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Investigating inefficiencies in the German rental housing market: The impact of disclosing total costs on energy efficiency appreciation

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Investigating Inefficiencies in the German Rental Housing Market: The Impact of Disclosing Total Costs on Energy Efficiency Appreciation

HEMF Working Paper No. 05/2023

by

Lisa Sieger

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Investigating Inefficiencies in the German Rental Housing Market: The Impact of Disclosing Total Costs on Energy Efficiency Appreciation

by Lisa Sieger

Abstract

Energy efficiency and renewable energy are key pillars of the energy transition that is high on the political agenda of governments in face of the climate crisis. Germany, however, is underperforming in its emissions reduction goals. There is still room for improvement, especially in the building sector – but this is often associated with high upfront investments. There is evidence that the market for energy efficiency in the German rental housing market is inefficient, resulting in underinvestment. To investigate these inefficiencies, this study estimates a hedonic pricing model combined with a total-cost-of-use perspective based on the observation of warm rents for a sample of 3,903,473 rental offers from 2014 to 2021. In a “perfect world”, the effect of the energy performance score given in energy performance certificates as an indicator of energy consumption or demand, respectively, is expected to be zero, as corresponding costs are already included in the warm rent. If the coefficient is significantly different from zero, it can be interpreted as measure for inefficiencies. The study further investigates whether disclosing heating costs in real estate advertisements could lead to a better appreciation of energy efficiency in the rental market and thus contribute to closing the information gap. Results show that the market for energy efficiency is indeed inefficient; however, the disclosure of full information can help to overcome these inefficiencies. These results lead to several important policy implications.

Keywords : energy efficiency; rental housing market; information asymmetry; hedonic pricing

JEL-Classification : C31, Q40, R21, R31

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1 Introduction

Energy efficiency and renewable energies are crucial for the energy transition, which is high on the policy agenda of governments and organizations around the world in the face of the climate crisis. Germany, however, is underperforming in its emission-reduction goals (UBA, 2020). With 35 % of end-energy use and about one third of CO₂ emissions (BMW_i, 2021), the building stock provides high opportunities for emission reductions. However, low renovation rates and a lack of investment in sustainable heating technologies prevent this potential from being sufficiently exploited to date. Thus, increasing the refurbishment rates from about 1 % to 2 % per year is necessary to reach a climate-neutral building stock by 2045 (Luderer et al., 2021).

As Germany has one of the largest shares of rented accommodations across Europe, incentives for energy refurbishments are split among property owners and tenants (Gillingham et al., 2012). Landlords or landladies, respectively, invest in higher energy efficiency while tenants profit from lower energy bills¹. Consequently, private investments in energy improvements to existing buildings may still lag behind the optimal level (Allcott and Greenstone, 2012; Gerarden et al., 2017), leading to the so-called energy efficiency gap (Jaffe and Stavins, 1994).

The German government has already passed a law making energy refurbishments mandatory in certain cases to a prescribed minimum extent (GEG, 2022). However, this law currently applies almost exclusively when the owner of the building changes. Further, a CO₂ price for heating energy, among others, was introduced in 2021. From January 2023, the additional costs arising from this CO₂ pricing scheme must be shared between the two parties in private leases. The worse the energy quality of the respective building, the higher the share of costs to be borne by the landlord or landlady (CO₂KostAufG, 2023). In the case of inefficient buildings, the property owner thus may consider renovating the apartment.

Even if new incentives for energy refurbishments are created, especially through the sharing of CO₂ costs, it plays a major role whether the required investment costs can be covered by additional rental income. There is evidence that energy efficiency is still not enough capitalized into rents so that no further incentives are created for property owners to invest (Ambrose, 2015; Groh et al., 2022; Hope and Booth, 2014). To overcome these inefficiencies in the market for energy efficiency (Sieger and Weber, 2023), one proposal is to adjust policies regarding the mandatory disclosure of information (Frondel et al., 2020; Myers, 2020).

¹ In Germany, it is common for tenants to pay the costs for their energy consumption directly to the energy supplier.

In this context, two hypotheses are proposed and tested in this study:

[H 1] The market for energy efficiency in the German rental housing market is inefficient, even if warm rents are disclosed.

[H 2] The disclosure of heating costs in (online) real estate advertisements can help to close the information gap und thus to overcome these inefficiencies.

The first hypothesis is tested by estimating a hedonic pricing model combined with a total-cost-of-use (TCU) perspective, as already implemented in Sieger and Weber (2023). Using the warm rent as dependent variable and additionally including a measure for the energy performance of the respective apartment, arising inefficiencies in the market for energy efficiency can be examined. In a “perfect world”, the impact of the energy performance score as indicator for energy consumption or demand, respectively, on the warm rent is expected to be zero, as corresponding costs are already included in the warm rent. If the effect of the energy performance score on warm rents is significantly different from zero², there is evidence for inefficiencies in this market.

To evaluate whether the disclosure of heating costs can help to close the information gap, a moderation analysis is conducted, making use of the rich dataset with almost 4,000,000 individual apartment observations for the time period 2014 to 2021. Thereby, a distinction is made between advertisements that (a) only report basic rents, (b) report an overall warm rent – consisting of basic rent, heating costs and other auxiliary costs – and (c) those that also provide explicit information on heating costs.

A review of the extant literature reveals several groups of studies that estimate a so-called *green premium* for efficient buildings. The first strand examines the effects of labeled vs. non-labeled homes (e.g., Aroul and Hansz, 2012; Bloom et al., 2011; Brounen and Kok, 2011) in either the sales (Högberg, 2013; Taruttis and Weber, 2022) or rental (Fuerst et al., 2020; März et al., 2022) segment of real estate markets. These label effects are mostly found to be positive, leading to higher sales prices for houses or higher rental incomes for property owners, respectively. Overall, effects are found to be larger in the sales sector (cf. Hyland et al., 2013).

Only small or negligible label effects were found by Olausson et al. (2017) and Wahlström (2016). However, they still find effects of single efficiency measures, which is a second strand in the existing literature. For instance, Feige et al. (2013) investigated the Swiss rental housing market and found significantly positive price effects of the environmental performance of the

² This applies for both negative and positive effects. The first implies financial advantages for tenants, the latter results in financial advantages for the property owners.

respective building. Further, Fuerst and Warren-Myers (2018) combined research on the pure label effect with investigations on sustainable building characteristics and also found positive effects on sales prices and rents for both features.

In addition, a third strand of literature captures energy efficiency differences in apartment buildings for sale vs. rent, addressing the split-incentives in multi-family buildings. For instance, Broberg and Egüez (2018) examine the efficiency of the housing stock in Sweden, where it is common that heating costs are included in the apartment rent so that there are no incentives for tenants to actively control their heating and ventilation behavior. Further, differences in energy efficiency measures between rental and owner-occupied properties were investigated for Ireland (Petrov and Ryan, 2021) and Germany (Singhal et al., 2023). Both studies find no significant divergence in the energy quality of properties according to the mode of tenure in the market of apartments.

Finally, a recent study by Galvin (2023b) compares effects on apartments for rent and sale in the period 01/2019 to 12/2021 and thereby focuses on buildings that were built between 1800 and 1945. The study further excludes all observations that have consumption certificates and thus focuses on buildings that were certified by energy demand. The author finds that only the sales market compensates owners of pre-war apartments who first renovate and then sell their houses. All other actors – owners who either renovate and then rent out or renovate and live in – suffer shortfalls.

The present study takes an in-depth look at an issue that lies at the crossroads of these different research directions: the impact of the different types of information presented to (potential) tenants. Thereby, it makes several important contributions to the extant literature. First, it examines the market efficiency of the German rental housing market in regards of energy efficiency by considering the total costs of renting and living in an apartment rather than relying on basic rents only. Second, it analyzes different moderating effects for the valuation of energy efficiency and thus explores options to close the information gap. Finally, this study distinguishes between different kinds of energy performance certificates (EPCs), leading to compelling outcomes that have important policy implications.

Results suggest that there are inefficiencies in the market for energy efficiency leading to advantages for tenants. In addition, reporting warm rents does not automatically result in a better appreciation of energy efficiency. The market valuation for higher energy efficiency standards only increases when the exact heating costs are disclosed in addition to the warm rent in the online advertisement.

The remainder of this paper is organized as follows. Chapter 2 discusses some theoretical considerations for the influence of energy efficiency on basic and warm rents. Building on this, the empirical approach and data used are described in Chapter 3. Chapters 4 and 5 report and discuss the empirical results. Finally, Chapter 6 concludes and gives some important policy implications.

2 Theoretical Considerations

The willingness-to-pay (WTP) for a specific apartment can be described as a function of the apartment's structural (x) and locational (n) attributes:

$$WTP = f(x, n) \quad (1)$$

From a renter's perspective, this WTP refers to total expenditures rather than just basic rent. The (expected) total costs of renting and living in a property for the tenant thus equals the sum of basic rent and auxiliary costs that cover heating, electricity, and other utility costs. They can be written as:

$$E[TotalCosts_{ie}] = BasicRent(X_i, N_i) + E[P_e \cdot eps_i] + Utility_i + Electricity_i \quad (2)$$

The basic rent thereby depends on hedonic (X_i) and neighborhood (N_i) attributes of apartment i . Expected heating costs are given by the price for heating energy (P_e) multiplied by the energy performance score (eps_i) of the respective apartment, which is measured in energy units and is used as a proxy for the expected quantity of energy used. $Utility_i$ costs include other than energy and electricity costs, e.g., garbage disposal, road cleaning and maintenance as well as winter services. These costs are passed through by landlords and landladies and are hence neither (directly) adjustable by themselves nor by tenants. Finally, $Electricity_i$ costs³ depend mainly on tenants' behavior and the appliances they use. In Germany, they are paid directly to the electricity provider and are not included in the so-called warm rent, so that these costs are not included in the analyses of this study. Therefore, the expected warm rent can be written as:

$$E[WarmRent_{ie}] = BasicRent(X_i, N_i) + E[P_e \cdot eps_i] + Utility_i \quad (3)$$

Parallel to electricity costs, it is also common in Germany for heating costs to be paid on the basis of measured consumption. In the case of rented apartments, this usually involves a 30/70 key, i.e., 30 % of the energy costs of the apartment building are apportioned to the individual

³ Costs for electric heating are already included in expected heating costs.

tenants (e.g., according to the size of the apartment and the number of people living in it) and the remaining 70 % consists of the tenants' individual consumption (measured by metering devices on all heaters). Accordingly, tenants can influence their own heating costs through appropriate heating and ventilation behavior.

If a dwelling is now renovated to make it more energy efficient, the energy performance score will decrease, so that the (expected) heating costs will also decrease if prices remain the same and tenants' behavior does not change. As a result of the consumption-based billing, this refurbishment creates monetary benefits for the tenant. Consequently, the basic rent could be increased to keep the total cost of use at the same level while making the energy-related refurbishment profitable for the property owner.

According to the Efficient Market Hypothesis (EMH), first proposed by Fama (1970), prices reflect all available information. The term *efficient market* was originally developed for the stock market in particular, but as time went on, the concept has been generalized to other markets such as the real estate market (Sunjo and Yilmaz, 2017). In the vein of this hypothesis⁴, the market for energy efficiency in the rental market is to be considered efficient if basic-rent increases balance out with heating-cost savings after energy retrofits, given that information on the energy performance score and/or expected heating costs are given in the property advertisement, i.e., full information is provided for the prospective tenant.

Table 1 gives an overview of possible changes in basic and warm rents as well as heating costs after an energy retrofit has taken place and the energy performance score has decreased. As previously described, utility costs are not adjustable so that they will not change in the context of an energy refurbishment. The expected heating costs will decrease by $P_e \cdot \Delta eps_i$ as long as prices stay constant, and the tenants do not change their ventilation and heating behavior after the renovation.

Case (A) describes the worst case⁵, in which the basic rent does not change at all after the energy refurbishment. The entire advantage lies with the tenants, so that investments in higher energy efficiency are not profitable for the property owner. Case (B) also has disadvantages for landlords or landladies; however, they generate more rental income than before the renovation, so that part of the investment costs can be refinanced. Case (C) shows an efficient market, where the increase in basic rents corresponds to the decrease in expected heating costs. Thus, tenants receive a better energy standard for which they adequately compensate the property owner.

⁴ In its semi-strong form, where all publicly available information are reflected in the price.

⁵ The possibility of decreasing basic rents after renovations is not considered.

Finally, the last case (D) shows an inefficient market again in which the increase in basic rents exceeds the reductions in heating costs. In this case, energy efficiency is over-proportionately valued. From the landlord's point of view, the investment costs can be amortized most quickly in case (D).

Table 1 Changes in heating costs and possible changes in rents after energy refurbishments.

Heating Costs (HC)	+	Basic Rents (BR)	=	Warm Rents (WR)	
$\Delta HC = E[P_e \cdot \Delta eps_i] < 0$		$\Delta BR = 0$		$WR_{after} = WR_{before} + \Delta HC$	↓ (A)
		$0 < \Delta BR < \Delta HC $		$WR_{after} = WR_{before} + \Delta BR + \Delta HC$	↓ (B)
		$\Delta BR = \Delta HC $		$WR_{after} = WR_{before}$	- (C)
		$\Delta BR > \Delta HC $		$WR_{after} = WR_{before} + \Delta BR + \Delta HC$	↑ (D)

Notes: The arrows indicate whether warm rents increase or decrease, depending on the change in basic rents. $\Delta HC = E[P_e \cdot \Delta eps_i]$ denotes the expected change in heating costs if prices stay the same before and after energy-efficiency improvements, with $\Delta eps_i < 0$. ΔBR is expected to be ≥ 0 , as a decrease in basic rents after refurbishments does not seem plausible. Columns marked in red report market inefficiencies with advantages for tenants after refurbishment. Yellow indicates market inefficiencies with advantages for property owners. Green stands for an efficient market.

Source: Own illustration.

The amount of heating cost savings and thus possible rent increases depends not only on the energy price but also on the extent of the refurbishment. Buildings with a poor initial performance typically have greater savings potential than buildings that are already more energy efficient.

3 Empirical approach and data

The research approach in this paper is twofold. In the first part, I examine in more detail whether there are inefficiencies in the market for energy efficiency. The focus here is on the submarket where the total costs, i.e., the warm rents, are given in the advertisement⁶ (referred to as “submarket warm”). I also distinguish between advertisements that 1) only provide information on the overall warm rent and 2) additionally provide full information on the heating costs.

In the second part, I examine the entire rental market (i.e., both submarkets “cold” and “warm”) and investigate whether the disclosure of total costs helps to overcome information asymmetries and thus better evaluate the energy efficiency of an advertised dwelling in order to minimize inefficiencies in the market for energy efficiency.

⁶ In contrast to advertisements that only provide information on the basic rent (referred to as “submarket cold”).

3.1 Total-cost-of-use (TCU) perspective

The first model is based on a standard hedonic regression model in its common semi-logarithmic form going back to Lancaster (1966) and Rosen (1974) to control for price differences due to different apartment and neighborhood characteristics. However, I combine the model with a TCU perspective, as previously implemented in Sieger and Weber (2023), to be able to compare the results with engineering-economic estimates of heating cost savings. For a detailed model description see Sieger and Weber (2023).

To measure inefficiencies in the market for energy efficiency, I use the warm rent as a proxy for the total costs of use. I further subtract the expected heating costs – computed as the energy performance score (eps_i) multiplied by an empirical parameter β_1 – to test whether there is a specific effect of the heating costs beyond the warm rent. The costs for renting apartment i in neighborhood n at time t can then be described by the following equation:

$$\ln(WarmRent_{int} - \beta_1 eps_i) = \alpha + \gamma X_i + \delta N_{nt} + \mu_t + \varepsilon_{int} \quad (4)$$

In this specification, the coefficient β_1 provides an indication on the inefficiency in the market for energy efficiency – in a “perfect world” with a fully efficient market it would be zero, as the warm rent then fully captures the impact of the energy performance on the total cost of use (cf. case (C) in Table 1).

If the coefficient is positive, the market is inefficient with benefits from improved efficiency accruing (partly) to tenants. If the energy performance score decreases, heating costs should decrease as well. With a positive coefficient, the overall warm rent will also decrease, which means that the basic rent does not increase up to the limit of energy cost savings and consequently investments are less profitable for property owners (cf. cases (A) and (B) in Table 1). If the coefficient is negative, the financial advantage would be on the landlord’s or landlady’s side, as the energy efficiency is then valued higher than the current heating price (cf. case (D) in Table 1).

To obtain the monthly warm rent in euro per square meter of living area as dependent variable on the left-hand side, I rearrange the terms in Eq. (4) and estimate Eq. (5) using nonlinear least squares:

$$WarmRent_{int} = \beta_1 eps_i + \exp(\alpha + \gamma X_i + \delta N_{nt} + \mu_t) + \varepsilon'_{int} \quad (5)$$

The main variable of interest – eps_i – is the energy performance score for heating of apartment i measured in 10 kWh/m²a. Vector \mathbf{X}_i includes all other apartment characteristics, while neighborhood characteristics are contained in vector \mathbf{N}_{nt} . Finally, μ_t are time-fixed effects on quarterly-year level and ε'_{int} is the error term of the regression for which I report cluster-robust standard errors to correct for temporal and spatial correlation between subdivisions (Angrist and Pischke, 2008). An overview of the full set of control variables is given in Table A 1 in the appendix. Interpretation of the coefficient β_1 is straight forward: if the energy performance score decreases – and energy efficiency thus increases – by 10 kWh/m²a, the monthly warm rent decreases by β_1 euro per square meter.

I start the analysis by estimating the regression as given by Eq. (5) for the “submarket warm” sample as well as for subsamples according to the disclosure of explicit heating costs. I further test the robustness of the results by excluding newly built apartments to focus on energy retrofits only and additionally excluding all observations that have at least one “unknown” factor variable. Finally, I check for different income levels, different energy efficiency levels, different (basic) rent levels, different heating and fuel types used for heating and also different types of EPCs.

Since the nature of the data does not allow for a comparison of inefficiencies between the “cold” and “warm” submarkets, I instead estimate the impact of energy efficiency on basic rents for both submarket samples. I thereby use the model as specified in Sieger and Weber (2023) (cf. Eq. (6)). The coefficient β_2 is then expected to be positive given that the lowering effect of an increasing energy performance score on basic rents is already included in the negative sign. Interpretation now changes to: if the energy performance score decreases – and energy efficiency thus increases – by 10 kWh/m²a, the monthly basic rent increases by β_2 euro per square meter.

$$BasicRent_{int} = -\beta_2 eps_i + exp(\alpha + \gamma \mathbf{X}_i + \delta \mathbf{N}_{nt} + \mu_t) + \varepsilon'_{int} \quad (6)$$

3.2 Moderation analysis

To investigate a possible moderating effect of information disclosure on the valuation of energy efficiency, two dummy variables are created. Using the full sample, the first dummy, $basic_only_i$, discriminates between the submarkets “cold” and “warm”, taking a value one if only basic rents are disclosed and zero otherwise (Eq. (7)). Using the subsample “warm”, the

second dummy, $warm_only_i$, is constructed, taking the value one, if only warm rents are disclosed and zero if explicit heating costs are disclosed (Eq. (8)).

$$basic_only_i = \begin{cases} 0, & \text{warm rent disclosed (submarket "warm")} \\ 1, & \text{only basic rent disclosed (submarket "cold")} \end{cases} \quad (7)$$

$$warm_only_i = \begin{cases} 0, & \text{exact heating costs disclosed} \\ 1, & \text{only warm rent disclosed} \end{cases} \quad (8)$$

I then implement a traditional hedonic model in its semi-logarithmic form and use the high-dimensional fixed effects (HDFE) method developed by Guimarães and Portugal (2010) and Gaure (2013), among others, to control for possible omitted variable bias due to unobservable geographical and locational conditions⁷. Furthermore, I focus on relative effects of energy efficiency on basic rents, so that the model allows to directly compare results for the full market with results for the submarket “warm” sample.

In a first step, I examine the full rental market to test whether the disclosure of warm rents has positive effects on the valuation of energy efficiency, compared to only providing basic rents in the online advertisements. To estimate the moderating effect, the dummy $basic_only_i$ as well as an interaction between the dummy and the energy performance score $eps_i \times basic_only_i$ are included in the regression. The equation thus takes the following form:

$$\begin{aligned} \ln(BasicRent_{insdt}) &= \alpha + \beta_3 eps_i + \beta_4 basic_only_i + \beta_5 (eps_i \times basic_only_i) + \gamma \mathbf{X}_i \quad (9) \\ &+ \delta \mathbf{N}_{nt} + \mu_t + \tau_s + \nu_d + \rho_n + \varepsilon_{insdt} \end{aligned}$$

μ_t again describes time-fixed effects on a quarterly-year level; τ_s, ν_d, ρ_n are regional-fixed effects on state, district and neighborhood level, respectively. eps_i was scaled prior estimation, so that the main effect for $basic_only_i$ can be interpreted for mean levels of energy efficiency.

In this specification, the coefficients β_3 and $(\beta_3 + \beta_5)$ report semi-elasticities: a one-unit change in eps_i results in a $100 \cdot \beta_3$ percent change in basic rents for $basic_only_i$ equal to zero, i.e., warm rents are disclosed. Otherwise, the change in basic rents amounts to $100 \cdot (\beta_3 + \beta_5)$ percent.

⁷ An inclusion of such high numbers of fixed effects was not possible for the nonlinear model due to computational power.

In a second step, the submarket “warm” is examined, to test whether the disclosure of explicit heating costs provides further positive effects on the valuation of energy efficiency, compared to only disclosing overall warm rents. The approach and interpretation are analogous to the first moderation analysis; however, the dummy $warm_only_i$ and the interaction $eps_i \times warm_only_i$ are now included in the regression. The equation for the second moderation analysis is thus given as:

$$\begin{aligned} \ln(BasicRent_{insdt}) &= \alpha + \beta_6 eps_i + \beta_7 warm_only_i + \beta_8 (eps_i \times warm_only_i) + \gamma X_i \quad (10) \\ &+ \delta N_{nt} + \mu_t + \tau_s + \nu_d + \rho_n + \varepsilon_{insdt} \end{aligned}$$

I additionally run subsample regressions according to the type of EPCs to check for heterogeneous effects. Thereby, the full sample as well as the submarket “warm” subsample are used to test for the disclosure of warm rents as well as full information.

In a last step, I also add the dummy $\beta_9 warm_only_i$ as well as the interaction $\beta_{10}(eps_i \times warm_only_i)$ to Eq. (5) and re-estimate the model using nonlinear least squares. Since the effect of the energy performance score on the warm rent is still linear, interpretation of the moderation effect is straight forward. If the coefficient $\widetilde{\beta}_1$ for eps_i is statistically significantly different from zero, it reports the remaining inefficiencies even when full information is disclosed. If $warm_only_i = 1$ and β_{10} is also statistically significantly different from zero, this coefficient shows additional inefficiencies when only overall warm rents are provided in the advertisement.

3.3 Data

Micro-level information on asking rents of flats advertised on the internet platform *ImmobilienScout24.de* are provided by *RWI-GEO-RED* (RWI and ImmobilienScout24, 2022). The dataset contains information on basic rents as well as on a variety of apartment characteristics and special features. Additionally, for most observations, utility costs and at least some information on heating costs are reported. The data is georeferenced in terms of 1 km² grids. For limitations that arise with this dataset, see Sieger and Weber (2023).

Socio-economic characteristics, compiled at the level of 1 km² grids as well, are provided by *RWI-GEO-GRID* (RWI and microm, 2022). The data originates from microm Micromarketing-Systeme und Consult GmbH, a market research company specializing in regional analysis. Both

datasets were merged based on georeference and year⁸. After clearing the data from duplicates and outliers based on 1st and 99th percentiles of all numeric variables and applying a Cook's Distance filter with cutoff $4/N$, the final dataset consists of 3,903,473 observations from May 2014⁹ to December 2021 distributed over 55,733 grid cells across Germany. Descriptive statistics of all numeric variables are presented in Table 2.

Statistics are shown for the submarket “cold”, where only basic rents are given, as well as for the submarket “warm”, where warm rents are reported. For the latter, there are also separate statistics displayed for subsamples according to the disclosure of explicit heating costs as well as differences between these subsamples. A flow chart explaining the generation of submarkets and subsamples is given in Figure A 1. An overview of all factor variables is given in Figure A 2 to Figure A 5 in the appendix.

A comparison of the “cold” and “warm” submarkets indicates that the first shows cheaper basic rents, but it also has older and less efficient buildings. An average flat is offered for €7.83 per square meter of living area and shows an energy performance score of 135 kWh/m²a (which is equal to energy efficiency class E). In terms of living area and selected neighborhood characteristics, differences are rather small.

Within the “warm” submarket, a distinction between subsamples according to the disclosure of heating costs reveals some interesting insights. Overall, flats are on average advertised for 8.16 €/m²; however, there are large differences across subsamples. When heating costs are fully disclosed (subsample B), the basic rent only amounts to 7.50 €/m² which is even less than in the “cold” submarket sample. When there is no disclosure of explicit heating costs and only the overall warm rent is given, the basic rent amounts to 8.74 €/m², resulting in a difference of 1.24 €/m². The difference between subsamples in terms of the overall warm rent is slightly smaller with 1.07 €/m².

Average heating costs per square meter can only be calculated for the subsample that reveals full information. These costs amount to 1.14 €/m²/months. Nonetheless, Figure 1 shows the conditional probability of estimated monthly heating costs across subsamples. Using subsample B, monthly heating costs were regressed on the (monthly) energy performance score: $HeatCost_i \sim \alpha + \beta eps_i + \varepsilon_i$.

⁸ The socio-economic data was merged to the real estate data with a one-year lag.

⁹ I use the specific cut-off because this is the date from which energy performance certificates must be mandatorily disclosed in online advertisements. By limiting the dataset this way, I reduce the likelihood of selection bias related to the disclosure of information about the building's energy performance.

Table 2 Descriptive statistics.

Variable	Submarket				Difference ^c :	
	“Cold”	“Warm”	Subsample A: No disclosure of heating costs	Subsample B: Disclosure of heating costs	Subs. B – Subs. A	
	Full submarket	Full submarket			Diff.	t
Basic rent (in €/m ² /month)	7.82 (2.81)	8.16 (3.10)	8.74 (3.30)	7.50 (2.70)	-1.24***	374.73
Warm rent ^a (in €/m ² /month)		10.76 (3.31)	11.26 (3.59)	10.19 (2.86)	-1.07***	297.35
Heating costs ^b (in €/m ² /month)				1.14 (0.35)		
Energy performance score (in kWh/m ² a)	135.31 (60.62)	116.00 (50.36)	110.70 (49.29)	121.99 (50.89)	11.29***	-202.32
Living area (in m ²)	66.66 (23.74)	68.21 (23.13)	70.74 (25.28)	65.36 (20.06)	-5.368***	213.16
Age (in years)	60.21 (30.90)	50.80 (31.68)	47.69 (34.63)	54.32 (27.56)	6.63***	-191.68
Population density (in inh/km ²)	5,140 (4,158)	4,935 (3,852)	4,698 (3,784)	5,204 (3,911)	506***	-117.91
Unemployment rate (in %)	8.47 (4.24)	7.94 (4.07)	6.80 (3.66)	9.23 (4.12)	2.43***	-559.96
Households with foreign head (in %)	13.50 (8.38)	12.45 (8.33)	12.07 (8.28)	12.88 (8.37)	0.81***	-87.79
Purchasing power (in €/inh)	21,833 (3,907)	22,021 (4,223)	22,912 (4,424)	21,015 (3,736)	-1,807***	418.38
Observations N	663,385	3,240,088	1,719,127	1,520,961		
in %	16.99	83.01				
		100.00	53.06	46.94		

Notes: St. Dev. in parentheses. ^a Warm rent consists of basic rent plus auxiliary costs plus heating costs. ^b Only given in Subsample B. ^c t-tests for equality of means assume unequal population variances. This was determined using the Welch Two Sample t-test with its alternative hypothesis: true difference in means between group 0 and group 1 is not equal to 0. Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Using the resulting $\alpha = 44.17$ €/month as fixed costs and $\beta = 0.04502$ €/kWh/month as variable costs, heating costs were estimated for all subsamples. The conditional probability of having low monthly heating costs (< 1 €/m²) is highest in subsample A, where overall warm rents are provided but exact heating costs are not disclosed. Contrary, the probability of monthly heating costs above 2 €/m² is highest in the submarket “cold” sample. Overall, heating costs are still very similar, so that price differences in warm rents should mainly be driven through price differences in basic rents.

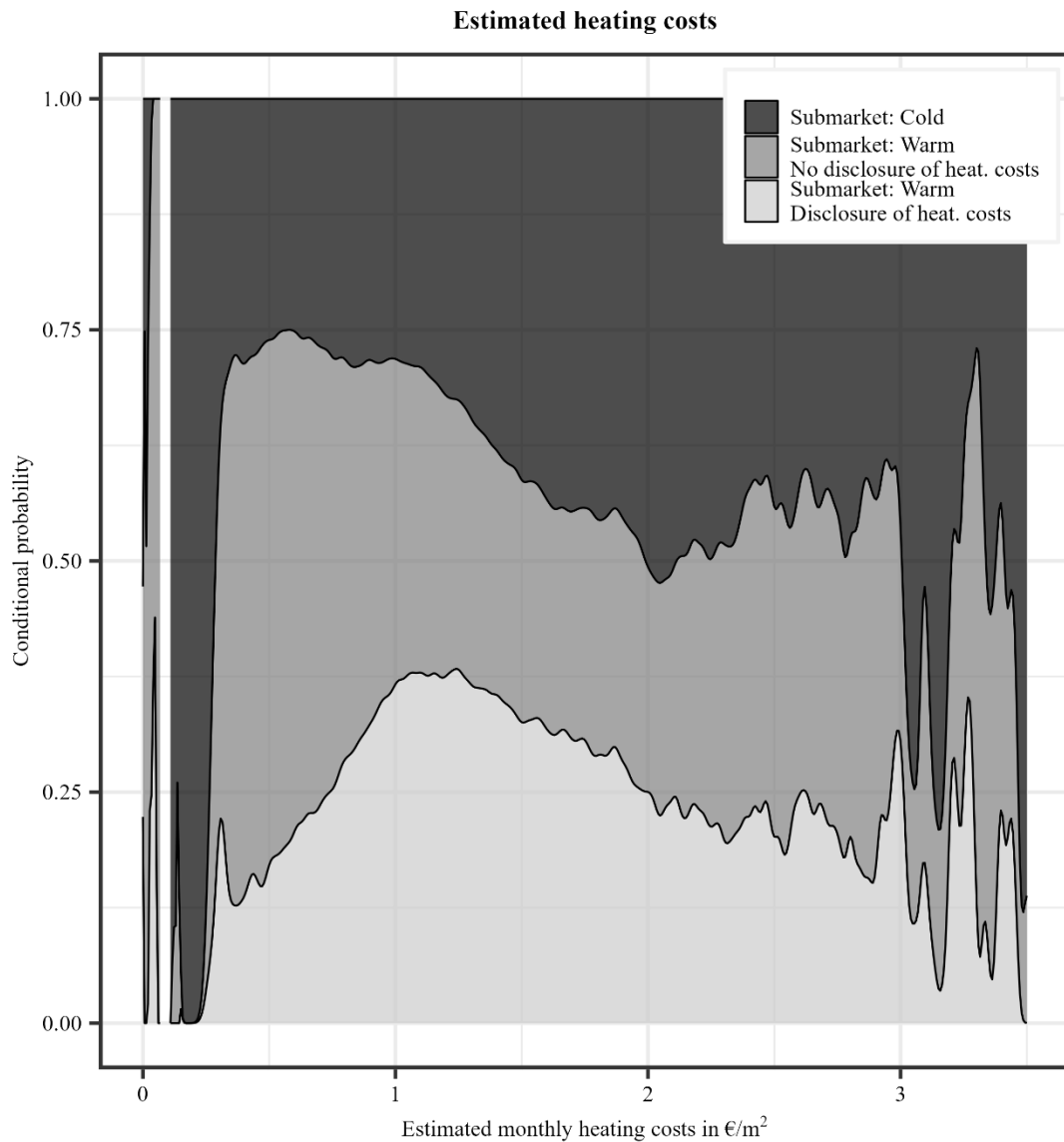


Figure 1 Conditional probability of estimated heating costs across subsamples.

Source: Own calculation and illustration based on RWI-GEO-RED. The plot was created using the ggplot2-package in R. Probability density estimation was done using geom_density().

Additionally, the distribution of energy efficiency ratings across submarkets and subsamples is illustrated in Figure 2. Overall, most apartments fall into the reference category D. The most efficient buildings (categories A+, A and B) are mostly found in the warm submarket with no disclosure of heating costs. This might be related to newly built apartments, as they are most likely to be efficient with no references for heating costs e.g., from previous tenants. It is further in line with the estimated probability of low monthly heating costs. However, this could also be a result of strategic self-selection, if the buildings that are (very) good on paper according to the energy rating are relatively worse off in terms of heating costs and vice versa.

A high share of least efficient apartments (categories G and H) either belongs to the cold submarket or to the subsample with full information disclosed. Given the overall lower

percentage of observations in the cold submarket, the shares in the least efficient categories are overproportioned. Again, this is in line with the estimated probability of higher monthly heating costs and could also be a result of self-selection.

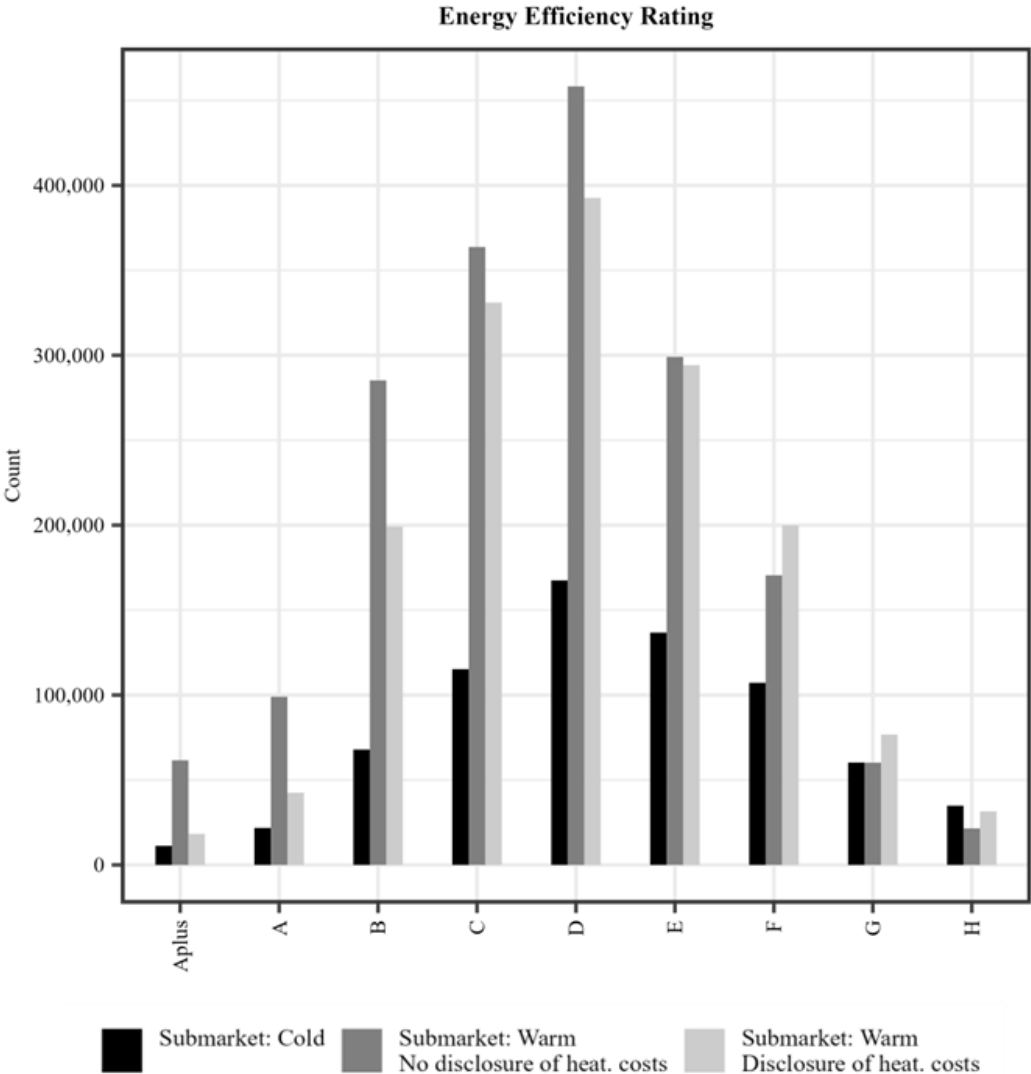


Figure 2 Distribution of energy efficiency ratings.
 Source: Own calculation and illustration based on RWI-GEO-RED.

Finally, it is worth looking at differences across types of the EPC as there is evidence that the valuation of energy efficiency differs across EPCs (Galvin, 2023a; Sieger and Weber, 2023; Taruttis and Weber, 2022). Table 3 reports descriptive statistics across EPC types for the full sample as well as both subsamples in the warm submarket. Basic rents as well as overall warm rents (in the submarket “warm”) are higher for flats that have a demand-based certificate (*Bedarfsausweis*) compared to consumption-based certificates (*Verbrauchsausweis*).

Furthermore, there are differences of about 10 kWh/m²a regarding the energy performance score of the advertised apartments – with it being lower if the apartment is certified based on

demand. Even larger differences are found in the subsamples, where only total costs but no heating costs are disclosed: While apartments show an average energy performance score of 120 kWh/m²a when certified based on consumption, flats only report an average of 92 kWh/m²a when certified based on demand. However, about one fourth of all flats in the latter subsample are advertised as 1st occupancy. Better energy efficiency, higher rents as well as the non-disclosure of heating costs can thus be explained by the fact that the building was most likely newly built.

On the other hand, 1st occupancy rates in the consumption-based certificate subsample are quite low and can probably be explained mainly by incorrect entries made by landlords on the internet platform. Moreover, buildings with demand certificates and no disclosure of heating costs are on average approximately 20 years younger than those with consumption certificates. A significant part of this difference might yet be explained by the first-time rentals; the rest corresponds to the difference observed in the samples with disclosed heating costs.

Table 3 Descriptive statistics for different types of energy performance certificates.

	Demand-based certificate			Consumption-based certificate		
	Full subsample	Submarket “warm”		Full subsample	Submarket “warm”	
		Disclosure of heating costs	No disclosure of heating costs		Disclosure of heating costs	No disclosure of heating costs
Basic rent (in €/m ² /month)	9.10 (3.37)	8.33 (2.99)	10.22 (3.58)	7.58 (2.73)	7.07 (2.42)	8.05 (2.91)
Warm rent (in €/m ² /month)		10.92 (3.18)	12.75 (3.90)		9.80 (2.59)	10.56 (3.20)
Heating costs (in €/m ² /month)		1.10 (0.35)			1.16 (0.35)	
Energy performance score (in kWh/m ² a)	112.53 (66.69)	116.48 (61.38)	92.11 (59.35)	122.81 (43.31)	124.80 (44.36)	119.44 (40.94)
Age (in years)	45.25 (34.87)	49.67 (31.20)	34.73 (36.06)	56.14 (29.30)	56.69 (25.19)	53.78 (32.18)
1 st occupancy (in %)	14.71	7.46	25.25	0.84	0.60	1.08
Observations N	1,339,230	512,330	549,796	2,564,243	1,008,631	1,169,331

Note: St. Dev. in parentheses.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

4 Empirical Results

4.1 Are markets for energy efficiency inefficient?

Main regression results for the TCU approach in the warm submarket are displayed in Table 4. Overall, monthly warm rents increase [decrease] on average by 0.008 €/m² if the energy performance score increases [energy efficiency increases] by 10 kWh/m²a. The installed heating system also plays a role when it comes to pricing. For example, if the advertised flat is connected to district heating, its warm rent is on average 3.96 % higher compared to similar flats with gas heating. Furthermore, flats that were modernized in 2010 or later rent out at a premium of about 1.2 %.

Table 4 Main regression results in TCU model – submarket “warm”.

Dependent Var.:	Submarket “warm”		
	Newly built apartments included.		
	Full submarket	Subsample A: No disclosure of exact heating costs	Subsample B: Disclosure of exact heating costs
WarmRent in €/m ² /month			
Energy performance score (in 10 kWh/m ² a)	0.0077 *** [0.0002]	0.0061 *** [0.0003]	0.0060 *** [0.0003]
<i>Selected heating system, reference: gas heating</i>			
District heating	0.0396 *** [0.0005]	0.0404 *** [0.0007]	0.0327 *** [0.0007]
Oil heating	0.0095 *** [0.0008]	0.0050 *** [0.0011]	0.0156 *** [0.0014]
Floor heating	0.0450 *** [0.0005]	0.0461 *** [0.0006]	0.0412 *** [0.0009]
Central heating	0.0096 *** [0.0004]	0.0124 *** [0.0005]	0.0062 *** [0.0006]
Last renovated in 2010 or later	0.0119 *** [0.0002]	0.0125 *** [0.0003]	0.0081 *** [0.0004]
<i>Controls for ___included?</i>			
Apartment characteristics	yes	yes	yes
Neighborhood characteristics	yes	yes	yes
Season FE (quarterly-year)	yes	yes	yes
RMSE	1.68	1.76	1.56
Pseudo-R²	0.741	0.759	0.702
Observations	3,240,088	1,719,127	1,520,961

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

The coefficients for the energy performance scores are slightly smaller in both subsamples but remain positive and statistically significant. Somewhat larger differences can only be found for the valuation of oil compared to gas heating with effects being larger in subsample B. Excluding

newly built apartments leads to slightly larger effects in subsample A; however, no differences in the valuation of energy efficiency can be found in the full sample and subsample B (cf. Table A 2).

Overall, the positive β_1 -coefficients point to inefficiencies in the valuation of energy efficiency. As previously described, the coefficients should be zero (or at least not statistically significant) if the market for energy efficiency was efficient. Nonetheless, all effects appear to be rather small compared to actual energy cost savings for improvements of 10 kWh/m²a. At average energy prices for heating¹⁰ of 0.0871 €/kWh, the expected monthly heating cost savings would be approximately 0.07 €/m². As warm rents only decrease by less than 0.01 €/m², large parts should be already included in higher basic rents resulting in higher rental income for property owners.

By excluding all observations with some missing attribute values from the regression, a robustness check may be performed – this excludes distortions resulting from the deliberate omission of some values by property owners for hidden reasons. In such a case, the inclusion of these observations may lead to biased results. Some data may, of course, also be missing due to (inadvertently) incorrect entries by the landlord or landlady. These observations can usually be included in the regression without causing any problems.

Results for the robustness checks – with newly built apartments being either included or excluded – are shown in Table A 3. Sample size is reduced by almost 80 % when excluding all observations with missing values. Nonetheless, effects of the energy performance score on warm rents are still positive in all regressions and only slightly differ compared to the previous results. The decrease in monthly warm rents remains less than 0.01 €/m² for improvements of 10 kWh/m²a in all specifications.

Besides checking the robustness of the results, I also test for heterogeneity in the sample. I therefore estimate different subsample regressions; results are illustrated in Figure 3 and further provided in Table A 4. Panel A shows estimates for varying income levels in the neighborhoods. In the 1st and 2nd tercile subsamples, the effect of the energy performance score on monthly warm rents are positive; however, effect size is twice as large in the 2nd tercile than in the 1st tercile subsample. For the highest income tercile, the coefficient becomes slightly negative and statistically insignificant. In high-income neighborhoods, the market for energy efficiency thus seems to be efficient.

¹⁰ Weighted average during study period.

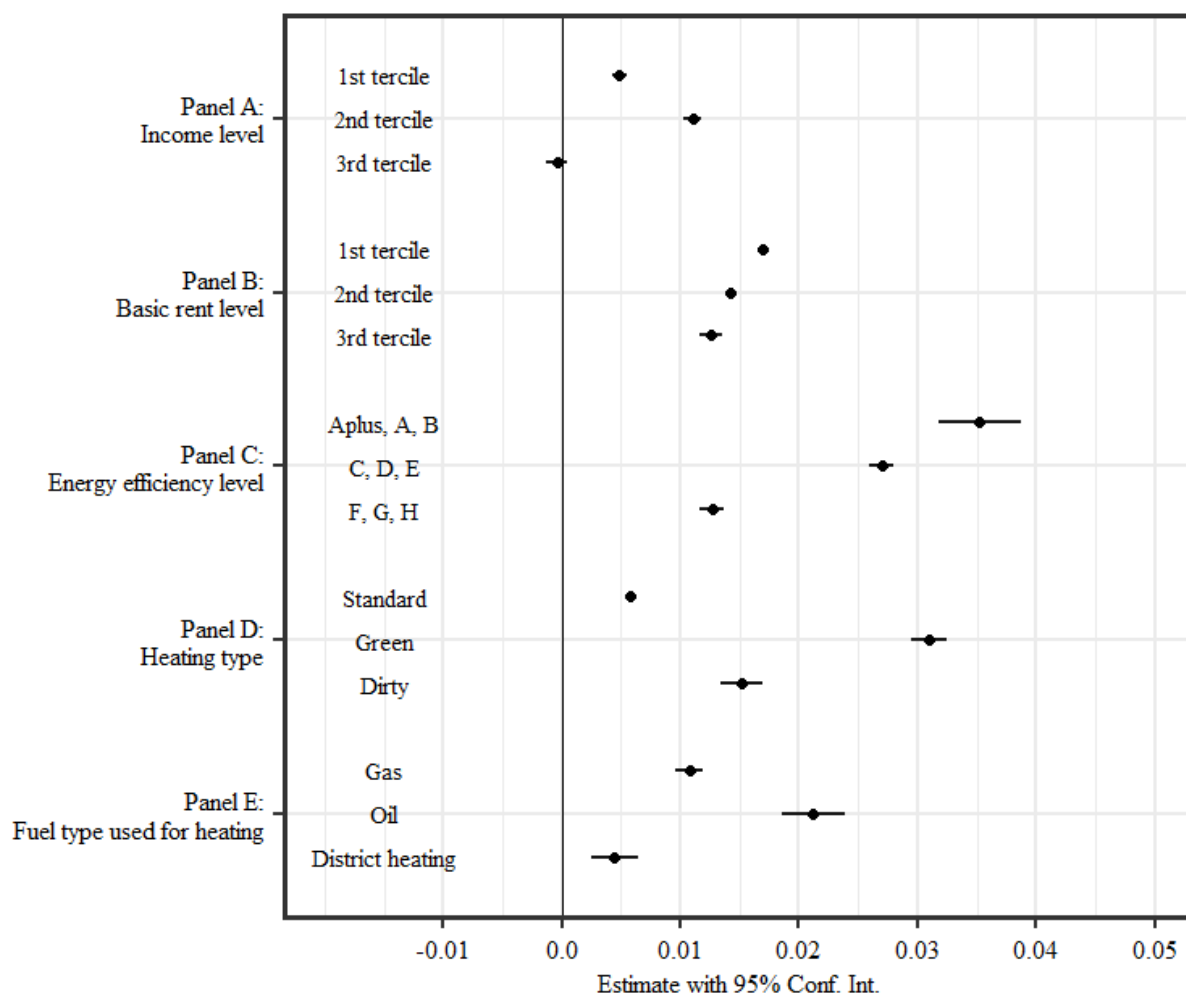


Figure 3 TCU results for subsample regressions.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID. Corresponding results are reported in Table A 4.

In Panel B, results are given for different basic rent levels. Effects are found to be larger than in the full sample; however, there are no differences between the 2nd and 3rd tercile subsample and only slightly higher effects in the 1st tercile subsample. Panel C focuses on variations across energy efficiency ratings. Roughly 60 % of all advertised flats either have a C-, D- or E-label, which corresponds to an energy performance score of 75 kWh/m²a to 160 kWh/m²a.

Within this subsample, monthly warm rents decrease on average by 0.03 €/m² when the energy performance score decreases by 10 kWh/m²a. Effects are less than half the size for flats with higher energy performance scores. In the subsample with the most efficient apartments, the effect of the energy performance score on warm rents is the highest with a coefficient of 0.05 €/m². This might be explained due to already very low energy performance measures so that there is a kind of (psychological) “saturation effect” regarding energy efficiency which induces a zero WTP from tenants for further improvements in energy efficiency.

A similar conclusion can be drawn for results of different heating systems, as shown in Panel D. If the flat is equipped with a sustainable heating system (cf. “green” technology), effect sizes are larger compared to those in both other subsamples. Thus, the WTP might be lower for additional improvements in energy efficiency when sustainable heating technologies are already implemented – although this is not economically rational in a total-cost-minimization perspective.

Somewhat contrary results are, however, found among different fuel types used for heating (Panel E). If flats are connected to district heating, monthly warm rents only decrease by 0.003 €/m² when energy efficiency is improved by 10 kWh/m²a. Apartments that use gas or oil as primary energy source for heating show effects of the energy performance score on monthly warm rents of about 0.01 €/m² or 0.02 €/m², respectively.

Lastly, I check for heterogeneous results among flats with different EPCs. Results are shown in Table 5. On the one hand, I find positive and statistically significant effects in the consumption-based-certificate subsample. If energy efficiency is improved by 10 kWh/m²a, monthly warm rents decrease on average by 0.02 €/m². Thus, the market for energy efficiency again turns out to be inefficient.

Table 5 Regression results in TCU model for EPC type subsamples.

Dependent Var.: WarmRent in €/m ² /month	EPC Subsamples	
	Demand-based	Consumption-based
Energy consumption (in 10 kWh/m ² /a)	-0.0114 *** [0.0004]	0.0240 *** [0.0003]
RMSE	1.86	1.56
Pseudo-R²	0.744	0.721
Observations	1,062,126	2,177,962

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics are included in the regression, including newly built apartments and all observations including the factor “unknown”.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID

On the other hand, effects are negative in the demand-based-certificate subsample. Accordingly, energy-efficiency improvements as indicated by the demand-based EPC are apparently over-proportionally valued in the market. As only asking prices are observed, it is likely that property owners overestimate the impact of energy efficiency improvements as reflected in the demand-based EPC. Actual heating costs apparently decrease less with better energy performance scores than expected according to the EPC – which results in increasing warm rents in this case.

4.2 Can the disclosure of total costs and exact heating costs help overcome information asymmetries and thus lead to a better valuation of energy efficiency?

Before testing the disclosure of more information as a moderator for the effect of the energy performance score on basic and warm rents, I rather estimate the original nonlinear model (cf. Eq. (6)) separately for both submarkets “cold” and “warm” to see whether differences occur in the estimated effects. I also run separate subsample regressions according to the EPC as prior results suggest that the effects of the energy performance score differ strongly across subsamples. Results are reported in Table 6.

Table 6 Results for basic rents in TCU model for submarket "cold" vs. submarket "warm".

	Full sample		Demand-based EPC subsample		Consumption-based EPC subsample	
	Submarket:		Submarket:		Submarket:	
Dependent Var.:	Cold	Warm	Cold	Warm	Cold	Warm
BasicRent in €/m ² /month						
Energy performance score (in 10 kWh/m ² /a)	0.0044 *** [0.0003]	0.0166 *** [0.0002]	0.0202 *** [0.0005]	0.0296 *** [0.0003]	-0.0066 *** [0.0005]	0.0048 *** [0.0002]
Last renovated in 2010 or later	0.0139 *** [0.0007]	0.0229 *** [0.0003]	0.0116 *** [0.0010]	0.0450 *** [0.0023]	0.0134 *** [0.0009]	0.0139 *** [0.0003]
<i>Controls for ___included?</i>						
Apartment characteristics	yes	yes	yes	yes	yes	yes
Neighborhood characteristics	yes	yes	yes	yes	yes	yes
Season FE (quarterly-year)	yes	yes	yes	yes	yes	yes
RMSE	1.51	1.52	1.57	1.69	1.44	1.41
Pseudo-R²	0.711	0.758	0.716	0.760	0.704	0.738
Observations	663,385	3,240,088	277,104	1,062,126	386,281	2,177,962

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics are included in the regression, including newly built apartments and all observations including the factor “unknown”.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

For the full sample, effects are four times larger in the submarket “warm” compared to the submarket “cold”. If the energy performance score decreases – and energy efficiency thus increases – by 10 kWh/m²a, the monthly basic rent increases on average by 0.004 €/m² in the “cold” and by 0.017 €/m² in the “warm” submarket. Therefore, energy efficiency is more appreciated when warm rents are reported in the online advertisement. Furthermore, apartments that were renovated in 2010 or later are rented out at a premium of roughly 2.3 %, if warm rents are disclosed in the online advertisement, and at a premium of only 1.4 %, if only basic rents are reported – both compared to non-renovated flats.

Similar patterns arise for the EPC-type subsamples. Energy efficiency is again more appreciated when warm rents are disclosed. However, in the demand-based certificate subsample, effects only slightly differ between the “cold” and “warm” submarkets, but effect sizes are generally much larger. If energy efficiency improves by 10 kWh/m²a, basic rents increase on average by 0.02 €/m² in the “cold” and by 0.03 €/m² in the “warm” submarket. In the consumption-based certificate subsample, I yet even find negative effects when only basic rents are reported in the advertisement. Overall, effect sizes are much smaller compared to the full sample and the demand-based EPC subsample.

Results for the first moderation analysis, investigating effects of a disclosure of warm rents compared to only providing information on basic rents, are shown in Table 7. The non-disclosure of warm rents already impacts the basic rent of the advertised apartment. The effect is negative yet mostly statistically insignificant for all OLS specifications (columns (1) to (3)) and also when including time fixed effects. Once regional fixed effects are included, the coefficients turn positive and statistically significant.

Table 7 Moderation-analysis results in semi-log model: Disclosure of warm vs. basic rents.

	Full sample – both submarkets combined						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Var.:							
Ln(BasicRent) in €/m ² /month							
	OLS 1	OLS 2	OLS 3	FE 1	FE 2	FE 3	FE 4
Energy performance score (in 10 kWh/m ² /a)	0.0026 *** [0.0003]	0.0024 *** [0.0003]	-0.0023 *** [0.0002]	-0.0020 *** [0.0002]	-0.0018 *** [0.0002]	-0.00176 *** [0.0001]	-0.0017 *** [0.0001]
Basic_only = 1 (only basic rent given)	-0.0028 [0.0030]	-0.0026 [0.0030]	-0.0056* [0.0022]	-0.0049* [0.0022]	0.0028 [0.0021]	0.0107 *** [0.0016]	0.0104 *** [0.0013]
Energy performance score × basic_only	-0.0011 ** [0.0004]	-0.0013 *** [0.0004]	0.0012 *** [0.0002]	0.0012 *** [0.0002]	0.0008 ** [0.0002]	0.0002 [0.0002]	0.0002 [0.0001]
<i>Controls for ___included?</i>							
Heating type	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Apartment characteristics	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Neighborhood charact.	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Seasonal FE (quarterly-year)	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Regional FE (county)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Regional FE (district)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>
Regional FE (neighborhood)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>No</i>	<i>yes</i>
RMSE	0.26	0.25	0.18	0.18	0.17	0.14	0.12
Adj.-R²	0.436	0.439	0.727	0.732	0.758	0.820	0.868
Observations	3,903,473	3,903,473	3,903,473	3,903,473	3,903,473	3,903,473	3,903,473

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. RMSE in log(€/m²). All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

In the full model (column (7)), apartments with an average energy performance score are rented at a premium of roughly 1 %, when no information on warm rents are disclosed. In other words, the lack of knowledge of the tenants is already exploited in the form of higher basic rents. The

impact of a non-disclosure on the effect of the energy performance score, however, is rather small. If overall warm rents are provided in the online advertisement ($basic_only_i = 0$), monthly basic rents increase on average by 0.17 % if the energy performance score decreases by 10 kWh/m²a. For the non-disclosure, this effect decreases to 0.15 %; however, the moderating effect is statistically insignificant. This means that no statistically significant differences arise regarding the appreciation of energy efficiency.

A different picture emerges when looking at the submarket “warm”. Results for the second moderation analysis, including a dummy for only providing overall warm rents in comparison to the additional disclosure of exact heating costs, are reported in Table 8. The non-disclosure of additional information ($warm_only_i = 1$) leads to higher monthly basic rents, confirming the full sample results.

Table 8 Moderation-analysis results in semi-log model: Disclosure of exact heating costs vs. warm rents.

Submarket “warm”							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent Var.:							
Ln(BasicRent) in €/m ² /month	OLS 1	OLS 2	OLS 3	FE 1	FE 2	FE 3	FE 4
Energy performance score (in 10 kWh/m ² /a)	0.0002 [0.0003]	-0.0001 [0.0003]	-0.0037*** [0.0002]	-0.0034*** [0.0002]	-0.0029*** [0.0002]	-0.0023*** [0.0002]	-0.0024*** [0.0001]
Warm_only = 1 (only warm rent given)	0.0270 *** [0.0040]	0.0243 *** [0.0039]	-0.0007 [0.0029]	0.0005 [0.0030]	0.0253 *** [0.0023]	0.0350 *** [0.0014]	0.0284 *** [0.0010]
Energy performance score × warm_only	0.0054 *** [0.0004]	0.0057 *** [0.0004]	0.0030 *** [0.0003]	0.0029 *** [0.0003]	0.0023 *** [0.0003]	0.0011 *** [0.0002]	0.0012 *** [0.0001]
<i>Controls for ___included?</i>							
Heating type	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Apartment characteristics	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Neighborhood charact.	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Seasonal FE (quarterly-year)	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Regional FE (county)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>	<i>yes</i>
Regional FE (district)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>	<i>yes</i>
Regional FE (neighborhood)	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>no</i>	<i>yes</i>
RMSE	0.25	0.25	0.18	0.18	0.17	0.14	0.12
Adj.-R²	0.457	0.460	0.736	0.740	0.747	0.829	0.877
Observations	3,240,088	3,240,088	3,240,088	3,240,088	3,240,088	3,240,088	3,240,088

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. RMSE in log(€/m²). All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Effects of the energy performance score on basic rents are negative in all specifications (except the first OLS in column (1)) and becoming statistically significant as soon as all control variables are included in the model. The monthly basic rent of apartments for which full information on warm rents and exact heating costs are provided increases on average by 0.24 % for energy efficiency improvements of 10 kWh/m²a. This premium decreases to 0.12 %, when

only warm rents are provided. The lack of information for tenants thus leads to a reduction in the rent premium for property owners by 50 %.

Including the moderation effect in the nonlinear model additionally provides information on these differences in direct monetary terms. The remaining inefficiencies in the market for energy efficiency for apartments with fully disclosed information on warm rents and exact heating costs amount to an average of 0.005 €/m²/month. When exact heating costs are not provided in the advertisement, additional inefficiencies of 0.004 €/m²/month occur (Table 9).

Table 9 Moderation-analysis results in TCU model: Disclosure of exact heating costs vs. warm rents – Effect on warm rents.

Submarket “warm”	
Dependent Var.: WarmRent in €/m ² /month	Full submarket
Energy performance score (in 10 kWh/m ² a)	0.0053 *** [0.0003]
Warm_only = 1	-0.2070 *** [0.0050]
Energy performance score × warm_only	0.0039 *** [0.0004]
RMSE	1.68
Pseudo-R²	0.742
Observations	3,240,088

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics are included in the regression, including newly built apartments and all observations including the factor “unknown”.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Finally, I test both moderation effects across EPC types. Results are shown in Table A 5. In the submarket “warm” sample, using the disclosure of exact heating costs as moderator again, I find a decrease of the rent premium of about 0.1 percentage points in both subsamples when exact heating costs are not disclosed. However, the overall effect size is much larger in the subsample with demand-based certificates compared to the consumption-based certificate subsample – which is in line with results reported in Table 5.

Contrary to full sample results (cf. Table 7), statistically significant moderation effects of the disclosure of warm rents compared to only providing basic rents are found, with differences arising across subsamples. While providing information on warm rents is beneficial for property owners of flats with consumption-based certificates, it results in slight disadvantages for landlords or landladies of demand-based certified flats (as indicated by the negative coefficient

for the interaction term). Nonetheless, main effects of energy efficiency on basic rents are again twice the size in the demand-based certificate subsample.

5 Discussion

Since the estimated effect sizes are generally small in all regressions, Figure 4 provides the changes in yearly basic rents (cf. Table 6, submarket “warm”), yearly warm rents (cf. Table 4, “Full submarket”, Table 5) and resulting energy cost savings in euro per square meter of living area in the case of a full refurbishment, i.e., an improvement of about 100 kWh/m²a. Additionally, theoretical energy cost savings and changes in basic and warm rents are shown in case of efficient markets.

In the submarket “warm”, regression results show that basic rents increase on average by 1.99 €/m² per year after a full energy refurbishment has been carried out. If the dwelling has a demand-based EPC, the yearly basic rent increase amounts to 3.55 €/m²; if it has a consumption-based EPC, the surplus is only 0.58 €/m². The expected annual heating cost savings after such refurbishment are approximately 8.71 €/m², computed based on a heating energy price of 0.0871 €/kWh – the weighted average price for heating energy in the study period.

Given the regression results for basic rents, the expected heating cost savings should hence lead to a decrease in warm rents by 6.72 €/m² (5.16 €/m² for demand-based EPCs; 8.13 €/m² for consumption-based EPCs) – assuming that auxiliary costs remain unchanged. However, in sharp contrast, regression results show a decrease in warm rents by an average of only 0.92 €/m² per year. For demand-based EPCs, apartments even show an increase in warm rents of 0.14 €/m² per year; for consumption-based EPCs, yearly warm rents decrease by 2.88 €/m².

Taking it the other way round, if the 8.71 €/m² energy cost savings are offset against the 0.92 €/m² (consumption: 2.88 €/m²) lower warm rent, then around 7.79 €/m² (consumption: 5.83 €/m²) should remain as additional income for the property owner in the form of higher basic rents. However, this is obviously not the case, as the basic rent increase is a factor of four (consumption: five) lower. In the demand-based EPC subsample, this factor only amounts to about 2.5.

The regression results regarding the warm rent are contrary to those by Weber and Wolff (2018). They find that energy cost savings in rentals do not offset the additional costs that were charged after a renovation has taken place. Only in the demand-based EPC subsample, the estimated basic rent increase is greater than the empirically observed energy cost savings, resulting in a small increase in the warm rent. The remaining results are yet in line with findings

of Kholodilin et al. (2017) and Sieger and Weber (2023) – both studies also find that expected energy cost savings for the (future) occupant exceed the monetary benefit for the owner by a factor of four or three to seven, respectively.

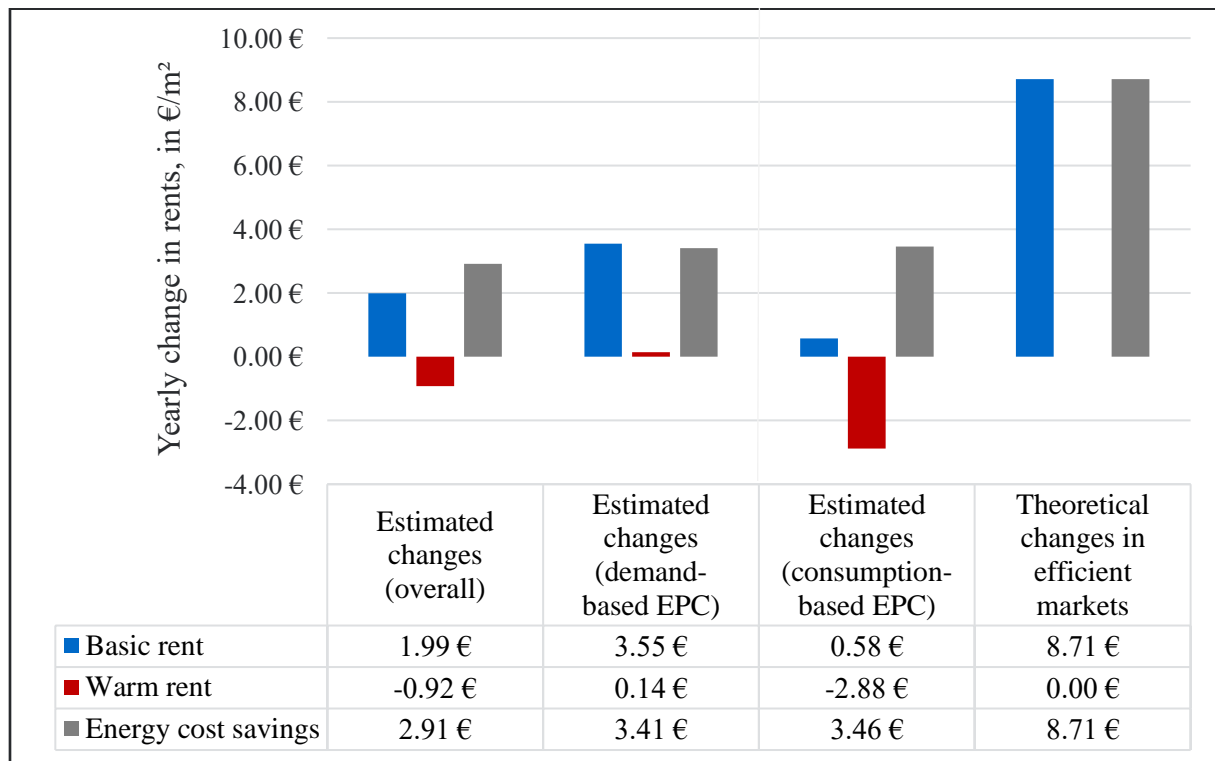


Figure 4 Theoretical and estimated change in yearly rents per m² living area for improvements in the energy performance score of 100 kWh/m²a.

Source: Own illustration based on estimation results shown Table 4, Table 5 and Table 6.

The results obtained in the present analysis yet indicate that actual energy cost savings are significantly lower than those theoretically calculated. This may be attributed to the so-called rebound effect (Greening et al., 2000)¹¹. Theoretically, basic rents should increase by the same amount as energy cost savings if the market is efficient (right-hand side in Figure 4). However, regression results only report energy cost savings of 2.91 €/m² per year (left-hand side in Figure 4), resulting from the increase in basic rents and decrease in warm rents.

This can be explained by tenants changing their heating and ventilation behavior to the extent that they heat more than before the refurbishment, for example, and thus save less energy than initially assumed. Similar results were found in Aydin et al. (2017) and Peñasco and Anadón (2023). A further explanation for parts of the observed gap between expected and observed energy cost savings could be that the calculated values are overly optimistic regarding the

¹¹ An alternative explanation is that the energy performance scores given in the EPC do not provide an exact measure of the heating energy use attributable to the building. This may notably be a consequence of individual user behavior having a substantial stochastic impact on the actual energy consumption which forms the basis of the consumption-based EPCs.

technical energy savings of the implemented measures (Sunikka-Blank and Galvin, 2012). This would obviously also lead to an overestimation of the potential energy cost savings.

Furthermore, large differences across EPC-type subsamples are found. One possible explanation, especially for the higher valuation of energy efficiency in the demand-based EPC subsample, may be that, compared with consumption certificates, market participants have a higher level of trust in the technically calculated values.

Finally, providing information on exact heating costs leads to a better valuation of energy efficiency in all samples. This is in line with results of prior studies that evaluated whether monetary values instead of energy performance measures in certificates leads to higher premia for more efficient homes (Carroll et al., 2020; Carroll et al., 2016; Myers et al., 2022; Pommeranz and Steininger, 2021).

6 Conclusion and policy implications

The decarbonization of the dwelling stock is high on the policy agenda of the German government in order to reduce GHG emissions and achieve the stated emission-reduction goals. However, low monetary incentives, especially in the rental market, are slowing down energy refurbishments. By estimating a modified hedonic pricing model and using offering data from Germany's largest real estate internet platform as well as micro-level neighborhood information, this study evaluated the (in)efficiencies in the valuation of energy efficiency in the German rental housing market. Taking advantage of the rich dataset with 3,903,473 observations from 2014 to 2021, a moderation analysis further revealed that the valuation of energy efficiency varies for different levels of provided information in the advertisement.

Overall, the market for dwelling energy efficiency is found to be inefficient with potential monetary benefits arising for tenants. Energy cost savings due to energy improvements usually exceed basic rent increases, resulting in lower overall warm rents. Nearly efficient markets were only found in subsamples with high-income neighborhoods. If the advertised apartments are certified by energy demand, overall warm rents are even found to increase when energy efficiency is improved.

Furthermore, including information on warm rents in the online advertisements does not lead to a higher valuation of energy efficiency in comparison to only providing basic rents. However, once information about exact heating costs is included, the premium for better energy efficiency standards increases by 50 %. These effects also vary across apartments with different types of energy performance certificates.

Two main policy implications can be derived from these results. First, a mandatory indication of heating costs in either energy performance certificates or online real estate advertisements could lead to a better valuation of energy efficiency, resulting in a higher willingness-to-pay from tenants for more efficient apartments and thus to higher rental income for property owners, that can be invested in energy retrofits.

Second, further research on the different (German) EPC types is needed to better understand the major differences between the samples and to identify their actual information content. This might help to get a more coherent picture of the interplay between technical improvements, behavioral changes and stochastic effects and to fully exploit the information potential of these certificates in future. On that basis, a transition towards a more standardized approach should be envisaged to develop more realistic energy ratings (Galvin, 2023a).

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Appendix

Table A 1 Overview of variables included in the regression model.

Variable	Description	Unit/Values
$WarmRent_{int}$	Monthly total warm rent of apartment i in neighborhood n at time t	€/m ²
$BasicRent_{int}$	Monthly basic rent of apartment i	€/m ²
eps_i	Energy performance score as indicated in the EPC	10 kWh/m ² a
<i>HEATING</i>	Factor variable, indicating the heating system of apartment i	CHP, ELECTRIC, SCC, DISTRICT, FLOOR, PELLET, NIGHT STORAGE, STOVE, OIL, GAS (Ref), SOLAR, PUMP, CENTRAL, unknown
<i>TYPE</i>	Factor variable, indicating the type of apartment i	ATTIC, RAISED GROUND FLOOR, FLAT (Ref), MAISONETTE, PENTHOUSE, SOUTERRAIN, WITH TERRACE, OTHER, unknown
<i>FACILITIES</i>	Factor variable, indicating the facilities of apartment i	SIMPLE, NORMAL (Ref), SOPHISTICATED, DELUXE, unknown
<i>CONDITION</i>	Factor variable, indicating the condition of apartment i	NEW, 1st OCC after reconstruction, LIKE NEW, RECONSTRUCTED, MODERNIZED, WELL KEPT (Ref), RENOVATED, NEEDS RENOVATION, BY ARRANGEMENT, unknown
<i>FLOORS_BUILD</i>	Factor variable, indicating the number of floors of the building in which apartment i is located	1 to 3 (Ref), 4 to 6, 7 to 10, more than 10, unknown
<i>ROOMS</i>	Factor variable, indicating the number of rooms of apartment i	1, 2 (Ref), 3, 4, 5 and more
<i>BALCONY</i>	Factor variable, indicating the appearance of a balcony in apartment i	yes, no (Ref), unknown
<i>GARDEN</i>	Factor variable, indicating the appearance of a garden in apartment i	yes, no (Ref), unknown
<i>KITCHEN</i>	Factor variable, indicating the inclusion of a kitchen in apartment i	yes, no (Ref), unknown
<i>CONSTRUCTED</i>	Factor variable, indicating the construction period of apartment i	5-year steps, starting at 1900; Ref. = constr. betw. 1961 and 1970
<i>LIVINGAREA</i>	Factor variable, indicating the living area of apartment i	10 m ² steps, starting at 20; Ref. = 60 to 70 m ²
<i>HOTWATER</i>	Factor variable, indicating whether the energy used for producing hot water is included in eps	yes, no (Ref), unknown
<i>MOD2010</i>	Dummy variable, indicating whether apartment i was renovated in 2010 or later	yes, no (Ref)
<i>PURCHPOWER</i>	Purchasing power per capita	€1,000 per capita
<i>POPULATION</i>	Population density	1,000 inhabitants per km ²
<i>UER</i>	Unemployment rate	%
<i>FOREIGN</i>	Share of households with foreign household head	%
τ_s	Regional fixed effects on state level	16 states (<i>Bundesländer</i>)
ν_d	Regional fixed effects on NUTS3 level	401 NUTS3 regions
ρ_n	Regional fixed effects on neighborhood level	55,733 neighborhoods
μ_t	Time fixed effects on quarterly-year level	27 Time periods from Q2/2014 to Q4/2021

Source: Own illustration.

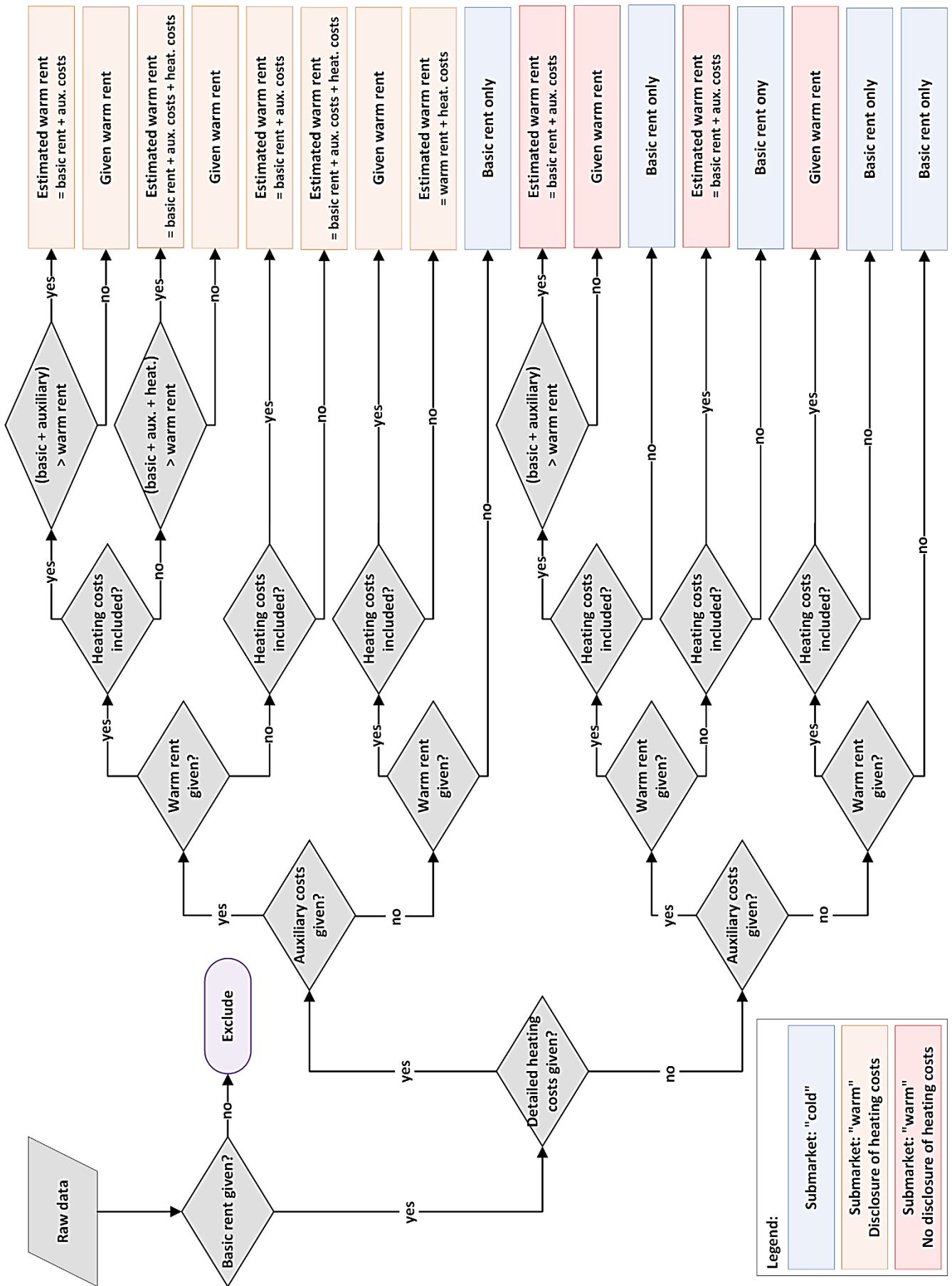
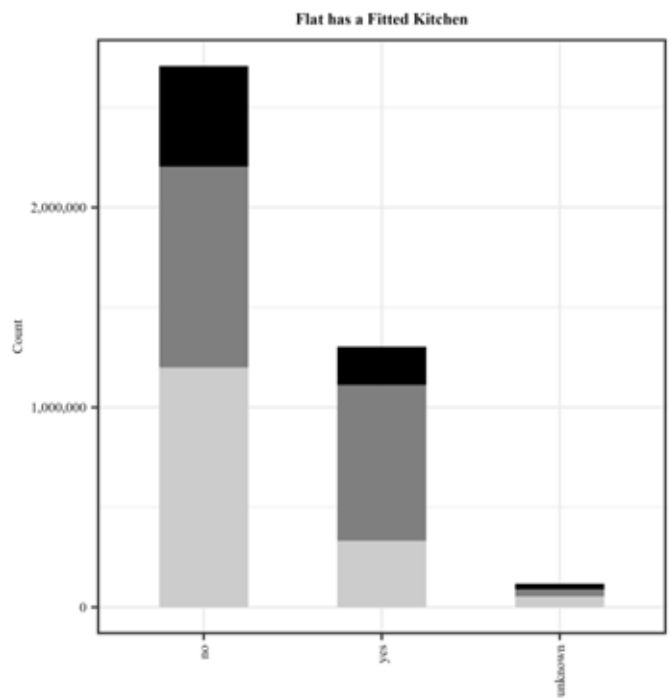
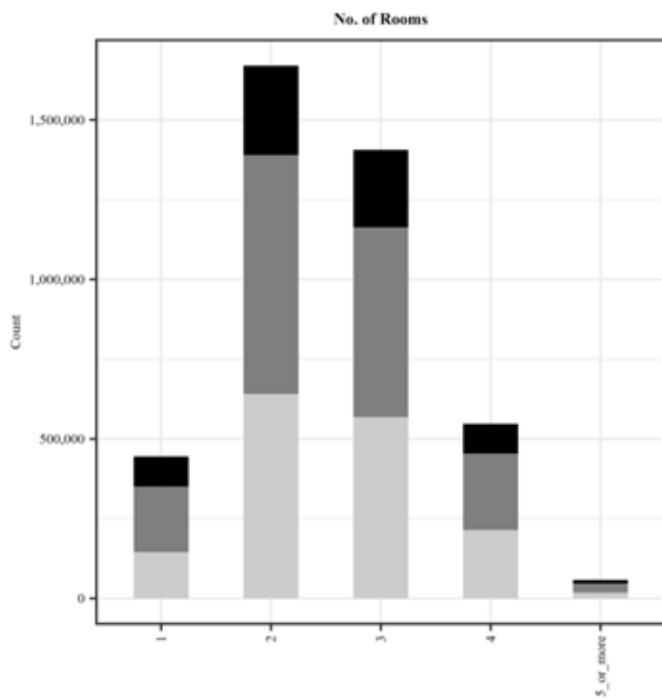
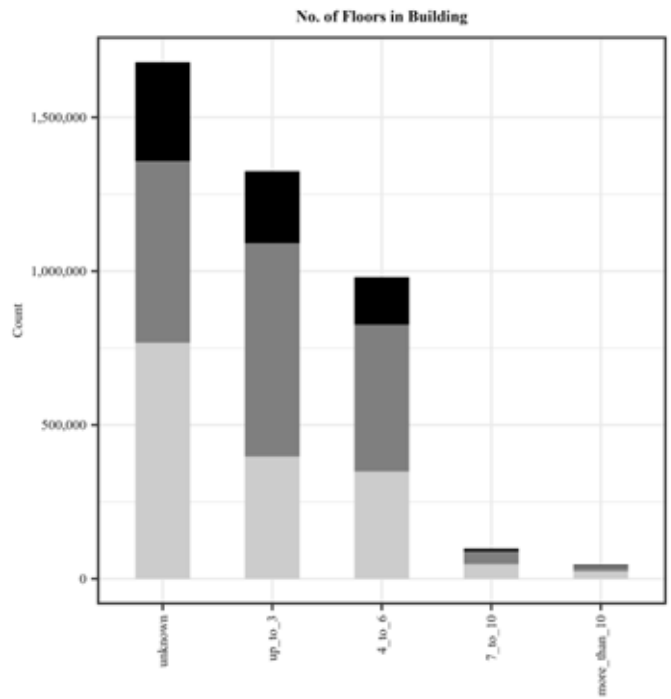
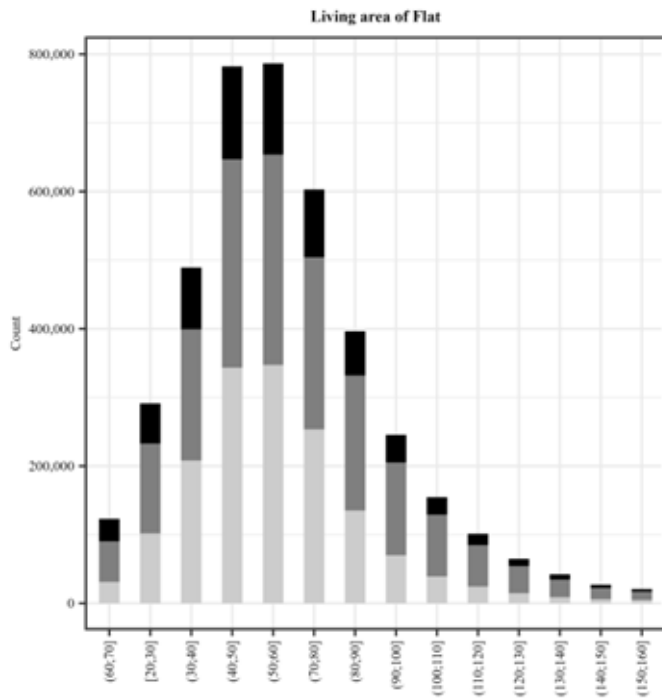


Figure A 1 Variable selection and classification of submarkets and subsamples.
 Source: Own illustration.



Submarket: Cold
 Submarket: Warm No disclosure of heat. costs
 Submarket: Warm Disclosure of heat. costs

Figure A 2 Distribution of different factor variables (1).
 Source: Own calculation and illustration based on RWI-GEO-RED.

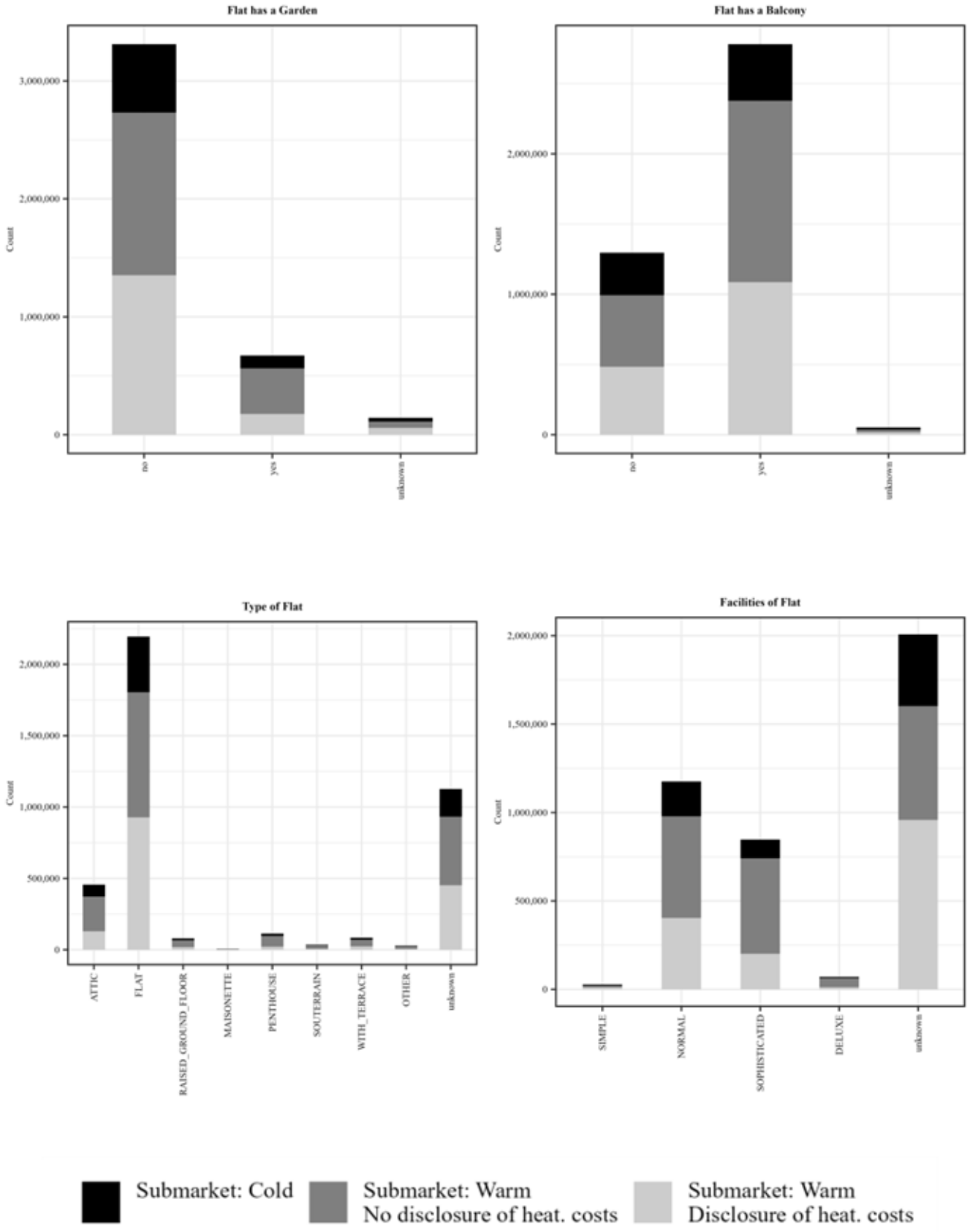


Figure A 3 Distribution of different factor variables (2).
 Source: Own calculation and illustration based on RWI-GEO-RED.

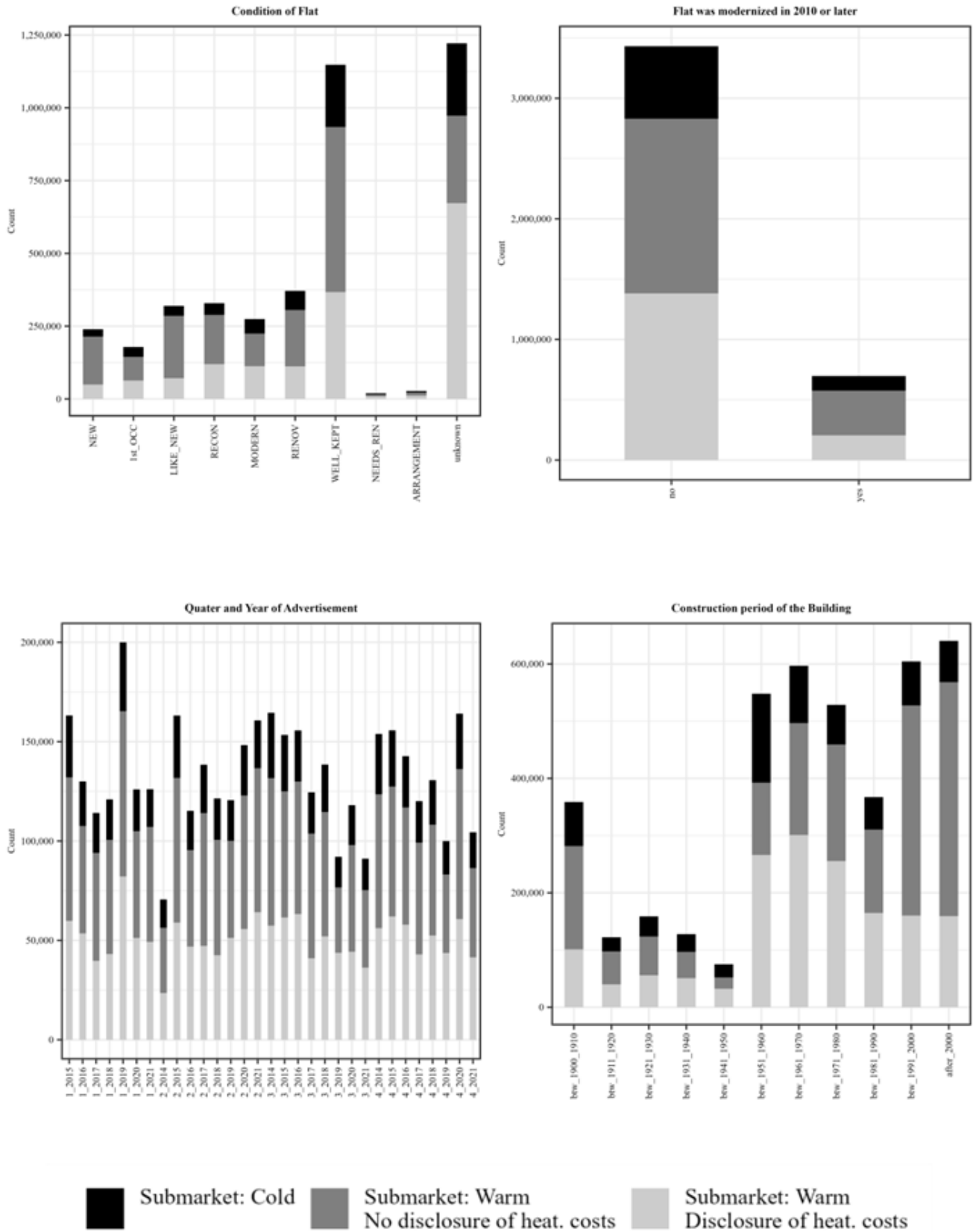


Figure A 4 Distribution of different factor variables (3).
 Source: Own calculation and illustration based on RWI-GEO-RED.

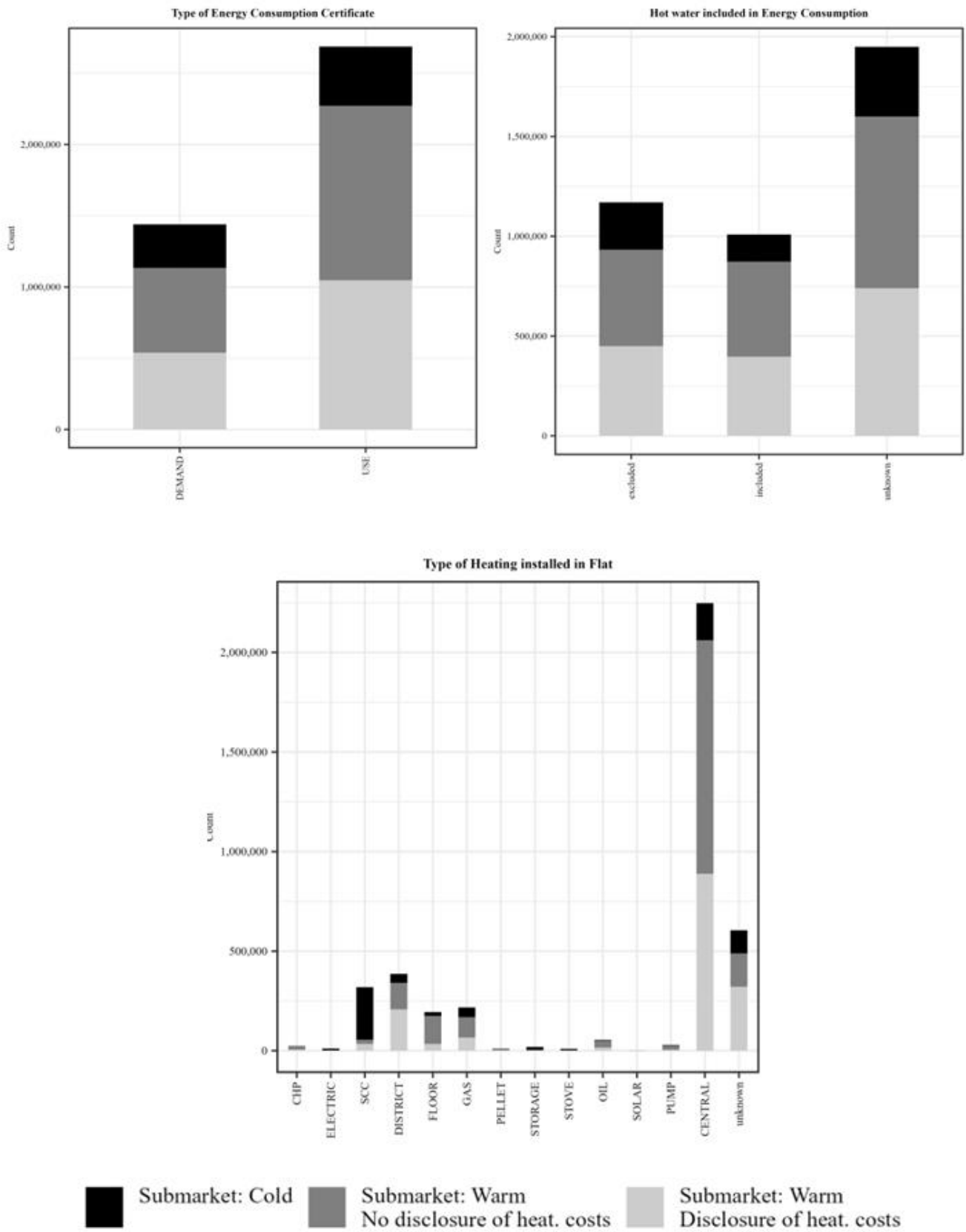


Figure A 5 Distribution of different factor variables (4).
 Source: Own calculation and illustration based on RWI-GEO-RED.

Table A 2 Main regression results in TCU model – newly built apartments excluded.

Submarket “warm” Newly built apartments excluded.				
Dependent Var.:			Subsample A: No disclosure of exact heating costs	Subsample B: Disclosure of exact heating costs
WarmRent in €/m ² /month	Full submarket			
Energy performance score (in 10 kWh/m ² a)	0.0077 *** [0.0002]		0.0066 *** [0.0003]	0.0059 *** [0.0003]
<i>Selected heating system, reference: gas heating</i>				
District heating	0.0372 *** [0.0005]		0.0386 *** [0.0007]	0.0300 *** [0.0007]
Oil heating	0.0076 *** [0.0008]		0.0033 ** [0.0010]	0.0145 *** [0.0014]
Floor heating	0.0555 *** [0.0006]		0.0563 *** [0.0007]	0.0604 *** [0.0011]
Central heating	0.0076 *** [0.0004]		0.0103 *** [0.0005]	0.0053 *** [0.0006]
Last renovated in 2010 or later	0.0090 *** [0.0002]		0.0091 *** [0.0003]	0.0068 *** [0.0004]
<i>Controls for ___included?</i>				
Apartment characteristics	<i>yes</i>		<i>yes</i>	<i>yes</i>
Neighborhood characteristics	<i>yes</i>		<i>yes</i>	<i>yes</i>
Season FE (quarterly-year)	<i>yes</i>		<i>yes</i>	<i>yes</i>
RMSE	1.65		1.72	1.53
Pseudo-R²	0.726		0.748	0.684
Observations	3,044,367		1,567,674	1,476,693

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Table A 3 Robustness checks in TCU model – unknown factors excluded from regression.

Submarket “warm”				
Factors = “unknown” excluded.				
Newly built apartments included.				
Dependent Var.:			Subsample A:	Subsample B:
WarmRent in €/m²/month	Full submarket		No disclosure of exact heating costs	Disclosure of exact heating costs
Energy performance score (in 10 kWh/m ² a)	0.0071 *** [0.0005]		0.0065 *** [0.0007]	0.0065 *** [0.0008]
RMSE	1.64		1.66	1.58
Pseudo-R²	0.724		0.729	0.717
Observations	620,189		393,330	226,859

Submarket “warm”				
Factors = “unknown” excluded.				
Newly built apartments excluded.				
Dependent Var.:			Subsample A:	Subsample B:
WarmRent in €/m²/month	Full submarket		No disclosure of exact heating costs	Disclosure of exact heating costs
Energy performance score (in 10 kWh/m ² a)	0.0083 *** [0.0005]		0.0083 *** [0.0007]	0.0071 *** [0.0008]
RMSE	1.63		1.65	1.57
Pseudo-R²	0.720		0.728	0.711
Observations	591,803		371,667	220,136

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the ‘rsquare’-function from the ‘modelr’-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Table A 4 Regression results in TCU model for different subsamples.

Panel A: Income levels			
Dependent Var.:			
WarmRent in €/m ² /month	1st tercile	2nd tercile	3rd tercile
Energy performance score (in 10 kWh/m ² a)	0.0048 *** [0.0003]	0.0110 *** [0.0004]	-0.0004 [0.0004]
RMSE	1.34	1.61	1.95
Pseudo-R²	0.580	0.630	0.714
Observations	1,080,055	1,080,011	1,080,022
Panel B: Basic rent levels			
Dependent Var.:			
WarmRent in €/m ² /month	1st tercile	2nd tercile	3rd tercile
Energy performance score (in 10 kWh/m ² a)	0.0169 *** [0.0002]	0.0142 *** [0.0002]	0.0126 *** [0.0005]
RMSE	0.72	0.87	1.95
Pseudo-R²	0.248	0.205	0.561
Observations	1,085,520	1,078,884	1,075,684
Panel C: Energy efficiency levels			
Dependent Var.:			
WarmRent in €/m ² /month	A+, A, B	C, D, E	F, G, H
Energy performance score (in 10 kWh/m ² a)	0.0352 *** [0.0018]	0.0270 *** [0.0005]	0.0127 *** [0.0005]
RMSE	1.91	1.59	1.59
Pseudo-R²	0.763	0.712	0.721
Observations	658,798	2,049,579	531,711
Panel D: Heating types			
Dependent Var.:			
WarmRent in €/m ² /month	Standard	Green	Dirty
Energy performance score (in 10 kWh/m ² a)	0.0058 *** [0.0003]	0.0310 *** [0.0008]	0.0152 *** [0.0010]
RMSE	1.71	1.69	1.54
Pseudo-R²	0.736	0.779	0.734
Observations	2,302,318	367,538	98,973
Panel E: Fuel type			
Dependent Var.:			
WarmRent in €/m ² /month	Gas	Oil	District Heating
Energy performance score (in 10 kWh/m ² a)	0.0108 *** [0.0006]	0.0212 *** [0.0014]	0.0044 *** [0.0010]
RMSE	1.78	1.73	1.82
Pseudo-R²	0.734	0.741	0.802
Observations	507,199	80,001	315,005

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. Pseudo-R² is estimated using the 'rsquare'-function from the 'modelr'-package in R (Version 4.1.2). RMSE in €/m². All apartment and neighborhood characteristics are included in the regression, including newly built apartments and all observations including the factor "unknown". Exception 1: Heating type information were excluded in Panel D. Standard-technology subsample includes Central, Floor, and Gas. Dirty-technology subsample includes Oil, Stove, SCC and Night storage. Green-technology subsample includes CHP, Solar, Pump, Pellet and District (cf. Hahn et al., 2018). Exception 2: Panel E only includes observations from 2019 to 2021 since the fuel type is only provided from 2019 onwards.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

Table A 5 Moderation-analysis results in semi-log model: EPC-type subsamples.

Dependent Var.:	Full sample – both submarkets combined		Submarket “warm”	
	Demand	Consumption	Demand	Consumption
Ln(BasicRent) in €/m ² /month (in 10 kWh/m ² a)	-0.0026 *** [0.0001]	-0.0012 *** [0.0001]	-0.0034 *** [0.0002]	-0.0017 *** [0.0001]
Basic_only = 1	0.0068 *** [0.0020]	0.0103 *** [0.0012]		
Energy performance score × basic_only	-0.0004 * [0.0002]	0.0006 *** [0.0002]		
Warm_only = 1			0.0362 *** [0.0016]	0.0265 *** [0.0010]
Energy performance score × warm_only			0.0009 *** [0.0002]	0.0010 *** [0.0002]
<i>Controls for ___included?</i>				
Heating type	yes	yes	yes	yes
Apartment characteristics	yes	yes	yes	yes
Neighborhood characteristics	yes	yes	yes	yes
Seasonal FE (quarterly-year)	yes	yes	yes	yes
Regional FE (county)	yes	yes	yes	yes
Regional FE (district)	yes	yes	yes	yes
Regional FE (neighborhood)	yes	yes	yes	yes
RMSE	0.12	0.12	0.12	0.12
Adj.-R²	0.880	0.863	0.891	0.870
Observations	1,339,230	2,564,243	1,062,126	2,177,962

Notes: Cluster-robust standard errors in brackets. *** p < 0.001, ** p < 0.01, * p < 0.05. RMSE in log(€/m²). All apartment and neighborhood characteristics included in the regression are listed in Table A1.

Source: Own calculations based on RWI-GEO-RED and RWI-GEO-GRID.

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