce not only the use of electricity but also the use of water and heat.

We discovered several problems with the certification data. First, the way the energy performance indicator is calculated makes the energy labeling influenced by measurement errors. Firstly, according to our results, the energy performance depends on what year the certification was conducted. Secondly, the energy performance certification data lacks information about household characteristics. Average family size in the buildings has a potentially significant influence on the energy performance indicator. More people in the building means more body heat, but also higher energy consumption for showering. The second effect could be captured by collecting data on the consumption of heated water. Today the certifications lack a standardized method for estimating heated water. Thirdly, the ultimate goal of the certification should be to inform consumers about the energy performance of the building in relation to similar buildings. In that way, consumers are informed about the factors that are subject to asymmetric information, e.g., the weatherization standard and the efficiency of the heating system. The overall impression is that the certifications are based on insufficient data, which in the end means that the energy labeling of buildings may be misleading. For example, the certifications include no information on the headroom of the average apartment in the buildings. This lack of information is a serious problem as the energy labels could affect the market value of multi-dwelling buildings. We strongly recommend that the responsible authority in Sweden improve the directives for the certification system in order to improve the quality of the data and methodologies underlying the energy performance indicator.

8 Appendices

Appendix A: Summary statistics of energy use intensity (kWh/m^2) by type of ownership

Descriptive statistics of energy use intensity (kWh/m2) by type of ownership									
Ownership type	**N**	**mean**	**median**	**sd**	**min**	**max**	**Std. Err.**	**95 % Confidence Interval**	
Private person	9 720	136.72	137	51.00	15	505	0.52	135.70	137.73
Private rental company	16 331	144.96	144	45.66	16	459	0.36	144.26	145.66
Cooperative (COAA)	31 554	138.17	138	36.16	22	613	0.20	137.77	138.57
Public rental company	28 193	153.22	151	40.29	15	645	0.24	152.75	153.69
Other	4 246	146.08	145	43.99	31	691	0.68	144.76	147.40
Total	90 044	144.33	144	41.96	15	691	0.14	144.06	144.60

Appendix B: Model 1

Linear regression

Number of obs	=	89,437
F(329, 89107)	=	267.60
Prob > F	=	0.0000
R-squared	=	0.4905
Root MSE	=	29.981

energyintensity	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
JurformGrp						
Private person	-10.29816	.5111269	-20.15	0.000	-11.29996	-9.296352
Private rental company AB	-1.389328	.3842279	-3.62	0.000	-2.142411	-.6362447
Cooperative BRF	-8.557063	.2943083	-29.08	0.000	-9.133904	-7.980221
Other	-2.16326	.6441368	-3.36	0.001	-3.425762	-.9007574
Nybyggnads√•r_group						
1800-1900	22.23073	1.025927	21.67	0.000	20.21992	24.24154
1901-1949	19.68066	.4618323	42.61	0.000	18.77547	20.58585
1950-1973	19.25434	.4003827	48.09	0.000	18.4696	20.03909
1974-1980	13.48239	.50928	26.47	0.000	12.48421	14.48057
1991-2007	-5.26799	.4050512	-13.01	0.000	-6.061886	-4.474093
2008-2014	-19.70041	.8810589	-22.36	0.000	-21.42728	-17.97355
lnAtemp	-8.70756	.2785163	-31.26	0.000	-9.253449	-8.16167
apartments	.0548738	.0073096	7.51	0.000	.0405471	.0692006
apsize	-.2821433	.0072226	-39.06	0.000	-.2962994	-.2679871
BRFaTOT	.0030947	.0006224	4.97	0.000	.0018749	.0043146
PPaTOT	.0333514	.002608	12.79	0.000	.0282397	.0384631
PCaTOT	-.000444	.0001827	-2.43	0.015	-.000802	-.000086
OTHERaTOT	-.0012214	.0002813	-4.34	0.000	-.0017727	-.0006701
temp_avg_year	-1.600455	.8872402	-1.80	0.071	-3.339437	.1385279
Fsize	5.210579	.3589316	14.52	0.000	4.507077	5.914082
Medelvarde_CDISP04H	1.65e-07	9.15e-09	18.04	0.000	1.47e-07	1.83e-07
hasbasement	-6.135481	.2747494	-22.33	0.000	-6.673987	-5.596974
hasavarmgarage	5.556707	.3703453	15.00	0.000	4.830833	6.28258
bul_levels_AG_group						
2 floors	-3.959485	.7481812	-5.29	0.000	-5.425913	-2.493057
3 to 11 floors	-6.903422	.7945465	-8.69	0.000	-8.460726	-5.346119
11 or more floors	-8.547108	1.576489	-5.42	0.000	-11.63701	-5.457205
residence_percent	.1004098	.0469923	2.14	0.033	.0083054	.1925142
Measured_M2	-5.801695	.2321737	-24.99	0.000	-6.256754	-5.346637
Middle	-9.1352	.4728869	-19.32	0.000	-10.06205	-8.208346
End	-3.525769	.4510945	-7.82	0.000	-4.40991	-2.641628
Complex	1.259517	.7514359	1.68	0.094	-.2132905	2.732324
mainvent_F	2.87037	.2858328	10.04	0.000	2.310141	3.4306
mainvent_FT	6.133799	.6500384	9.44	0.000	4.85973	7.407869
mainvent_FX_FTX	-2.158018	.4200658	-5.14	0.000	-2.981343	-1.334693
mainuse_combustion	17.1564	.7441063	23.06	0.000	15.69795	18.61484
mainuse_elH	-31.70276	.6179306	-51.30	0.000	-32.9139	-30.49162
mainuse_WPHP	-34.91493	.6353662	-54.95	0.000	-36.16024	-33.66962
1.Sec_HP	-34.31251	.5659462	-60.63	0.000	-35.42176	-33.20326
cert_year_group						
2009	2.936628	.2533937	11.59	0.000	2.439978	3.433277
2010	3.727685	.3424139	10.89	0.000	3.056557	4.398813
2011	2.865466	.5420368	5.29	0.000	1.803079	3.927853
20122016	1.352983	.5124093	2.64	0.008	.3486652	2.3573
_cons	244.0362	7.629388	31.99	0.000	229.0827	258.9898

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