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Title: Tearing down the information barrier: the price impacts of energy efficiency ratings for buildings in the German rental market

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Tearing down the information barrier: the price impacts of energy efficiency ratings for buildings in the German rental market

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ABSTRACT

Improving the energy efficiency levels of the housing stock is of particular concern in the private rental market where capital costs and utility cost savings are not shared in equal measure by landlords and tenants. This problem is particularly pronounced in the German housing market with its predominance of rented accommodation over owner occupancy. The present study is the largest to date to investigate the effect of energy efficiency ratings on rental values. Using a semiparametric hedonic model and an empirical sample of nearly 760 thousand observations across 403 local markets in Germany with full hedonic characteristics, we find evidence that energy-efficient rental units are rented at a premium. However, this effect is not confirmed for the largest metropolitan housing markets. In a second step, a survival hazard model is estimated to study the impact of the energy ratings on time-on-market. It is found that energy inefficient dwelling have longer marketing periods and are hence less liquid than their more energy efficient counterparts.

1. Introduction

The building sector is crucial for climate change mitigation goals asit accounts for a large fraction of CO_2 emissions in developed economies. One of the principal policies implemented in the European Union is the 2010 Energy Performance of Buildings Directive along with the 2012 Energy Efficiency Directive which stipulate the use of Energy Performance Certificates (EPC) for revealing the expected energy consumption of a building to prospective buyers and tenants. While EPCs throughout the European Union are part of a broader strategy to increase the mandatory energy efficiency requirements for buildings at both the European and national levels, they are primarily designed to increase the environmental awareness of market participants and enhance the transparency of property transactions with regard to energy consumption [1,2]. The legislative implementation of EPCs has not been homogenous across EU members and compliance rates vary across countries and regions.

EPCs have received rather mixed reviews in the policy assessment literature. While it is generally acknowledged that they fill an important gap in the provision of energy efficiency information, empirical studies indicate that their effectiveness is limited, because they are not made available or are being ignored or their implications for household finances are not understood by buyers. These limitations are confirmed empirically by a number of studies, for example by Murphy [3] who found EPCs to have only a weak influence pre and post-purchase in the Netherlands and Amecke [4] who arrived at the same conclusion in his study of Germany, citing limitations in design, legal status and overall low importance of energy efficiency as the main reasons.

Despite these limitations, it appears that the EPC was at least partially successful in mitigating information asymmetry in the marketplace and that information provision has improved over time. Lack of information about energy consumption patterns and energy efficiency measures has been identified previously as a major barrier to energy efficiency in empirical studies on Germany [5]. Additionally, the information conveyed by the disclosure of dwelling energy efficiency has arguably also played a supportive role in the 'greening' of the existing housing stock via energy efficiency retrofits that many government agencies in the European Union have sought to promote. The EPC provides a tool for estimating baseline and post-retrofit energy efficiency levels but may also have contributed in more indirect ways by strengthening public awareness of energy efficiency in buildings.

Making information provision compulsory in real estate markets creates – from a microeconomic point of view – a new information set for landlords and tenants which in turn affects rent formation. While EPCs are generally compulsory for landlords when leasing and selling residential properties, they are primarily intended for buyers and

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tenants, which leads to diverging information sets and rental expectations. The latter arises whenever the expected marginal willingness to pay for energy efficiency by the tenant differs from the expected marginal rent premium asked by the landlord. And since EPCs aim at anchoring the energy efficiency awareness in the decision making process of both parties, the benefits might be reflected in a stronger willingness to pay for energy efficient assets. In other words, EPCs might lead to a simultaneous increase in the marginal utility function of both parties. In the longer run, this may also entail lower equilibrium rents for assets with poor environmental performance and thus to elevated refurbishment levels in the residential stock.

This paper explores the mechanism by which energy efficiency is capitalised into residential rents using market evidence from Germany. It estimates both the willingness to pay for energy efficiency and the liquidity of energy efficient assets relative to their less efficient counterparts. By interrogating one of the largest real estate databases in Germany supplemented with information on EPCs (*Energieausweise*), we empirically estimate the energy premium as well as the liquidity premium. Finally, we construct residential property rental indices to study the impact of EPCs when creating value in institutional portfolios.

This paper is organised as follows. We first position the current study in the existing literature, provide some background on the EPC in the German context and review the split incentive problem as a major obstacle towards achieving higher energy efficiency of the rental stock. The following sections then describe our research approach and econometric models, followed by a description of the data, presentation of results and finally a discussion of the implications with a view towards deriving policy recommendations.

2. Previous research

Recent empirical research has provided evidence for the existence of an energy efficiency premium across European residential markets. First evidence on green market effects was found in the Netherlands by Brounen and Kok [6] and Kok and Jennen [7] with subsequent empirical studies carried out in several European countries: Germany [8,9], England [10], Wales [11,12], Finland [11,12], Ireland [13], Portugal [14], Spain [15], among others. Additionally [11,12],) find sale prices premiums for high EPC-rated buy-to-let properties with premiums of 18.5% and 4% for A/B and C-rated properties respectively (relative to D-rated properties). However, no significant discount for F/G-rated buy-to let properties was found. The authors attribute this to the split incentive problem, i.e. landlords base their willingness to invest in energy efficiency on achievable rental values which are net of utility costs as these are typically covered by tenants.

The notion that energy efficiency may be rewarded by real estate markets has not only caused landlords and tenants to pay more attention to this dimension but has also shaped the emergence of green investment and portfolio strategies by institutional investors (e.g. Deutsche Bank, MSCI or SEB). However, while the first official evaluation report by the European Commission on the impact of EPCs in real estate markets confirms a general statistical green energy premium effect on real estate prices and rents [16], two caveats seem in order. Firstly, the evaluation report focusses primarily on countries with highly owner-occupied residential markets such as Belgium, Ireland and the United Kingdom. Secondly, it highlights the large variations in the green premium effect between and within the observed countries, mainly ascribed to macroeconomic and legislative differences as well as local market conditions and/or regional factors.

Hence, the green premium in the German residential market might differ significantly from other European countries due to the low ownership rate and the strong polycentric distribution of urban centres and consequently the importance of regional factors. There are two main studies of the impact of EPCs on the German residential market: While [8], find a rent premium of ca. 1.7% based on 2600 observations, [9], focus on the capitalisation effects in Berlin's residential market for 150,000 observations and find evidence that energy efficiency is capitalised in apartment prices although they also report that the value of energy cost savings is not matched by the implicit willingness to pay of tenants.

Moreover, energy efficient dwellings may also be more liquid and have shorter marketing periods. Liquidity in the context of energy efficiency in the residential market has hitherto remained largely unexplored in the literature, a gap that the present study seeks to fill. There are a number of existing studies that have explored time on market (TOM) empirically and conceptually. Most of these studies report a positive relationship between list price and TOM [17,18] with a divergent finding being reported by Kang and Gardner [19] who find a negative correlation. Moving beyond the bid-ask spread argument, Haurin [20] uses search theory to demonstrate that TOM is longer where a large range of offers exist and shorter where the bids of prospective buyers are of a similar order of magnitude. Non-standard properties and/or sellers are more likely to elicit a larger range of bids as the fair property value may be harder to determine and sellers may provide information differently to the marketplace and through different channels [21–23]. In the context of this study, we expect that energy efficient dwellings exhibit smaller variation than their non-efficient counterparts as they have to conform to certain norms to achieve a high rating. It may also be expected that the owners of these dwellings are generally more up-to-date with building requirements and standards and may hence also take a more professional approach in marketing their properties than the owners of non-efficient buildings.

3. Regulatory characteristics of EPCs in Germany

The regulations pertaining to EPCs were initially laid out in the German Energy Savings Act (EnEV) which stipulates that all residential buildings require an EPC whenever a sales or rental transaction occurs. The seller or landlord is obliged to provide a copy of the EPC to the buyer or tenant upon request. An important characteristic of the German EPC compared to how the EU directive was implemented in other member states is that it combines the inspection-based intrinsic evaluation system with a consumption-based system. Most other EU countries have opted for only one of these two systems. The energy demand certificate (Bedarfsausweis) is based on an accredited expert's opinion of the energy efficiency of a building after an inspection of roof and wall insulation, heating and electricity systems, etc. By contrast, the energy usage certificate (Verbrauchsausweis) is based on actual meter readings and utility bills over the past three years. The energy demand certificate is considerably costlier (around €500) than the usage certificate and is legally required unless the building is (a) a multi-apartment building with more than four units or (b) built to more recent (post-1977) standards. The EPC measures or estimates the energy required for heating and distinguishes between primary energy demand and final energy demand. This distinction is relevant as some heating systems, for example electric heating, do not generate emissions on-site when the property is heated but still have an unfavourable emissions profile when emissions in energy generation in coal power plants etc are taken into account.

While this dual approach to the EPC has its advantages in terms of flexibility towards particular types of dwellings and ownership constellations, it also has its drawbacks, notably in the comparability of ratings across dwellings and providing the consumer with clear and comprehensible information. The use of the consumption-based usage certificate is also limited by the fact that consumption is strongly dependent on the individual behaviour of occupants which may or may not be indicative of the expected bills of the prospective tenants or owners. Hence, future tenants may discount the information value of a consumption-based EPC as it may have low predictive power for the utility bills to be expected by these new tenants. Likewise, the intrinsic energy demand EPC may be discounted as it is not derived from actual consumption.

4. The split incentive problem

Unlike the owner-occupied segment, the private rental market is subject to the split incentive problem. This problem occurs when costs and benefits of an investments accrue to different parties without any mechanism of redistributing costs and benefits in a fair manner. This is the case in rented residential buildings where landlords are typically responsible for maintenance and tenants pay for electricity and heating bills directly. Any investment in the energy efficiency of a building, for example via a green retrofit, would thus mainly benefit the tenant via lower utility bills while the landlord faces the burden of the capital investment. There are various mechanisms that may alleviate this split incentive problem, notably green leases which include a cost-benefit sharing mechanism but these are not widespread and require specialised expertise. The most important aspects of a green lease are improved (sub)metering and measurement of a tenant's energy consumption as well as a clause that allows landlords to pass a part of the costs of energy upgrades to the tenant. In the absence of an established mechanism, higher market rents for more energy-efficient buildings are the only possibility for landlords to recoup some of their investments. This adds practical relevance to the present study which aims to test the existence of such a market-based recoupment channel. In the German context, it is important to note that regulations allow a landlord to charge up to 11% p.a. in higher rents following a refurbishment. However, rents are generally capped at 20% above the average market rent. This regulation is a serious impediment for landlords of properties with above-average rents as they are prohibited by law to recoup these investments from their tenants.

5. Research approach

Our identification strategy for the capitalisation of energy efficiency into rents is twofold: firstly, we estimate the elasticity of asking prices with respect to energy consumption and/or EPC-categories in order to examine whether higher energy consumption has a significant (negative) effect on prices. The functional form is a log-log equation with (R) representing the response variable of asking rents in € per month (p.m.) and a vector of exogenous hedonic factors (X), including both energy consumption and EPC bands. Our dataset consists of pooled cross-sectional observations of residential units (i) observed at different times (t), NUTS3-markets (j) and also includes socioeconomic variables (Z) in j. The NUTS (Nomenclature of Territorial Units for Statistics) has a number of hierarchical spatial tiers whereby NUTS3 regions cover small regions similar to counties or administrative districts. We estimate our regression following the approach of Rigby and Stasinopoulos [24] as a Generalized Additive Model for Location, Scale and Shape (GAMLSS) as follows:

$$R_{i,j,t} = \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}_j\alpha_j + \boldsymbol{\mu}_t\alpha_t + u_{i,j,t} \quad (1)$$

where $\boldsymbol{\mu}_j$ and $\boldsymbol{\mu}_t$ form a matrix of NUTS3-regional-dummies and quarterly dummies respectively. The GAMLSS corresponds to a regression method in which all the parameters of observed distribution for the response are modelled as additive (non-linear) functions of the explanatory variables. The four moments of the response – mean, variance, skewness and kurtosis – vary depending on the observed variable and consequently on the underlying explanatory variables. Based on the research results of [25–28,47], GAMLSS is a suitable regression model for real estate purposes, especially when the underlying variables are skewed and the sample is not centred around the estimators. The GAMLSS approach is a robust estimator whenever the expected conditional variance of the errors is not expected to be homoscedastically distributed. Eq. (1) controls for fixed effects across NUTS-3-markets, fixed quarterly time effects and socioeconomic variables to control together for unobserved market-specific and household heterogeneity.

Finally, we focus on the construction of a hedonic price index for the German housing market that accounts for differences in energy efficiency. In this step, we test if portfolios including energy efficient dwellings diverge significantly from those made up of inefficient dwellings. In line with the "Handbook on Residential Property Prices" of Eurostat [29], we calculate a time dummy hedonic model without imputation and build an interaction term between the vector of quarterly dummies and a binary variable ($\boldsymbol{EPC_{i,j,t}}$) taking the value of 1 for observations with energy consumption above a specific threshold. In order to show the sensitivity of energy efficient portfolios we define two different cut-off points: the more stringent portfolio is made up of properties up to 125 kW h per square meter and year (kWh/m^2/p.a.) of primary energy consumption and the second portfolio includes a broader set up to 200 kW h/m^2/p.a.:

$$R_{i,j,t} = \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}_j\alpha_j + \boldsymbol{EPC_{i,j,t}}\phi + [\boldsymbol{EPC_{i,j,t}} * \boldsymbol{\mu}_t]\theta_t + u_{i,j,t} \quad (2)$$

After applying the antilog of the coefficients of $\hat{\phi}$ and $\hat{\theta}_t$ and rebasing the values to 100 in 2013-Q1, we show the aggregated market development of low and high energy consuming dwellings over time. The index for low energy consuming dwellings is built as $e^{\hat{\theta}_t}|EPC_{i,j,t} = 0$, whereas for high energy consuming it is $e^{(\hat{\phi}+\hat{\theta}_t)}|EPC_{i,j,t} = 1$.

Next, we test for the existence of a green liquidity premium as reflected in potentially shorter marketing periods of rental units with superior energy efficiency. To do so, we require a regression model that captures the factors affecting user demand for dwellings. However, since these factors are difficult to observe directly, we proxy liquidity with the time a dwelling is available on the market until it is rented out to a new tenant. Survival estimation methods have rarely been employed to the energy efficiency of buildings, perhaps due to restricted access to high-frequency market data in previous studies. They have, however, been used in a number of studies in various other research fields [30–33]. Since a survival model captures primarily the factors affecting the decision process when renting out a property, it can be expanded to include exogenous factors such as energy consumption or energy categories in order to estimate whether the time-on-market for low-energy consuming dwellings is higher than their counterparts. Simply put, we estimate the elasticity (also known as the odds) of a dwelling's time-on-market as a function of its energy consumption and EPC rating.

The time period (T) during which a dwelling is offered on the market, corresponds to a continuous positive response variable and is interpreted as the duration of an event (offer), in this case the time in weeks, prior to the occurrence of an event (t), e.g. the letting agreement. Two functions are relevant for estimating survival models: the survival function (S) and the hazard rate function (h). While the former estimates the probability of each observation of surviving the event in dependence of the time elapsed, the latter estimates the rate of occurrence per unit of time of an event, formally expressed as:

$$S(t) = P(T > t) = 1 - \int_t^\infty f(x)dx \quad (3)$$

$$h(t) = \frac{P(t < T \leq t + \Delta t | T > t)}{\Delta t} \quad (4)$$

The survival function gives the probability that a dwelling remains on the market until a certain time t, whereas the hazard specifies the rate of failure at $T = t$ given that the dwelling survived up to time t. Since the numerator in Eq. (4) corresponds to a conditional probability and the denominator is elapsed time Δt, the hazard function gives the probability or rate of "mortality" per units of time. A typical outcome in survival analyses is that a large proportion of dwellings do not change their survival event status, either because they remain available on the market or the landlord does not change the status in the database. In this case, the continuous response variable is said to be right-censored. To resolve this problem, proportional Cox hazard models do account for censoring in the response variable as they transform the response into a count variable per unit of time to estimate the effect of the covariates in

Table 1
Descriptive statistics.

Variable		Unit	Source	Descriptive Statistics						Pearson correlation				
				Mean	Sd	Q5%	Q30%	Q70%	Q90%	ii	iii	iv	v	vi
Log asking rent	i	Log €/p.m.	empirica	6.09	0.48	5.39	5.82	6.31	6.91					
Time on market	ii	Weeks	empirica	9.25	15.86	0.20	1.80	8.20	35.60	−11%				
Energy consumption	iii	kWh/m²/p.a.	empirica	128.27	55.52	65.00	101.40	145.00	209.00	−1%	−2%			
Living area	iv	m²	empirica	68.38	26.14	33.45	55.00	76.31	115.00	75%	4%	−3%		
Age	v	Years relative to 2017	empirica	52.72	30.68	16.00	33.00	61.00	117.00	−10%	6%	18%	−4%	
Number of rooms	vi	Number	empirica	2.56	0.93	1.00	2.00	3.00	4.00	54%	4%	−1%	78%	−1%
With Bathtub	vii	Binary 1 = yes	empirica	0.55	0.50	0.00	0.00	1.00	1.00	14%	7%	−4%	17%	−2%
With built-in kitchen	viii	Binary 1 = yes	empirica	0.36	0.48	0.00	0.00	1.00	1.00	31%	−9%	0%	11%	−10%
With parking lot	ix	Binary 1 = yes	Empirica	0.43	0.50	0.00	0.00	1.00	1.00	25%	1%	−9%	22%	−36%
With terrace	x	Binary 1 = yes	Empirica	0.12	0.33	0.00	0.00	0.00	1.00	19%	−1%	−3%	17%	−15%
With balcony	xi	Binary 1 = yes	Empirica	0.59	0.49	0.00	0.00	1.00	1.00	17%	−1%	−7%	14%	−21%
With elevator	xii	Binary 1 = yes	Empirica	0.21	0.41	0.00	0.00	0.00	1.00	13%	0%	−10%	3%	−19%
As good as new	xiii	Binary 1 = yes	Empirica	0.06	0.23	0.00	0.00	0.00	1.00	16%	3%	−3%	7%	1%
Refurbished	xiv	Binary 1 = yes	Empirica	0.19	0.43	0.00	0.00	0.00	1.00	7%	3%	4%	3%	7%
Longitude	xv	Gaussian coordinates	Empirica	10.03	2.40	6.75	8.28	11.85	13.69	−10%	11%	−18%	−9%	16%
Latitude	xvi	Gaussian coordinates	Empirica	51.32	1.54	48.27	50.85	52.08	53.80	−19%	3%	3%	−10%	13%
Distance to ZIP Centroid	xvii	Km.	Eurostat, GIS via R	1.24	1.03	0.22	0.65	1.44	3.11	−16%	7%	−3%	0%	−12%
Distance to NUTS3 Centroid	xviii	Km.	Eurostat, GIS via R	7.36	5.57	1.23	3.80	9.01	17.63	−9%	4%	−3%	2%	−16%
Log purchasing power	xix	€/household/p.a.	GfK	10.62	0.20	10.33	10.48	10.74	10.96	39%	−15%	9%	21%	−33%
Log number of households	xx	Number	GfK	9.20	0.53	8.16	9.08	9.48	9.87	−1%	−4%	−1%	−9%	9%

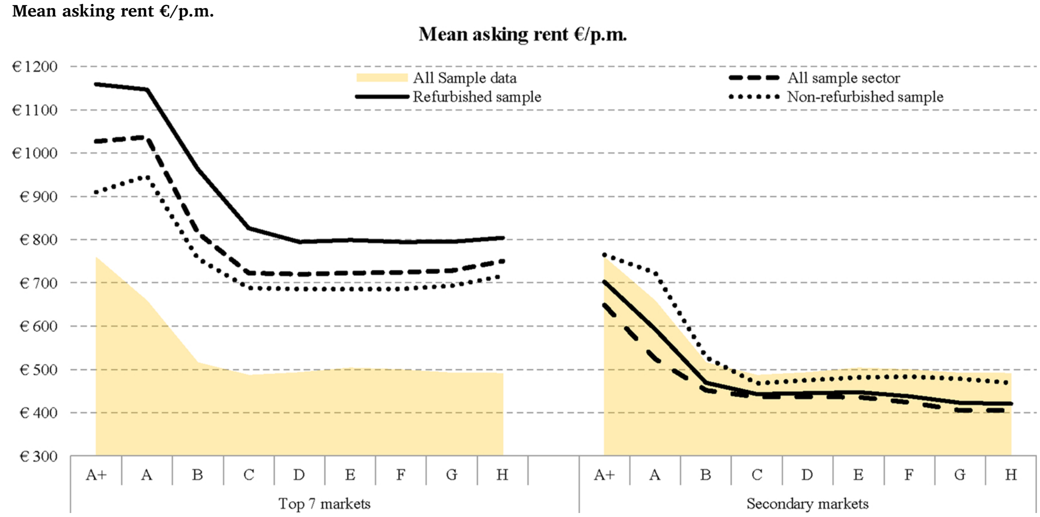
Variable	Pearson correlation													
	vii	viii	ix	x	xi	xii	xiii	xiv	xv	xvi	xvii	xviii	xix	xx
Log asking rent														
Time on market														
Energy consumption														
Living area														
Age														
Number of rooms														
With Bathtub	15%													
With built-in kitchen	−2%	5%												
With parking lot	11%	9%	20%											
With terrace	8%	3%	9%	16%										
With balcony	14%	12%	2%	10%	−12%									
With elevator	−7%	1%	7%	8%	1%	13%								
As good as new	4%	0%	0%	2%	4%	1%	6%							
Refurbished	1%	3%	4%	3%	0%	−1%	−1%	5%						
Longitude	−9%	9%	3%	−6%	−2%	−2%	7%	3%	−1%					
Latitude	−4%	0%	−3%	−22%	−5%	−2%	−4%	−1%	−5%	12%				
Distance to ZIP Centroid	5%	0%	−5%	11%	3%	−1%	−11%	−4%	−2%	2%	2%			
Distance to NUTS3 Centroid	5%	1%	2%	12%	4%	0%	−9%	−3%	−2%	17%	14%	32%		
Log purchasing power	11%	0%	22%	32%	14%	7%	−3%	0%	2%	−41%	−38%	13%	15%	
Log number of households	−6%	0%	−7%	−13%	−6%	3%	8%	0%	−1%	−4%	11%	−7%	−18%	−21%

Notes: Sample includes 1,029,202 observations of internet offers of rental flats in Germany from 2013-Q1 until 2017-Q4 across 403 NUTS3 regions. NUTS3 regions cover small regions similar to counties or administrative districts.

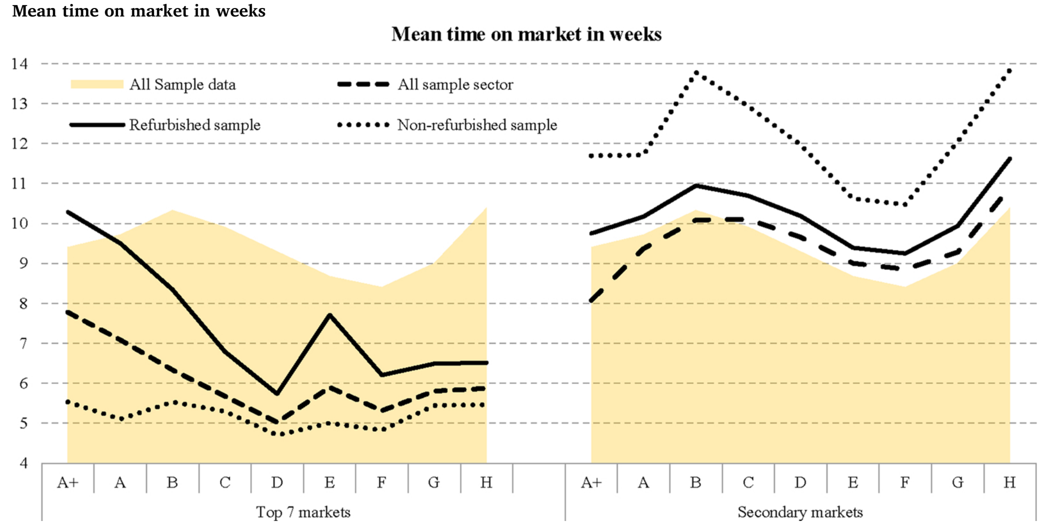
Table 2
Description of sample and metrics of the responses by energy categories.

		N	as of			A+	A	B	C	D	E	F	G	H
All Sample		1.029.202	100%			0.4%	1.2%	8.1%	19.3%	29.0%	21.9%	13.8%	4.8%	1.6%
Top 7	All sample	187.478		18%		0.4%	1.0%	6.0%	16.5%	27.4%	24.6%	16.3%	5.9%	1.9%
markets	Refurbished	59.492			32%	0.6%	1.4%	5.4%	13.1%	27.0%	25.7%	18.1%	6.4%	2.3%
	Non-refurbished	127.986			68%	0.3%	0.8%	6.3%	18.1%	27.6%	24.2%	15.5%	5.7%	1.7%
Secondary	All sample	841.724		82%		0.4%	1.2%	8.6%	19.9%	29.3%	21.3%	13.3%	4.5%	1.5%
markets	Refurbished	196.040			23%	0.8%	1.8%	8.6%	17.7%	29.0%	22.0%	13.9%	4.6%	1.6%
	Non-refurbished	645.684			77%	0.3%	1.1%	8.6%	20.5%	29.4%	21.1%	13.1%	4.5%	1.5%

Mean asking rent €/p.m.



Mean time on market in weeks



Notes: Sample includes 1,029,202 observations of internet offers of rental flats in Germany from 2013-Q1 until 2017-Q4 across 403 NUTS3 regions. NUTS3 regions cover small regions similar to counties or administrative districts.

a multiplicative way. In other words, the proportional Cox-hazard model decomposes the time of an event in units of time incorporating censoring into the count regression. Since the response variable is expressed as letting time T, survival models estimate a conditional survival probability for an event for each observation. Therefore, the interpretation of a survival regression, as a proportional hazard model is expressed as the probability of changing the survival status [40].

Endogeneity and the use of instrumental variables methods are a thoroughly discussed topic in the literature on hedonic and survival equations. As proposed by Benefield et al. [34], the estimation of both the rental and time-on-market equations would lead primarily to inefficient estimators whenever they are used as endogenous and exogenous simultaneously. The two stage least square (2SLS) approach has been therefore recommended to avoid endogeneity problems and provide efficient estimates. However, the data generating process (DGP) of both variables in the hedonic and survival equation model needs to be inspected before the model can be specified and estimated. Endogeneity arises when a covariate is correlated with the error term or is used as both an exogenous and an endogenous variable. That is, when rents and time-on-market are simultaneously used on both the left hand and right hand side of the equations, an endogeneity problem is highly likely. However, in this paper the DGP of rents R and time-on-market Δt is different. Landlords willing to let assets set an initial asking rent R_0 at time t_0 and wait Δt in order to either hand over the asset to the tenant or reconsider the rent level to $\dot{R} > R$ or $\widetilde{R} < R$ and then wait for a letting agreement. During the first period Δt, the DGP of R_0 is not determined

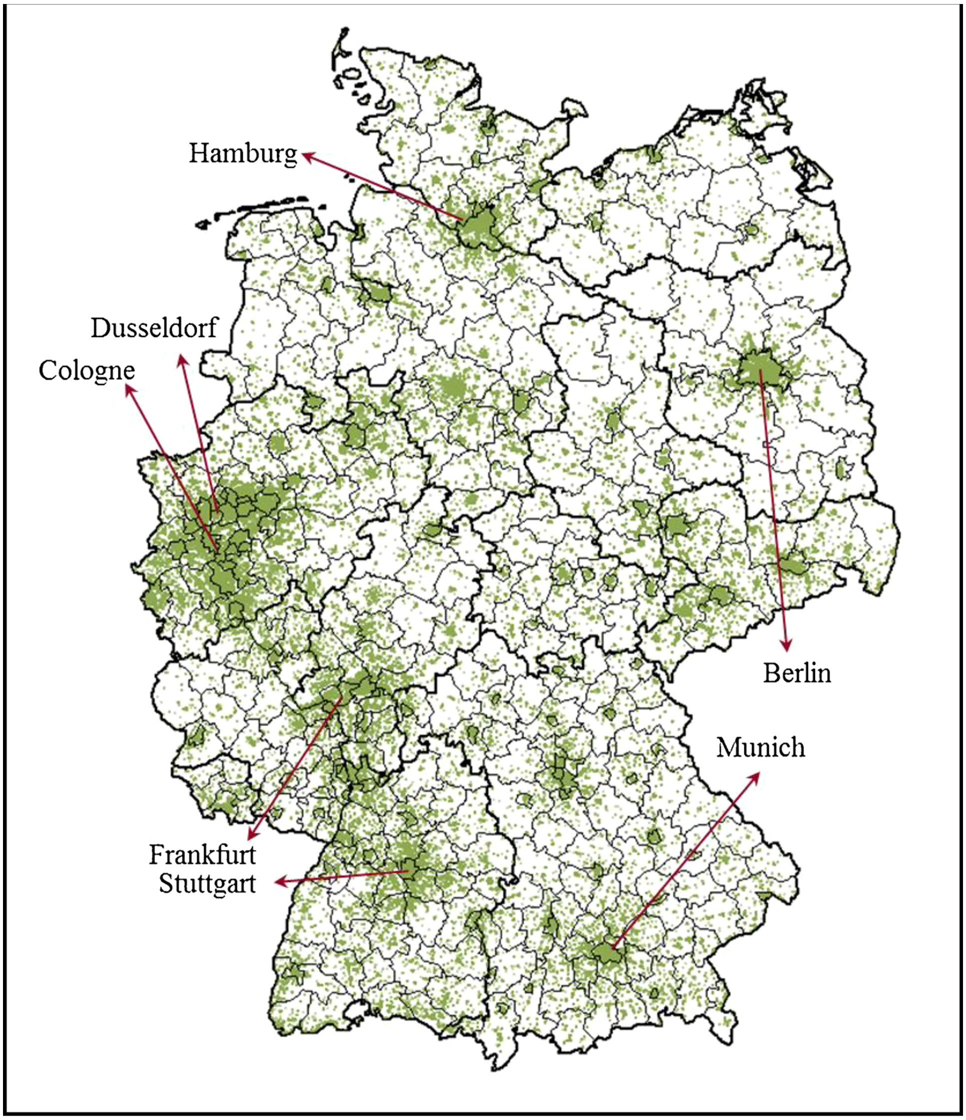


Fig. 1. Spatial description of sample across German NUTS3 areas.
Notes: Sample includes 1,029,202 observations of internet offers of rental flats in Germany from 2013-Q1 until 2017-Q4 across 403 NUTS3 regions. Dots represent the density of observations.

by Δt as landlords are not aware of Δt in achieving the asking rent R_0. Therefore, the variable time-on-market is not included in the hedonic equation as it is ex-post generated by R_0 and the market conditions. In contrast, the DGP of Δt is indeed influenced by the initial R_0, which is why the vector of asking rents is used as a covariate in the survival regression. Since the data base used here captures merely $\Delta t|R_0$ rather than $\dot{R}$ and $\widetilde{R}$, the use of 2SLS is not strictly required.

Based upon this information, we parameterise the equation of our parametric proportional hazard model as follows:

$$h_{i,j,t}(t) = exp(\alpha_0 + \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}_j\alpha_j) \quad (5)$$

The $\boldsymbol{X}$ and $\boldsymbol{Z}$ matrix contain identical covariates as in the rent model but include rents as an additional explanatory variable. In order to control for regional heterogeneity we also incorporate the $\boldsymbol{\mu}_j$ matrix.

6. Data description and preliminary statistics

The estimation sample comprises two merged databases. First, we gathered 1,029,202 observations of rental dwellings from multiple listing services (MLS) in Germany from 2013-Q1 until 2017-Q4 as collected by the Empirica Systems database (www.empirica-systeme.de), which contain the most important multiple listing service (MLS) providers such as Immoscout, Immonet and Immowelt as well as seven others. After filtering for and deleting duplicates, the empirica system databank provides geographically referenced data with over 30 hedonic characteristics, including dwelling's energy consumption in kilowatt hour per square meter in a year (kWh/m^2/p.a.) extracted from the environmental performance certificate (EPC). In order to avoid a large drop in sample size due to missing binary hedonic attributes such as wooden floor, sauna or laminate floor, we only include 12 relevant hedonic characteristics. We also merge two socioeconomic variables: the purchasing power per household and number of households on a postcode level from the GfK database (www.gfk.de). Next, we calculate two spatial gravity indicators measuring the Euclidian distance of each dwelling to the geographical centroid to the postcode and NUTS3 polygons in kilometres by gathering geodata from Eurostat (www.ec.europa.eu/eurostat). Both of these variables are used to control for the spatial distribution of dwellings within urban areas.

Our final data matrix consists of more than one million residential dwellings, each with a vector of 12 hedonic characteristics across 403 NUTS3 regions over 60 months. Table 1 shows the descriptive statistics of the entire sample. The mean asking rent of German flats during the

Table 3
Regression results of log asking rents €/p.m. in Germany.

Coefficients and t-statistics	All Sample Germany	Subsamples					All Sample Germany	Subsamples				
		2013	2014	2015	2016	2017		2013	2014	2015	2016	2017
EPC - A+ (Ref: D)	0.009	−0.008	0.009	0.003	0.032	−0.002						
	3.09***	−0.76	1.45	0.52	4.99***	−0.32						
EPC - A (Ref: D)	0.014	0.000	0.008	0.024	0.011	0.014						
	7.75***	−0.03	2.30**	6.65***	3.18***	3.89***						
EPC - B (Ref: D)	0.009	0.019	0.009	0.013	0.009	0.003						
	12.27***	5.3***	5.71***	8.65***	6.34***	2.4**						
EPC - C (Ref: D)	0.002	0.002	0.002	0.003	0.003	0.000						
	3.65***	0.97	1.83*	3.30***	2.79***	−0.56						
EPC - E (Ref: D)	0.000	−0.004	−0.001	0.001	0.001	0.000						
	0.60	−1.74*	−1.07	1.43	1.81*	−0.36						
EPC - F (Ref: D)	−0.001	−0.004	0.000	−0.002	−0.001	−0.002						
	−2.98***	−1.41	−0.54	−1.75*	−1.40	−2.07**						
EPC - G (Ref: D)	−0.003	−0.015	−0.005	−0.004	0.000	−0.003						
	−3.83***	−3.05***	−2.66***	−2.24**	−0.37	−1.60						
EPC - H (Ref: D)	−0.005	−0.046	−0.007	0.000	−0.009	0.000						
	−3.28***	−5.6***	−2.44**	0.10	−3.11***	−0.29						
Log energy consumption kWh/m²/p.a.							−0.006	−0.012	−0.006	−0.008	−0.007	−0.003
							−12.46***	−5.01***	−5.9***	−7.81***	−7.00***	−3.35***
Log living area	0.501	0.529	0.580	0.361	0.455	0.481	0.500	0.530	0.580	0.359	0.454	0.481
m²	274.37***	55.82***	154.37***	98.66***	124.49***	126.46***	274.23***	55.93***	154.47***	98.23***	124.4***	126.54***
Age	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	−10.21***	−2.75***	−5.1***	−5.16***	−4.96***	−4.75***	−10.35***	−2.93***	−5.14***	−5.3***	−5.03***	−4.8***
Number of rooms	−0.015	−0.018	−0.018	−0.017	−0.013	−0.010	−0.015	−0.018	−0.018	−0.017	−0.013	−0.010
	−41.79***	−10.01***	−23.69***	−23.14***	−18.83***	−14.25***	−41.73***	−9.86***	−23.65***	−23.05***	−18.81***	−14.27***
Log number of households in ZIP area	0.064	0.062	0.064	0.061	0.065	0.064	0.064	0.063	0.065	0.061	0.065	0.064
	165.68***	33.39***	81.48***	78.56***	84.14***	80.34***	165.79***	33.56***	81.58***	78.57***	84.18***	80.37***
Log purchasing power of household in ZIP area	0.415	0.449	0.432	0.425	0.407	0.389	0.415	0.449	0.432	0.424	0.407	0.389
	275.61***	58.94***	137.51***	140.18***	136.02***	126.24***	275.57***	58.82***	137.47***	140.09***	136.05***	126.23***
Log distance to ZIP centroid in Km.	0.020	−0.024	0.019	0.020	0.021	0.015	0.020	−0.024	0.019	0.020	0.021	0.015
	47.96***	−11.29***	21.73***	23.91***	25.49***	16.32***	47.86***	−11.27***	21.73***	23.99***	25.35***	16.31***
Log distance to municipality centroid in Km.	−0.065	−0.061	−0.069	−0.066	−0.063	−0.062	−0.065	−0.061	−0.069	−0.066	−0.063	−0.062
	−240.02***	−43.67***	−118.86***	−120.73***	−119.98***	−112.84***	−240.14***	−43.83***	−118.9***	−120.83***	−120.02***	−112.86***
With bathtub	−0.007	0.001	−0.002	−0.004	−0.011	−0.011	−0.007	0.001	−0.002	−0.004	−0.011	−0.011
	−18.29***	0.99	−2.86***	−5.56***	−14.23***	−13.81***	−18.31***	0.99	−2.88***	−5.55***	−14.25***	−13.84***
With built-in-kitchen	0.089	0.086	0.088	0.092	0.088	0.089	0.089	0.086	0.088	0.092	0.088	0.089
	202.18***	38.7***	95.29***	102.96***	100.7***	99.12***	202.11***	38.63***	95.27***	102.91***	100.67***	99.11***
With parking lot	0.020	0.030	0.021	0.023	0.021	0.016	0.020	0.03	0.021	0.023	0.021	0.016
	46.66***	13.43***	22.5***	26.26***	23.81***	18.37***	46.68***	13.45***	22.5***	26.26***	23.85***	18.38***
With terrace	0.040	0.039	0.039	0.039	0.041	0.042	0.040	0.038	0.039	0.039	0.041	0.042
	66.4***	13.64***	32.65***	32.79***	33.56***	31.51***	66.5***	13.59***	32.69***	32.88***	33.62***	31.52***
With balcony	0.034	0.030	0.034	0.033	0.033	0.036	0.034	0.030	0.034	0.033	0.033	0.036
	82.52***	14.36***	39.69***	39.97***	41.05***	42.37***	82.59***	14.48***	39.75***	40.01***	41.04***	42.36***
With elevator	0.051	0.047	0.051	0.049	0.049	0.055	0.051	0.048	0.051	0.049	0.049	0.055
	101.51***	19.19***	48***	48.34***	49.42***	53.61***	101.74***	19.35***	48.11***	48.53***	49.49***	53.68***
Newly built	0.130	0.116	0.125	0.128	0.131	0.137	0.130	0.116	0.125	0.128	0.132	0.137
	153.49***	27.84***	70.14***	74.69***	78.66***	76.73***	153.87***	27.93***	70.30***	74.96***	78.86***	76.78***
Refurbished	0.036	0.022	0.035	0.037	0.036	0.036	0.036	0.023	0.035	0.037	0.036	0.036
	82.16***	11.11***	38.41***	41.65***	40.95***	41.49***	82.11***	11.15***	38.4***	41.61***	40.91***	41.47***
Construction fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

(*continued on next page*)

Table 3 (*continued*)

Coefficients and t-statistics	All Sample Germany	Subsamples					All Sample Germany	Subsamples				
		2013	2014	2015	2016	2017		2013	2014	2015	2016	2017
Quarterly fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spatial fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	84.07%	85.91%	84.78%	84.31%	83.80%	83.54%	84.06%	85.88%	84.78%	84.30%	83.80%	83.54%
N	1,029,202	37,339	226,367	251,214	262,567	251,715	1,029,202	37,339	226,367	251,214	262,567	251,715

Notes: *Significant at the 10%-level; ** significant at the 5%-level; *** significant at the 1%-level. The exhibit shows the regression results of a semiparametric regression estimated via Generalized Additive Model for Location, Scale and Shape (GAMLSS) under the normal distribution. Rents in log €/p.m. Construction dummies in 10 years steps. NUTS3 refer to municipalities as defined by the European Commission. Sigma equation controls for area, number of rooms, households density and age.

last five years was ca. 445 €/ p.m. As expected, log asking rents are positively correlated with value-enhancing hedonic characteristics such as a built-in kitchen or the number of rooms. In contrast, dwellings' energy consumption shows a mean value of ca. 130 kW h/m^2/p.a. which corresponds to a D rating in the A + to H categories for EPCs in the German housing stock. To circumvent the problem of unobserved refurbishment of the historical building stock, we exclude all buildings that were built prior to 1900. Finally, the gravity-derived variables show that dwellings are located 7.46 km from the city centre on average (centroid to the NUTS3) and that rents and distance are negatively correlated. Finally, German landlords wait on average 9.3 weeks until they find a tenant.

The size of the data allows a closer look at the variations across regional housing markets in Germany. Therefore, we supplement our estimation of the entire sample with results from two subsamples. The first subsample includes secondary markets, whereas the second subsample comprehends the top-7 German metropolitan areas Munich, Berlin, Frankfurt, Cologne, Hamburg Stuttgart and Dusseldorf. These cities account for almost 11.8% of the German population and for ca. 18% of our data sample. A frequent concern when estimating green premiums is that a latent energy premium might be highly correlated with building age, i.e. newly-built or refurbished residential units achieve these premiums by virtue of being both energy-efficient and having a number of other desirable characteristics that remain unobserved in the model. Hence, we present our econometric results for both the entire sample and regional subsamples but include only units that have been refurbished, newly-built or renovated after 2010 and have been classified as equivalent to newly built.

Table 2 presents the sample distribution across the different subsamples as well as the mean asking rent and time-on-market by EPC category. The results show that almost 70% of the dwellings concentrate in the EPC categories C, D and E in each subsample. Asking rents increase significantly for dwellings with an EPC equal to or better than D in each market and segment subsample. It is noteworthy that the average asking rent for refurbished dwellings in the Top 7 markets is higher than for non-refurbished dwellings whereas the opposite is found in secondary markets. The analysis of time on market yields some mixed evidence. The average time-on-market in the Top 7 markets increases for dwellings with an EPC equal to or better than D for each of the observed subcategories of the dwelling stock, pointing to somewhat stronger demand for energy inefficient dwellings. In the secondary markets, time-on-market reveals that the most sought after apartments appear to be in the EPC bands A +, B and E, F and partly G. However, a more formal investigation with hedonic modelling is required to confirm this prima facie finding. Fig. 1 shows the entire sample across the 403 NUTS3 areas in Germany.

7. Econometric results

The econometric analysis consists of two parts as described above. We first estimate the price impact of energy efficiency ratings and then proceed to a survival estimation to predict the time on market outcome .

7.1. Pricing of energy efficiency in market rents

Table 3 shows the estimation results of the hedonic model in Eq. (1) with the log of asking rents in €/p.m. as an endogenous variable compared to energy consumption, hedonic, spatial, socioeconomic and time covariates. The regression models are estimated as Generalized Additive Model for Location, Scale and Shape (GAMLSS) including 1,029,202 observations from 2013-Q1 to 2017-Q4.

The results provide evidence that asking rents of low energy consumption dwellings are significantly higher compared to those with elevated energy consumption. When focussing on the overall German market in the first column of Table 3, asking rents within the energy

Table 4
Regression results of log asking rents €/p.m. in market segments.

Coefficients and t-statistics	Secondary markets						Top 7 markets					
	All Sample	Subsamples		All Sample	Subsamples		All Sample	Subsamples		All Sample	Subsamples	
		Refurbished	Existing		Refurbished	Existing		Refurbished	Existing		Refurbished	Existing
EPC - A+ (Ref: D)	0.023	0.018	0.027				0.017	−0.014	0.046			
	7.27***	3.78***	6.49***				2.64***	−1.45	5.06***			
EPC - A (Ref: D)	0.020	0.025	0.018				−0.003	−0.016	0.008			
	11.22***	7.57***	8.52***				−0.90	−2.44**	1.56			
EPC - B (Ref: D)	0.010	0.006	0.011				0.005	0.007	0.004			
	13.17***	3.84***	12.58***				3.01***	2.17**	2.21**			
EPC - C (Ref: D)	0.003	−0.001	0.003				0.004	0.006	0.003			
	5.61***	−1.14	6.11***				3.22***	2.87***	2.23**			
EPC - E (Ref: D)	−0.003	−0.005	−0.002				0.001	0.006	0.000			
	−6.61***	−5.06***	−4.55***				1.75*	3.19***	−0.29			
EPC - F (Ref: D)	−0.009	−0.006	−0.010				−0.003	0.001	−0.005			
	−14.11***	−4.49***	−13.63***				−2.60***	0.68	−3.61***			
EPC - G (Ref: D)	−0.017	−0.012	−0.019				0.005	0.006	0.004			
	−17.94***	−5.84***	−17.05***				3.06***	2.22**	1.86*			
EPC - H (Ref: D)	−0.018	−0.018	−0.018				0.004	0.013	−0.002			
	−11.44***	−5.73***	−9.82***				1.51	2.74***	−0.58			
Log energy consumption kWh/m^2/p.a.				−0.017	−0.012	−0.018				−0.002	0.002	−0.005
				−30.26***	−11.38***	−27.76***				−1.78*	1.17	−3.94***
Log living area	0.565	0.588	0.622	0.565	0.588	0.622	0.599	0.611	0.588	0.598	0.610	0.587
m^2	281.09***	139.99***	271.68***	281.16***	140.02***	272.05***	180.48***	112.08***	140.94***	180.4***	111.94***	140.92***
Age	0.000	0.000	−0.001	0.000	0.000	−0.001	0.000	0.001	0.000	0.000	0.001	0.000
	−14.82***	−0.79	−17.05***	−14.91***	−0.85	−17.11***	5.53***	7.48***	1.36	5.51***	7.57***	1.27
Number of rooms	−0.010	−0.010	−0.010	−0.010	−0.010	−0.010	−0.006	0.000	−0.008	−0.006	0.000	−0.008
	−27.66***	−13.18***	−23.38***	−27.76***	−13.27***	−23.48***	−7.73***	−0.44	−8.44***	−7.60***	−0.41	−8.36***
Log number of households in ZIP area	0.075	0.077	0.074	0.075	0.077	0.074	−0.041	−0.033	−0.045	−0.041	−0.033	−0.045
	198.03***	97.96***	172.83***	198.09***	97.98***	172.87***	−31.31***	−14.87***	−27.87***	−31.3***	−14.79***	−27.89***
Log purchasing power of household in ZIP area	0.368	0.384	0.362	0.368	0.384	0.362	0.300	0.296	0.301	0.300	0.296	0.301
	238.55***	122.04***	204.89***	238.5***	122.07***	204.84***	80.05***	45.07***	66.12***	80.04***	45.15***	66.11***
Log distance to ZIP centroid	−0.010	−0.009	−0.011	−0.011	−0.009	−0.011	0.005	0.008	0.002	0.005	0.009	0.002
	−24.19***	−9.72***	−23.09***	−24.22***	−9.73***	−23.09***	4.44***	4.23***	1.85*	4.57***	4.31***	1.94*
Log distance to municipality centroid	−0.048	−0.052	−0.046	−0.048	−0.052	−0.046	−0.109	−0.103	−0.111	−0.109	−0.104	−0.111
	−178.72***	−94.39***	−150.77***	−178.86***	−94.35***	−150.89***	−136.83***	−77.24***	−112.29***	−136.78***	−77.33***	−112.19***
With bathtub	−0.011	−0.010	−0.010	−0.011	−0.01	−0.01	0.004	−0.001	0.006	0.004	−0.001	0.006
	−27.34***	−12.27***	−23.62***	−27.34***	−12.28***	−23.62***	5.64***	−1.00	6.25***	5.67***	−1.04	6.31***
With built-in-kitchen	0.082	0.074	0.084	0.082	0.074	0.084	0.084	0.077	0.086	0.084	0.076	0.086
	177.97***	79.7***	157.81***	178.02***	79.69***	157.88***	94.88***	50.19***	78.68***	94.79***	50.13***	78.62***
With parking lot	0.026	0.018	0.029	0.026	0.018	0.029	0.044	0.023	0.052	0.045	0.023	0.052
	58.71***	19.55***	55.5***	58.73***	19.61***	55.52***	44.23***	13.76***	42.25***	44.28***	13.68***	42.44***
With terrace	0.043	0.047	0.042	0.043	0.047	0.042	0.034	0.039	0.032	0.034	0.039	0.032
	69.03***	36.29***	58.85***	69.01***	36.34***	58.84***	27.33***	18.51***	21.00***	27.39***	18.50***	21.06***
With balcony	0.032	0.034	0.032	0.032	0.034	0.032	0.021	0.022	0.021	0.021	0.022	0.021
	76.18***	38.07***	66.12***	76.29***	38.04	66.22***	24.4***	14.65***	19.53***	24.38***	14.6***	19.49***
With elevator	0.036	0.045	0.034	0.036	0.045	0.034	0.019	0.032	0.013	0.019	0.032	0.013
	67.92***	40.25***	55.8***	67.94***	40.32***	55.79***	19.69***	19.13***	11.75***	19.79***	19.20***	11.84***
Newly built	0.104			0.104			0.132			0.132		
	108.2***			108.29***			98.15***			98.2***		
Refurbished	0.030			0.030			0.029			0.029		
	65.02***			65.07***			33.45***			33.40***		

(*continued on next page*)

Table 4 (*continued*)

Coefficients and t-statistics	Secondary markets						Top 7 markets					
	All Sample	Subsamples		All Sample	Subsamples		All Sample	Subsamples		All Sample	Subsamples	
		Refurbished	Existing		Refurbished	Existing		Refurbished	Existing		Refurbished	Existing
Construction fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Quarterly fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Spatial fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	87.65%	88.40%	87.06%	87.65%	88.40%	87.05%	83.14%	84.02%	82.74%	83.14%	84.02%	82.73%
N	187,478	59,492	127,986	187,478	59,492	127,986	841,724	169,040	645,684	841,724	169,040	645,684

Notes: *Significant at the 10%-level; ** significant at the 5%-level; *** significant at the 1%-level. The exhibit shows the regression results of a semiparametric regression estimated via Generalized Additive Model for Location, Scale and Shape (GAMLSS) under the normal distribution. Rents in log €/p.m. Construction dummies in 10 years steps. NUTS3 refer to municipalities as defined by the European Commission. Sigma equation controls for area, number of rooms, households density and age.

categories A+, A, B and C, are on average 0.9%, 1.4%, 0.1% and 0.2% higher than the reference category D, whereas dwellings in the subsequent categories show negative coefficients, i.e. substantial rental discounts. Energy inefficient dwellings in the categories F, G and H exhibit rental discounts of up to -0.1%, -0.3% and -0.5% respectively. When re-estimating the models for each year separately, the coefficients of the energy categories remain stable and significant but show slight differences. The rent premium of A + dwellings is insignificant when looking at the different years. At the same time, the effect of A dwellings increases over time from 0% in 2013 to 1.4% in 2017. The rental discount across the G and H category levels off slightly over time. The log elasticity of asking rents to energy consumption is statistically significant and time-invariant negative.

The continuous hedonic covariates show that rents respond positively to dwelling size and to age whereas the effect of the number of rooms is negative. Not surprisingly, cities and areas with high purchasing power have on average higher rental values. As shown in the descriptive statistics, asking rents also rise the closer a dwelling is located to the centroid of the municipality centre (NUTS3 area) and/or the centroid of the postcode. Nearly all binary hedonic characteristics exhibit a positive effect on asking rents. All models explain at least 83% of the rent variation across the different subsamples.

Table 4 presents the results of energy consumption on asking rents for each market and stock quality subsample. The green premium and discount hold across the second-tier housing markets, but also across the subsamples with newly built and existing flats. The magnitude of the effects is more pronounced compared to the results for Germany in Table 3. Thus, dwellings in secondary markets within EPC A + and A have a green premium of 2.3% and 2.0%, almost +1.4%points and +0.6%points higher than the German average respectively, whereas energy inefficient dwellings show stronger a discount of up to 0.9% points, 1.7%points and 1.8%points in the F, G and H EPC categories respectively. The results show overall that energy efficiency commands a rental premium in secondary cities across Germany.

By contrast, the results for the Top 7 markets in Table 4 show mixed results. The same effect is observed when looking at existing and refurbished flats. In both cases, asking rents for some categories of energy inefficient dwellings are higher than the medium reference D, leading to the conclusion that asking rents across the Top 7 German markets only show limited sensitivity to energy efficiency. It may be surmised that strong demand and inelastic supply in the Top 7 markets create shortages in some segments and locations that push energy efficiency down the list of rental pricing determinants in these markets. If so, we might also expect to see similar shifts in the pricing patterns of other less important hedonic characteristics. Table 4 shows that some features such as distance to centroid, elevator and terrace, to name a few, indeed appear to command higher prices in second-tier markets. By and large, the coefficients of building characteristics seem higher in secondary markets but the relationship is far from conclusive. Fig. 2 summarises the hedonic results of EPCs on log asking for Germany, the Top 7 markets and the secondary markets extracted from Tables 3 and 4.

Finally, Fig. 3 shows the results of the residential property price indices for energy efficient and inefficient dwellings using two subsamples (secondary and Top 7 German markets) and two different energy thresholds (125 kW h/m^2/p.a. and 200 kW h/m^2/p.a.) to test the sensitivity of portfolios to geographic location and stringency of energy efficiency requirements.

The hedonic indices demonstrate an analogous rental growth pattern for highly efficient and inefficient dwellings when choosing 125 kW h/m^2/p.a. as portfolio criteria. However, when transferring the rental indices to absolute asking rents, a portfolio consisting of energy efficient dwellings is expected to lead to higher income returns as rents in the energy efficient segment are clearly higher. A more flexible portfolio approach consisting of dwellings above and below 200 kW h/m^2/p.a. shows a remarkable result. Despite higher indexed rental growth of energy inefficient dwellings in the Top 7, the income return

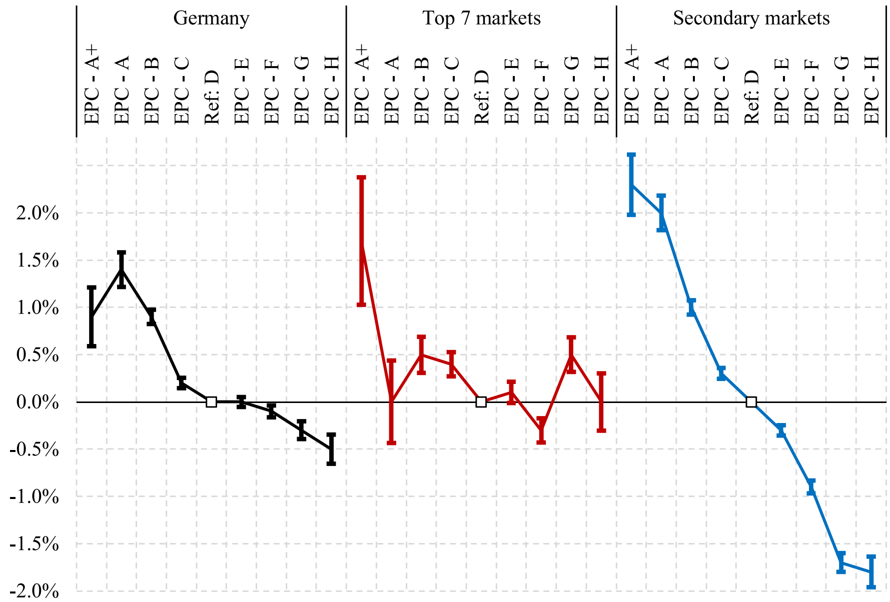


Fig. 2. Relative willingness to pay for energy efficiency by samples.
Notes: The exhibit shows the regression results of a semiparametric regression estimated via Generalized Additive Model for Location, Scale and Shape (GAMLSS) under the normal distribution. Rents in log €/p.m.

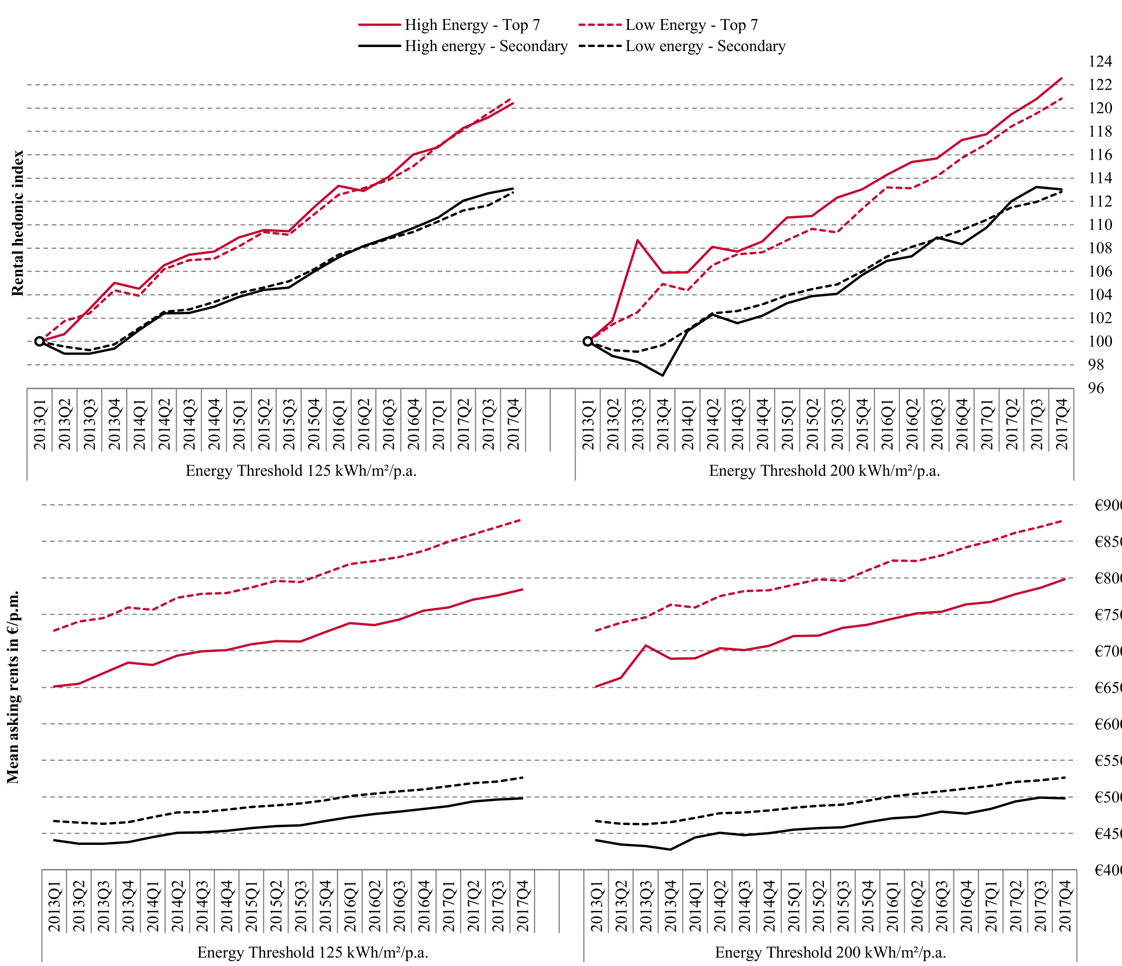


Fig. 3. Hedonic rent indices and portfolio performance of high and low energy consumption.
Notes: Indices estimated as theoretical portfolios of energy efficient and inefficient dwellings with two different energy thresholds 125 kW h/m²/p.a. and 200 kW h/m²/p.a. The approach corresponds to a dummy hedonic model without imputation.

Table 5
Cox survival regression of time-on-markets in weeks – EPC categories.

Exp(coefficients) and Chi squared statistic	All Sample Germany	Top 7 markets			Secondary markets		
		All Sample	Subsamples		All Sample	Subsamples	
			Refurbished	Existing		Refurbished	Existing
EPC - A+ (Ref: D)	0.985	0.981	0.862	1.075	0.981	0.979	0.989
	0.70	0.240	7.310***	2.160	0.910	0.530	0.160
EPC - A (Ref: D)	0.970	1.015	0.942	1.058	0.960	0.994	0.949
	7.71***	0.360	2.210	2.850*	11.760***	0.070	12.390***
EPC - B (Ref: D)	1.010	0.978	0.942	0.988	1.019	0.985	1.030
	5.08**	3.470*	7.230***	0.720	14***	1.940	27.120***
EPC - C (Ref: D)	1.007	0.976	0.948	0.985	1.020	1.012	1.021
	4.57**	8.570***	11.54***	2.380	29.170***	2.510	25.750***
EPC - E (Ref: D)	0.960	0.924	0.897	0.939	0.977	0.983	0.975
	154.45***	114.970***	72.510***	48.890***	41.700***	5.320**	37.540***
EPC - F (Ref: D)	0.945	0.915	0.92	0.913	0.949	0.952	0.950
	237.16***	116.710***	35.240***	81.570***	154.54***	32.65***	116.58***
EPC - G (Ref: D)	0.893	0.871	0.894	0.859	0.903	0.865	0.916
	413.49***	141.690***	33.070***	110.830***	263.29***	121.99***	147.80***
EPC - H (Ref: D)	0.862	0.831	0.829	0.828	0.867	0.838	0.877
	278.88***	97.680***	37.720***	63.180***	194.99***	67.62***	127.09***
Log asking rent €/p.m.	1.046	0.326	0.328	0.324	1.203	1.196	1.201
	57.20***	4,409***	1,381***	3,023***	681.23***	150.25***	504.43***
Log living area m^2	2.255	2.909	2.449	3.150	2.619	2.512	2.592
	486.52***	238.670***	50.640***	196.690***	472.02***	100.38***	363.78***
Age	0.998	1.000	1.001	1.000	0.999	0.998	0.999
	8.67***	1.170	1.390	0.260	5.310**	5.320**	3.660*
Number of rooms	1.078	1.173	1.189	1.168	1.067	1.053	1.073
	1,214***	1,004***	398.77***	628.00***	734.97***	114.4***	657.82***
Log number of households in ZIP area	1.14	1.002	1.000	1.000	1.143	1.12	1.149
	3,272***	0.070	0.000	0.000	2,892***	490.76***	2404***
Log purchasing power of household in ZIP area	1.747	1.335	1.413	1.299	1.784	1.721	1.796
	3,611***	138.49***	62.730***	76.940***	3,175***	691.8***	2,440***
Log distance to ZIP centroid in Km.	0.990	0.958	0.934	0.974	0.987	0.989	0.985
	5.45**	9.030***	6.930***	2.370	8.030***	1.290	6.910***
Log distance to municipality centroid in Km.	0.917	0.806	0.842	0.789	0.928	0.936	0.926
	2,699***	1,512***	327.14***	1,196***	1,770***	325.17***	1,410***
With bathtub	0.901	0.881	0.852	0.895	0.909	0.863	0.924
	1,945***	514.57***	258.1***	268.78***	1,363***	721.92***	710.76***
With built-in-kitchen	1.084	1.101	1.14	1.08	1.092	1.089	1.093
	883.35***	256.58***	157.97***	109.28***	845.37***	201.52***	641.46***
With parking lot	0.942	0.945	0.941	0.945	0.950	0.926	0.960
	508.97***	80.260***	29.610***	53.530***	301.31***	166.93***	141.58***
With terrace	1.008	0.981	0.964	0.990	1.029	0.999	1.037
	5.16**	5.880**	7.950***	0.930	51.090***	0.000	62.94***
With balcony	1.026	1.035	1.033	1.036	1.020	1.001	1.027
	105.39***	35.600***	10.410***	25.560***	55.400***	0.080	71.250***
With elevator	0.929	0.977	0.968	0.980	0.903	0.881	0.91
	570.05***	13.170***	8.370***	7.120***	834.33***	296.66***	550.97***
Newly built	0.833	0.891			0.849		
	1,086***	154.69***			662.01***		
Refurbished	0.932	0.971			0.921		
	702.65***	27.590***			759.00***		
Construction fixed effects	✓	✓	✓	✓	✓	✓	✓
Quarterly fixed effects	✓	✓	✓	✓	✓	✓	✓
Non linear effects	✓	✓	✓	✓	✓	✓	✓
Spatial fixed effects	✓	✓	✓	✓	✓	✓	✓
R^2	65.56	66.17	66.04	65.98	64.73	65.78	64.37
N	1,029,202	187,478	59,492	127,986	841,724	169,040	645,684

Notes: *Significant at the 10%-level; ** significant at the 5%-level; *** significant at the 1%-level. The exhibit shows the regression results of a semiparametric cox regression of dwellings' time-on-market in weeks on hedonic, spatial and socioeconomic covariates. The results are presented as coefficients, while significant values > 1 shorten the survival and thus increase the assets' liquidity, significant coefficients < 1 decrease the hazard rate and lengthen the survival. The Pseudo-R^2 based on Kendall's Tau measures the concordance between estimated survival time and the observed survival time for only the non-censored response sample.

of a portfolio targeting a more flexible sustainability approach is mainly generated by energy efficient dwellings.

Overall, our results confirm that the energy efficiency premium found previously in several European countries is also observable in Germany which suggests that the energy efficiency level of a rental unit ought to be considered in the purchasing or renting decision.

7.2. Time on market estimates

The parametric proportional Cox-hazard model is estimated with a right-censored response variable defined as the time a property is available on the internet, measured in weeks. For simplicity of interpretation, we define the reference category as the energy class D.

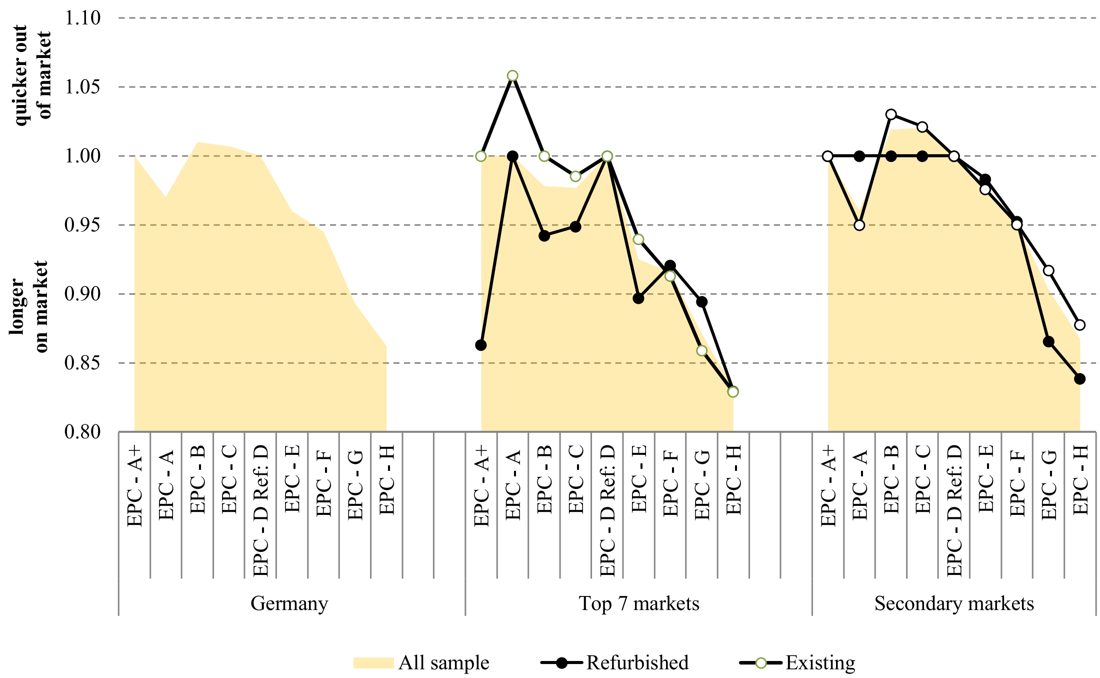


Fig. 4. Liquidity of dwellings by energy performance categories and samples.
Notes: The exhibit shows the antilog of the coefficients a semiparametric cox regression of dwellings' time-on-market in weeks on hedonic, spatial and socioeconomic covariates. Values > 1 shorten the survival and thus increase the assets' liquidity, coefficients < 1 decrease the hazard rate and lengthen the survival.

Coefficients significantly below one are expected to indicate longer 'survival time' of the dwelling on the market. Table 5 shows the factors that boost or restrict the liquidity of German dwellings to be rented within a certain time frame across different subsamples. The results for Germany overall in the first column show that dwellings in the EPC categories E, F, G, H but also A remain on the market for longer by 4%, 5%, 11%, 14% and 3% respectively than the reference D. At the same time, the most sought after dwellings are to find in the EPC categories B and C, whereas the effects of 1% and 0.7% are statistically significant but relatively low. Across all subsamples, the results fail to provide evidence for a green liquidity premium as the coefficients of the EPC categories are statistically not significant. However, the results show some empirical support that the most energy inefficient dwellings incur a liquidity penalty on the German rental market. Hence, energy inefficient dwellings with an H EPC stay up to 17% and 13% longer on market in case of the Top 7 and secondary markets respectively compared to reference category. It cannot be ruled out that the green rental premium interferes with the green liquidity premium to the extent that higher rental rates may delay the renting out of an apartment somewhat thereby offsetting some of the expected effect of shorter times on market.

The Cox regression in Table 5 yields robust and stable results. Since hazard models estimate event probabilities per units of time, a coefficient of determination just as in the OLS is difficult to obtain. As a substitute, we provide the Pseudo-R^2 based on Kendall's Tau, which measures the concordance between estimated survival time and the observed survival time for only the non-censored response sample. The goodness of fit measure indicates a reasonable fit with a Pseudo-R^2 around 65% for all model estimates. Turning to individual coefficient estimates, we observe that dwelling size and the number of rooms decreases time-on-market whereas age restricts liquidity. Proximity to the city centre appears to be an important determinant of liquidity. The coefficient value below one implies that time on market increases with distance from the city centre as expected. In terms of hedonic binary variables, the results show that landlords of dwellings with amenities such as a bathtub, a parking lot and an elevator take longer to close on a lease. At the same time, the most liquid dwellings in Germany have a built-in-kitchen, a terrace and a balcony. Fig. 4 provides a graphical overview of the effect of energy consumption on the liquidity of dwellings in Germany and the different subsamples.

Finally, survival models allow the estimation of the survival probability as a function of the time the dwellings are exposed to the market. The cox proportional hazard models allow the estimation of the probability of leaving the market after a certain time. Fig. 5 shows the survival probability of a standard dwelling with a fixed set of hedonic characteristics (80m^2, 3 rooms, 7 years old and all hedonic binary attributes) across different cities within 10 weeks, i.e. Berlin and Munich from the Top 7 and Dresden and Regensburg from the secondary markets. Dwellings with an EPC of A + leave the market more quickly than dwellings with an EPC of H regardless of the city but different gradients of the survival functions reflect the long-term differences in average marketing periods across cities.

8. Conclusions

This paper set out to test empirically whether energy efficiency is reflected in residential rents in Germany, the largest rental market in Europe. In our empirical analysis, we analyse more than a million observations in order to estimate the impact of EPC ratings on residential rents. The results show that landlords obtain a small but significant green premium when leasing residential dwellings. The results also provide robust evidence that energy efficiency is reflected in rents across the German residential market. Although the effects are less pronounced across the seven major cities, Berlin, Hamburg, Munich, Frankfurt, Stuttgart, Cologne and Düsseldorf, possibly due to the strong demand for housing and the low supply of housing over the last four years in the study period in these cities, our results confirm that the provision of EPCs has a notable effect on residential rents. Overall, these findings suggest that the utility function of tenants is significantly affected by the existence of EPCs, resulting in higher demand for more energy efficient dwellings and lower demand for rental properties that do not meet current energy efficiency standards. The survival

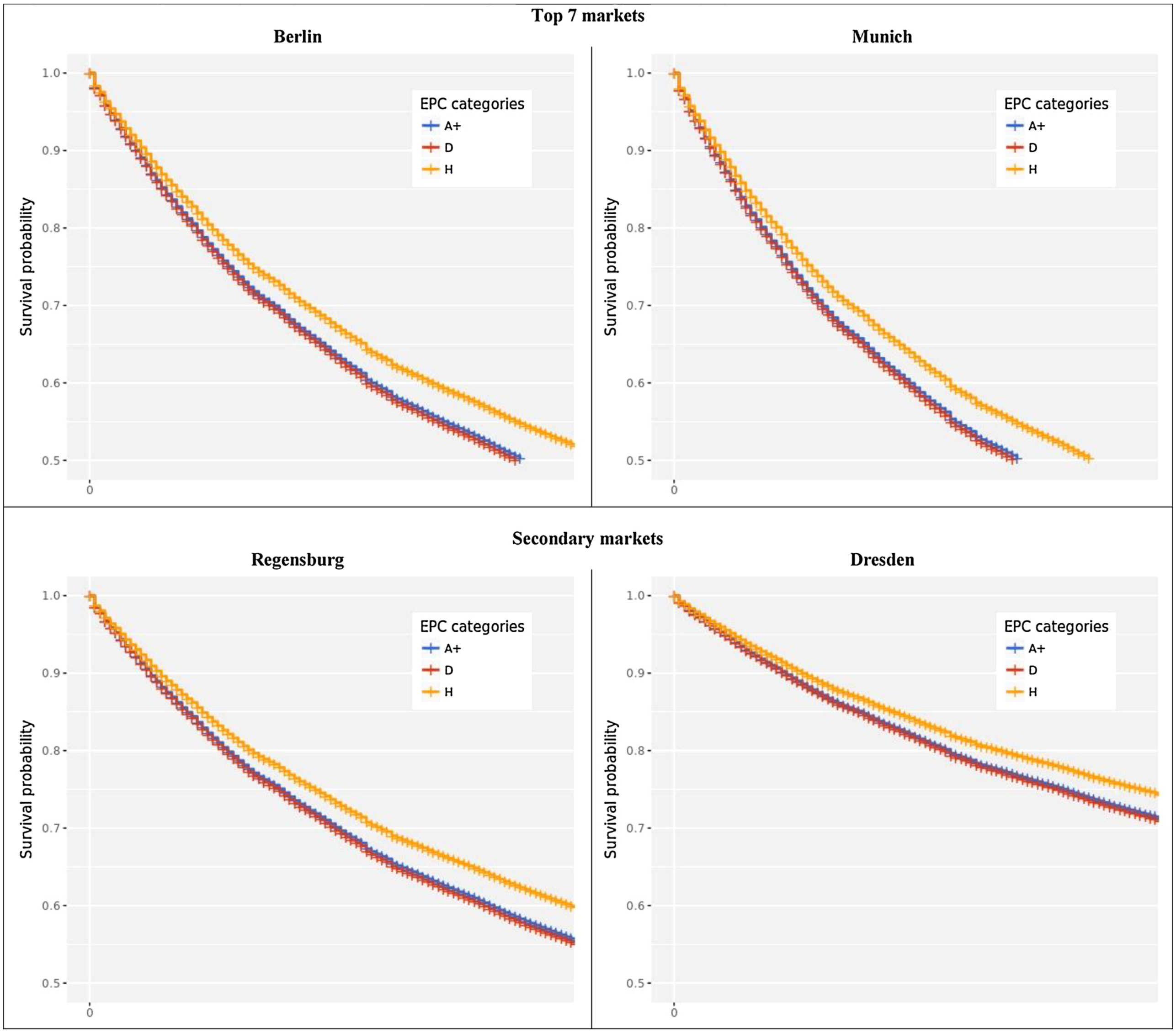


Fig. 5. Survival probability of a synthetic dwelling with high and low energy efficiency by cities after 10 weeks.
Notes: The exhibit shows the survival curves of a synthetic dwelling with different energy consumption levels across the different cities from week 0 until week 10.

regression results for the time-on-market of dwellings confirm that energy inefficient dwellings incur an additional 'time penalty' when offered on the market.

The presence of a measurable rental premium for energy efficiency should also act to mitigate the split incentive problem between landlords and tenants. A simple example illustrates this. In a pure split incentive case, a landlord would upgrade the energy efficiency of a building but is then unable to recoup the cost. Assuming a green rental premium, however, the investment becomes more feasible. Using the empirically estimated figures, a landlord can realistically hope to achieve a 1.4% rent increase after undertaking measures that improve the EPC rating from a standard D to an A rating. Taking the example of a landlord who owns an apartment building with 6 rental units of 100 sqm each and a gross rent of €10/sqm, the coefficient estimate suggests that they could obtain an extra €1000 in rental cash flow each year post-retrofit. Hence, they will be able to invest about €20,000 largely cost-neutrally to upgrade the energy efficiency of their property if they accept a standard 20 year payback period. Quicker lease-up times may shorten this payback period further but other factors such as higher discount rates and inflation may extend it, at least slightly.

While the design and metrics underlying the individual EPCs implemented in EU member countries has been subject to criticism, it appears clear that residential rental markets respond to the added transparency afforded to them by the energy efficiency information. This information, even if imperfect and subject to important limitations, appears to be not only valuable for tenants but potentially also for private and institutional investors seeking to acquire portfolios of energy-efficient assets as an investment strategy.

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References

[1] European Parliament, Directive 2010/31/EU of the European Parliament and of the Council of Europe, 19 May 2010 on the energy performance of buildings (recast),

Off. J. Eur. Union 18 (06) (2010) 2010.
[2] T. Dixon, M. Keeping, C. Roberts, Facing the future: energy performance certificates and commercial property, J. Prop. Invest. Financ. 26 (1) (2008) 96–100.
[3] L. Murphy, The influence of the energy performance certificate: the Dutch case, Energy Policy 67 (2014) 664–672.
[4] H. Amecke, The impact of energy performance certificates: a survey of German home owners, Energy Policy 46 (2012) 4–14.
[5] J. Schleich, Barriers to energy efficiency: a comparison across the German commercial and services sector, Ecol. Econ. 68 (7) (2009) 2150–2159.
[6] D. Brounen, N. Kok, On the economics of energy labels in the housing market, J. Environ. Econ. Manage. 62 (2) (2010) 166–179.
[7] N. Kok, M. Jennen, The impact of energy labels and accessibility on office rents, Energy Policy 46 (2012) 489–497.
[8] M. Cajias, D. Piazolo, Green performs better: energy efficiency and financial return of buildings, J. Corp. Real Estate 15 (1) (2013) 53–72.
[9] K. Kholodilin, C. Michelsen, The Market Value of Energy Efficiency in Buildings and the Mode of Tenure, DIW, Berlin, 2014.
[10] F. Fuerst, P. McAllister, A. Nanda, P. Wyatt, Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England, Energy Econ. 92 (2015) 20–33.
[11] F. Fuerst, P. McAllister, A. Nanda, P. Wyatt, Variations in the implicit pricing of energy performance by dwelling type and tenure: a study of wales, Energy Policy (2016), https://doi.org/10.13140/RG.2.1.4579.6961.
[12] F. Fuerst, E. Oikarinen, O. Harjunen, Green signalling effects in the market for energy-efficient residential buildings, Appl. Energy 180 (2016) 560–571.
[13] M. Hyland, R.C. Lyons, S. Lyons, The value of domestic energy efficiency – evidence from Ireland, Energy Econ. 40 (2013) 943–952.
[14] A. Ramos, A. Pérez-Alonso, S. Silva, Valuing Energy Performance Certificates in the Portuguese Residential Sector. Economics for Energy. WP 02-2015, (2015).
[15] A. de Ayala, I. Galarraga, J.V. Sparado, The Price of Energy Efficiency in the Spanish Housing Market 94 (2016), pp. 16–24.
[16] Bio Intelligence Service, Ronan Lyons, IEEP, Energy Performance Certificates in Buildings and Their Impact on Transaction Prices and Rents in Selected EU Countries, Final Report Prepared for European Commission (DG Energy), (2013).
[17] R. Kalra, K.C. Chan, P. Lai, Time on market and sales price of residential housing: a note, J. Econ. Financ. 21 (2) (1997) 63–66.
[18] A. Yavas, S. Yang, The strategic role of listing price in marketing real estate: theory and evidence, Real Estate Econ. 23 (3) (1995) 347–368.
[19] H. Kang, M. Gardner, Selling price and marketing time in the residential real estate market, J. Real Estate Res. 4 (1) (1989) 21–35.
[20] D. Haurin, The duration of marketing time of residential housing, J. Am. Real Estate Urban Econ. Assoc. 16 (No. 4) (1988) 396–410 (now Real Estate Economics).
[21] G.D. Jud, J.D. Benjamin, G.S. Sirmans, What do we know about apartments and their markets? J. Real Estate Res. 11 (3) (1996) 243–257.
[22] M. Glower, D.R. Haurin, P.H. Hendershott, Selling time and selling price: the influence of seller motivation, Real Estate Econ. 26 (4) (1998) 719–740.
[23] S.E. Ong, Y.C. Koh, Time on-market and price trade-offs in high-rise housing sub-markets, Urban Stud. 37 (11) (2000) 2057–2071.
[24] R.A. Rigby, D.M. Stasinopoulos, Generalized additive models for location, scale and shape, Appl. Stat. 54 (2005) 507–554.
[25] M. Cajias, Is there room for another hedonic model? – the Advantages of the GAMLSS approach in real estate research, J. Eur. Real Estate Res. 11 (2) (2018) 204–245.
[26] A. Mayr, N. Fenske, B. Hofner, T. Kneib, M. Schmid, GAMLSS for High-dimensional Data – a Flexible Approach Based on Boosting, Technical Report Number 098-2010, University of Munich, 2010.
[27] L. Florencio, F. Cribari-Neto, R. Ospina, Real Estate Appraisal of Land Lots Using GAMLSS Models, Cornell University Library, 2011 arXiv Preprint arXiv:1102.2015.
[28] A. Razen, W. Brunauer, N. Klein, T. Kneib, S. Lang, N. Umlauf, Statistical Risk Analysis for Real Estate Collateral Valuation Using Bayesian Distributional and Quantile Regression, Working Papers in Economics and Statistics, (2014).
[29] J. de Haan, W.E. Diewert, Handbook on Residential Property Price Indexes, Eurostat, Luxembourg, 2011.
[30] M. Cajias, P. Freudenreich, Exploring the determinants of liquidity with big data – market heterogeneity in German markets, J. Property Invest. Financ. 36 (1) (2018) 3–18.
[31] V. Zahirovic, K.M. Gibler, Historic district influence on house prices and marketing duration, J. Real Estate Financ. Econ. 48 (2014) 112–131.
[32] J.E. Larsen, An empirical investigation of the market duration of repossessed single-family houses, Int. J. Hous. Mark. Anal. 5 (1) (2012) 5–19.
[33] J.D. Benefield, R.C. Rutherford, M.T. Allen, The effects of estate sales of residential real estate on price and marketing time, J. Real Estate Financ. Econ. 45 (2012) 965–981.
[34] J.D. Benefield, C.L. Cain, K.H. Johnson, A review of literature utilizing simultaneous modelling technique for property price and time-on-market, J. Real Estate Lit. 22 (No. 2) (2014) 149–175.
[47] S. Wood, Generalized Additive Models: an Introduction With R. Texts in Statistical Science, Chapman & Hall/CRC, 2006.