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Title: Are Energy Efficiency Ratings ignored in the German housing market? – evidence from a large-sample hedonic study.

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ARE ENERGY EFFICIENCY RATINGS IGNORED IN THE GERMAN HOUSING MARKET? – EVIDENCE FROM A LARGE-SAMPLE HEDONIC STUDY

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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 Germany where rental properties make up the majority of the housing stock. 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 500k observations across 412 markets in Germany with full hedonic characteristics, we find strong evidence that energy-efficient rental units are rented at a significant 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 ratings on time-on-market. It is found that energy-efficient rental properties tend to lease up more quickly than their non-efficient peers.

KEYWORDS: Energy efficiency, residential buildings, Hedonic model, Hazard model, German housing

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INTRODUCTION

The building sector is crucial for climate change mitigation goals since it accounts for almost 40% of the CO_2 emissions across Europe. In this context, one of the most important policies implemented in the European Union was the introduction of Energy Performance Certificates (EPC) for assessing energy consumption in residential buildings. While EPCs aim at tightening relevant legal requirements for buildings at both the European and the national level, they are primarily designed as a regulatory instrument to increase the environmental awareness among the market players and enhance the transparency of property transactions in regard to energy consumption. Although the legislative implementation of EPCs has not been homogenous across EU members and is primarily aimed at residential buildings there is evidence that EPCs have accomplished their goal of providing more information and increasing environmental awareness across market participants. Additionally, an increase in landlords refurbishing their properties to reach a certain building quality level has also been observed although it is difficult to ascertain the role of EPCs in this increase compared to concomitant factors such as subsidies and cost of retrofits.

Empirical evidence from European residential markets generally confirms that energy efficiency is capitalised into property prices (Brounen and Kok, 2010;; Cajias and Piazolo, 2013; Fuerst et al, 2015, Fuerst, Oikarinen and Harjunen, 2016 and Kholodilin and Michelsen, 2014, Kok and Jennen, 2012). However, while the first comprehensive evaluation report by the European Commission on the impact of EPCs on housing markets confirms a statistical green energy efficiency premium on real estate transaction prices and rents, two factors need to be explained further . First, the evaluation report focusses on countries where owner occupancy is the predominant mode of tenure such as Belgium, Ireland and the United Kingdom. The full capitalization of energy efficiency into rental properties may be limited in these countries due to the transient nature of rentals in these markets, i.e. renting is typically considered a temporary choice until a property is purchased. Arguably, renters will not pay much attention to energy efficiency considerations in a short term rental situation.

There is very little evidence to date from countries such as Germany where rented housing is considered a long-term and widespread choice of tenure, a gap that this study seeks to fill. Secondly, empirical research over the last decade has focused exclusively on capturing willingness to pay for energy efficiency using hedonic modelling. The present study also investigates if more energy-efficient properties are also more liquid as measured by shorter time-on-market. As far as we are aware, this measure has only been applied in one previous study on the Finnish market (Fuerst, Oikarinen and Harjunen, 2016).

A further contribution of this paper is that it provides empirical evidence from Europe's largest rental housing market, Germany. The comprehensive EC report mentioned above does not cover Germany nor do further studies to our knowledge provide robust evidence of a country-wide energy efficiency premium. In the published literature, two empirical studies analyze the impact of EPCs on the German residential market. Cajias and Piazolo, 2013, find a rental green premium of ca. 1.7 % based on 2,600 observations and Kholodilin and Michelsen, 2014, focus on the capitalization effects in Berlin’s residential market based on 150,000 observations.

The present paper explores the mechanism by which energy efficiency is capitalized into prices by employing advanced econometric models for estimating both the willingness to pay for energy efficiency and the liquidity of energy efficient assets. By employing one of the largest databases on residential asking rents in Germany, we estimate the energy premium as well as the time to lease. Finally, we construct residential property price indices to study the impact of EPCs when creating value in institutional portfolios. The paper is organized as follows. The first section describes the research approach and econometric models, while the second section describes the empirical data used for this study. The third section presents the results before policy recommendations are derived.

RESEARCH APPROACH

Hedonic models estimate the response of prices within a pre-determined market over a period of time. In this paper, data for 412 markets across Germany was obtained with a total of 570,239 observations. Due to the strong variation across regional housing markets in Germany, we supplement our estimation of the entire sample with results from two subsamples. The first subsample comprises the Top 7 largest 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. 18.4 % of our data sample. The second subsample includes secondary and tertiary markets out of the Top 7.

Our identifying strategy for the capitalization of energy efficiency into rents is twofold: firstly, we estimate the elasticity of asking prices with respect to EPC categories in order to examine whether higher energy consumption has a significant (negative) effect on prices, ceteris paribus. The functional form is a log-log equation with (R) as the response variable of asking rents in €/m²/p.m. and several exogenous hedonic factors ($\boldsymbol{X}$), including both energy consumption and energy categories. Since our dataset consists of pooled cross-sectional observations of residential flats (i) observed at different times (t), NUTS3-markets (j) and also includes socioeconomic variables ($\boldsymbol{Z}$) at the NUTS3-spatial level (j), we estimate our regression in a first step with a baseline OLS model as follows:

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

where $\boldsymbol{\mu}^j$ and $\boldsymbol{\mu}^t$ constitute a matrix of NUTS3 regional dummies and quarterly dummies respectively. Thus, Equation 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. In order to incorporate latent non-linear and spatial effects between asking rents and exogenous metric variables, we include in a second step a series of smooth k terms $f\left(x_{i,j,t}^k\right)$ and re-estimate the model via iterative OLS as a generalized additive model (GAM) based on Hastie and Tibshirani, 1990, since it captures spatial effects based on smoothing functions and expands the baseline hedonic OLS model by identifying latent nonlinear effects in order to reduce the misspecification in the estimated coefficients and error variance:

$$R_{i,j,t} = \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}^j\alpha_j + \boldsymbol{\mu}^t\alpha_t + f\left(x_{i,j,t}^k\right) + u_{i,j,t} \qquad (2)$$

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. To this end, 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 higher than 125 kWh/m²/p.a. and 0 otherwise (see Eurostat 2013):

$$R_{i,j,t} = \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}^{j}\alpha_{j} + \boldsymbol{EPC_{i,j,t}}\phi + \left[\boldsymbol{EPC_{i,j,t}} * \boldsymbol{\mu}^{t}\right]\boldsymbol{\theta}_{t} + f\left(x_{i,j,t}^{k}\right) + u_{i,j,t} \quad (3)$$

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

Asking rents are an imperfect measure of willingness to pay for hedonic features, notably energy efficiency, since they mainly reflect a landlord's view of the market. However, while the difference has been shown to be significant in other markets such as the US office market (Webb and Fisher, 1996), asking rents and effective rents typically differ by a relatively small margin in the German residential market, especially considering the remarkable importance of the rental market. Furthermore, demand for energy-efficient dwellings should also be reflected in shorter marketing periods of rental units with superior energy efficiency and, vice versa, longer periods for inefficient dwellings. Differences in average time on market can be estimated with survival hazard models which have hitherto been rarely employed in the research field of energy efficiency of buildings, perhaps due to the restricted access to market data. Survival methods have, however, been applied in a number of studies in various research fields (Zahirovic-Herbert, Gibler, 2014; Larsen, 2012; Benefield, Rutherford, Allen, 2012). 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 categories in order to estimate whether the time-on-market, i.e. user demand, for low-energy consuming flats is higher than their counteracts. 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.

The time period (T) during which a flat is offered on the market corresponds to a continuous positive response variable and is interpreted as the duration of an event (offer), in our case the time in weeks, before the occurrence of an event (t), the letting agreement or removal from the market for other reasons. To main measures are important for understanding and 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 former estimates the rate of occurrence per unit of time of an event. Formally they are expressed as:

$$S(t) = P(T > t) = 1 - \int_t^\infty f(x)dx \qquad (4)$$

$$h(t) = \frac{P(t < T \leq t + \Delta t | T > t)}{\Delta t} \qquad (5)$$

While the survival function gives the probability that a dwelling survives until a certain time t, the hazard specifies the rate of failure at $T = t$ given that the flat survived up to time t. Since the numerator in equation (5) corresponds to a conditional probability and the denominator is a elapse of time Δt, the hazard function gives the probability or rate of mortality per units of time. Some observations or dwellings do not change their event status, either because they remain available on the market or the landlord do not change the status in the database, the latter constituting a data error or false negative result. In this case, the response variable is said to be right-censored. While simple models such as Kaplan-Meier or Kernel estimators estimate the survival function, they are unable to control for the latter effect correctly. 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 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 time T, survival models estimate a conditional survival probability for an event for each observation rather than estimating a single fitted value in the sense of the traditional OLS regression. Therefore, the interpretation of a survival regression, as a proportional hazard model is expressed as the probability of changing status. Based upon this information, we parametrize the equation of our parametric proportional hazard model as follows:

$$h_{i,j,t}(t) = \exp\,(\alpha_0 + \boldsymbol{X}_{i,j,t}\beta + \boldsymbol{Z}_{j,t}\gamma + \boldsymbol{\mu}^j\alpha_j) \qquad (6)$$

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

DATA DESCRIPTION AND PRELIMINARY STATISTICS

Our estimation samples comprises two merged databases. First, we gathered 570,239 observations of rental flats from multiple listing services (MLS) in Germany from 2013-Q1 until 2015-Q4 as collected by the Empirica Systems database (www.empirica-systeme.de), which contain the most important MLS providers such as Immoscout, Immonet and Immowelt as well as seven others. After filtering and deleting duplicates, the empirica system database provides geographically referenced data with over 30 hedonic characteristics, including dwelling's energy consumption in kWh/m²/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 16 relevant hedonic characteristics. On the other hand, we merge tree socioeconomic variables the number of inhabitants per households, the unemployment rate and the population in log on a NUTS-code level and yearly basis from the GfK-database (www.gfk.com/de). Our final data matrix consists thus on more than 500k residential flats, each with a vector of 16 hedonic characteristics across 412 NUTS-3 regions over 36 months.

Exhibit 1 shows the distribution of asking rents across energy categories in the subsamples for the Top 7 and secondary markets in Germany and also for the entire sample and for new builds only in each subsample. While asking rents across the secondary markets show a clear premium for the energy categories A+, A and partly B regardless of the construction year, the boxplots show a marginal discount for dwellings in the lowest energy efficiency category H. In the Top 7 markets instead, the results show mixed results. Thus, the energy premium in the first tree energy categories is remarkable in contrast to the category C regardless of dwellings age. However, a remarkable energy discount for energy inefficient dwellings is not to observe. Instead, asking rents tend to increase providing descriptive evidence for a rebound effect in the Top 7 residential markets. This effect is more pronounced in the overall sample, which might be ascribed to the high demand for housing in these cities. Nevertheless, the descriptive results indicate a premium for energy efficient flats in both samples.

----- See Exhibit 1 below -----

Over the observation period, the mean asking rent of German flats was 7.10 €/m²/p.m. per month with a mean deviation of ca. 2.5 €/m²/p.m. (Exhibit 2). However, asking rents show a strong variation across the markets ranging from 1 €/m² to 49 €/m²/p.m. per month. As expected, asking rents are positively correlated with value-enhancing hedonic characteristics such as a new kitchen, elevator or recent refurbishment. Energy consumption has a mean value of ca. 130 kWh/m²/p.a./dwelling which corresponds to a D rating in the A to H categories for EPCs in the German housing stock. Just as for asking rents, the variation in energy consumption is considerable as the sample contains either unused flats consuming less than 1 kWh/m²/p.a. and some dwellings in the last energy category with almost 1000 kWh/m²/p.a. To circumvent the problem of unobserved refurbishment of the historical building stock, we trimmed all buildings that were built prior to 1900.

----- See Exhibit 2 below -----

ECONOMETRIC RESULTS

A frequent concern when estimating a green premium is that a latent energy premium might be highly correlated with building age, i.e. newly-built or refurbished residential units. Hence, we present our econometric results for both the entire sample, regional subsamples and for each of these but including only units that have been refurbished, newly-built or renovated after 2010 and have been classified as equivalent to newly built.

Exhibit 3 shows the results for the secondary residential markets in Germany including a vector of 13 hedonic characteristics, construction dummies in ten year steps, quarterly dummies as well as socioeconomics variables. Model I and II are estimated via OLS based on equation 1, whereas model III to V are optimized via a backfitting algorithm as a Generalized Additive Model (GAM) based on equation 2 including semiparametric smooths between metric regressors.

----- See Exhibit 3 below -----

The results provide strong evidence that asking rents of energy efficient dwellings are significantly higher compared to flats with elevated energy consumption. When focussing on the aggregate German market, asking rents within the energy categories A+, A, B and C, are up to 4.1 %, 3.0 %, 1.8 % and 0.6 % higher than the reference category D respectably, whereas flats in the subsequent categories show negative coefficients, i.e. a substantial rental discount. While the coefficients of the energy categories are less sensitive to county and semi-parametric splines, the increase in the explanatory power in Model III of ca. 35 percentage points in comparison to the OLS models confirms the precision of the GAM model in estimating the hedonic equations accurately. The green premium for energy efficient and discount for energy inefficient flats holds in magnitude when focusing on newly built, as-good-as-new and initial let flats. Despite the insignificant effect in category G, the results show overall that energy efficiency commands a rental premium in secondary cities across Germany, ceteris paribus. The coefficients for the hedonic characteristics show the expected results as size, age and the number of rooms are negatively related to rents, whereas the socioeconomic variables point to higher rents in larger cities with active labour markets.

----- See Exhibit 4 below -----

The results for the Top 7 markets show, mixed results. The estimated coefficients for the energy categories in the overall sample show a low, but significant energy premium only for flats within the energy categories B and C of 0.7 % in comparison to the reference D. Moreover, highly inefficient G- and H-assets with more than 200 $kWh/m^2/p.a.$ show a premium of approx. 1 % relative to D, whereas dwellings within the category A show a 1.1 % discount relative to D. Thus, for the Top 7 German markets, the energy efficiency effect shows up to the B-category a U-shaped form, although the results for newly built, as-good-as-new and initial let flats are less pronounced. In our opinion, this finding is essential for policy makers towards the German sustainability strategy and might be ascribed to two effects: The current strong demographic demand into the main cities is increasingly leading to an enhanced demand for housing, which is directly transmitted to rising rents regardless of quality and energy consumption. Beyond this, the Top 7 German cities lack of sufficient supply as a consequence of low construction activities during the last decade. Thus, the U-shaped energy effect might therefore be interpreted as the mismatch between low supply and high demand.

----- See Exhibit 5 below -----

In a final step, we show in Exhibit 5 the results of the residential property price indices for energy efficient and inefficient dwellings on the two subsamples: secondary and Top 7 German markets. The hedonic indices generally show an analogous rental growth pattern for highly efficient and inefficient dwellings. However, in case of the Top 7 German cities, the indices confirm the strong demand for living space during the last three years, as the hedonic indices increased by ca. 10 % regardless of the energy group. Using a three year investment window, a portfolio consisting of dwellings with an energy consumption less than 125 kWh/m²/p.a. outperformed the low-efficiency portfolio by approximately 100 basis points. However, no outperformance is found in secondary markets. More importantly, when applying the indices to real asking rents in level form, the bottom of Exhibit 5 emphasises that the performance of energy efficiency portfolios diversified across primary and secondary markets leads to higher portfolio values and potentially to stable income returns. Overall, our results confirm thus that the energy efficiency premium observed in several European countries is also observable in Germany, confirming that the energy efficiency level of a rental unit is an important investment criterion which ought to be considered in the purchasing decision.

In the next phase of the analysis, we estimate a parametric proportional Cox-hazard model with a right-censored response variable defined as the time a flat offer is available on the internet in weeks. Exhibit 6 presents our results for Equation 6 on the aforementioned subsamples and for energy consumption as a metric and binary exogenous factor. For simplicity of interpretation, we define the reference category as the energy class A+. Since the Cox model estimates the survival time of an event as a probability function, t its coefficients are not directly comparable to those obtained in the OLS regression. In case of energy consumption as a metric regressor in secondary German markets, the estimated coefficient in both subsamples is below one and significant. A significant coefficient below 1 is expected to decrease the expected probability of a lease event and thus to increase the expected survival interval on the market. In other words, flats with high energy consumption across the German secondary markets remain longer on the market than dwellings with low energy consumption, pointing to higher tenant demand for these dwellings. For instance, dwellings with high energy consumption remain 6 % longer in the overall sample and 3 % longer in the newly-built sample ($1 - 0.94 \cong 6\%$) on market than dwellings with low energy consumption. When looking at the hazard ratios for the energy categories, flats within energy classes G and H in the overall sample are 0.928 and 0.909 times more likely to have a shorter survival than dwellings in energy class A+ respectively, holding other covariates fixed. In the newly-built sample the effects are similar as energy classes G and H are 0.941 and 0.895 times more likely than dwellings in energy class A+. In other words, flats in these energy categories are ca. 7 %, 9 %, 6 % and 10 % longer on-market respectably, ceteris paribus.

----- See Exhibit 6 below -----

When looking at the Top 7 cities, the results show that the risk for dwellings of remaining unleased for longer periods increases the higher the energy consumption of dwellings is, as the coefficient in the overall sample is below one and statistically significant at the 1% level. When decomposing the effect across the energy categories, dwellings within the categories D and E show 13 % and 8.9 % higher market liquidity than dwellings within the reference A+ as their expected survival time on-market is positive and significant. The Cox-hazard model provides further evidence that a stronger market liquidity is only given in the overall market rather than by newly-built dwellings across the Top 7 German residential markets. In these markets, the estimated coefficient is below one but statistically insignificant. However, the liquidity of dwellings within the categories C, D, E and F tends to be higher than for highly efficient and inefficient dwellings.

The econometric Cox regression results show that higher asking rents and bigger size of a flat depress the hazard rate which is interpreted as spending more time on the market. This seems plausible given that the demand for big and expensive flats might be restricted and the letting process of such flats might take longer. In contrast, every additional year of age increases the hazard and shortens the time a flats remains on the market, which means that the demand for older flats tends to be higher. 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. Across all models the Pseudo-R^2 were close to 65 % indicating a reasonable fit of the models.

CONCLUSION AND RECOMMENDATIONS

This paper set out to estimate whether energy-efficiency is reflected in residential rents in Germany, the largest rental market in Europe. Based on one of the largest databases for asking rents, we analyse more than 500k observations and find that landlords have a significant green premium when leasing residential dwellings, as our results provide robust evidence that energy efficiency is paid across the German residential markets. Although, the effects are less pronounced across the seven major cities, Berlin, Hamburg, Munich, Frankfurt, Stuttgart, Cologne and Dusseldorf, which might be ascribed to recent strong demand for housing and low new supply, our results appear to confirm that the provision of EPCs has a notable effect on residential rents. Despite some mixed evidence regarding lease-up times based on survival regression on the time-on-market of dwellings, our results show that energy efficient dwellings appear to lease up more quickly than their non-efficient counterparts but more empirical evidence is needed to generalize this finding.

In summary, this study provides some evidence that EPCs as mandated by the Energy Performance of Buildings Directive and corresponding Member State legislation has had some effect towards providing more transparency in property markets with a view towards internalizing the negative effects of building-related greenhouse gas emissions. A further corollary of these findings is that investing in energy efficiency may be an attractive proposition for investors and landlords seeking a competitive advantage and stable rental income, particularly in rental markets with higher vacancy rates.

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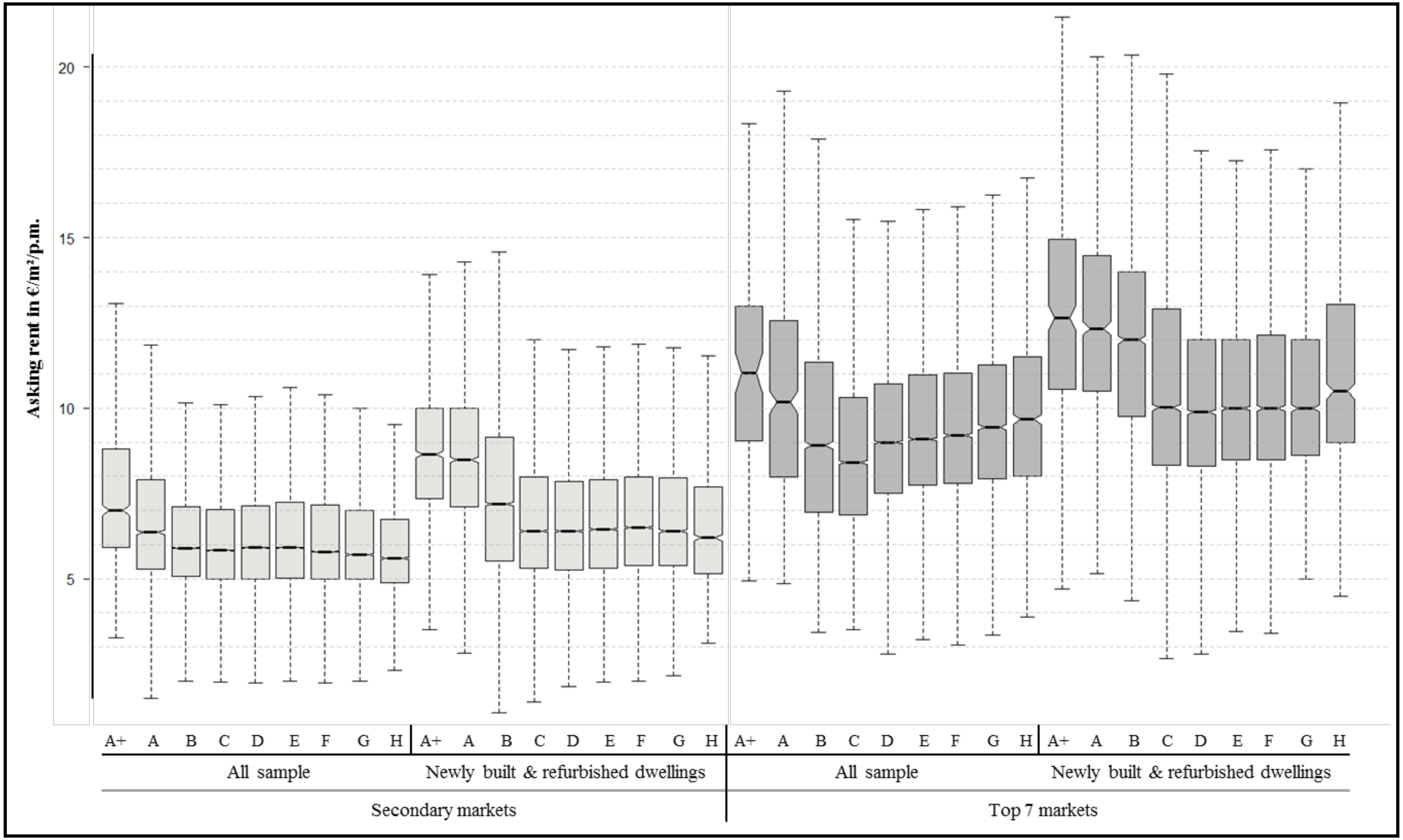
Exhibit 1: Asking rents by EPC category, stock quality and market segments



Notes: Sample includes 570'239 observations of internet offers of rental flats in Germany from 2013-Q1 until 2016-Q4 across 412 NUTS-3 regions. Top 7 defined as Munich, Berlin, Frankfurt, Cologne, Hamburg Stuttgart and Dusseldorf.

Exhibit 2: Descriptive Statistics

Variables		**Descriptive Statistics**				**Correlation matrix Correlation below the diagonal in %**																		
		Mean	**Sd**	**Min**	**Max**	**i**	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**	**ix**	**x**	**xi**	**xii**	**xiii**	**xiv**	**xv**	**xvi**	**xvii**	**xviii**	**xix**
Rent in €/m²/p.m.	i	7.10	2.48	1.01	49.09																			
Energy consumption kWh/m²/p.a.	ii	128.94	53.54	1	1000	-0.96																		
Area in m²	iii	69.89	27.10	8	527.44	7.16	-3.48																	
Age	iv	50.18	30.83	-1	115	-10.09	20.62	-4.76																
Number of rooms	v	2.60	0.94	1	9	-9.80	-0.79	77.95	-1.59															
With bathtub	vi	0.56	0.50	0	1	0.02	-3.92	16.74	-1.72	13.94														
With built-in-Kitchen	vii	0.36	0.48	0	1	36.05	-0.59	11.08	-11.45	-2.25	5.61													
With balcony	viii	0.61	0.49	0	1	8.18	-7.97	17.42	-23.08	15.52	11.13	4.86												
With park slot	ix	0.44	0.50	0	1	13.74	-10.86	22.81	-37.23	11.62	8.52	20.53	14.35											
With balcony and terrace	x	0.69	0.46	0	1	11.78	-9.82	24.06	-30.53	18.83	10.82	8.88	84.49	20.92										
With terrace	xi	0.13	0.34	0	1	13.18	-5.69	20.34	-15.86	8.57	5.36	11.08	1.26	17.30	25.78									
With elevator	xii	0.20	0.40	0	1	22.19	-12.71	4.67	-21.21	-6.11	1.56	8.75	13.11	11.07	14.04	4.24								
Brand new dwelling	xiii	0.04	0.20	0	1	18.42	-12.96	9.71	-12.34	4.54	-0.17	1.32	3.98	8.70	5.09	9.28	13.32							
Refurbished dwelling	xiv	0.19	0.43	0	1	6.92	4.13	2.60	7.80	0.53	2.33	3.82	-0.75	2.72	-1.16	-0.59	-1.13	-1.08						
As-good-as-new dwelling	xv	0.05	0.22	0	1	10.17	-7.57	8.39	-11.10	1.92	1.79	8.54	2.81	12.60	5.43	6.93	6.23	-2.76	-0.71					
Longitude	xvi	9.93	2.41	5.90	15.00	-2.00	-18.48	-8.18	15.77	-9.41	9.36	5.14	-3.44	-5.80	-4.88	0.18	5.93	1.46	-1.80	1.557				
Latitude	xvii	51.25	1.51	47.41	55.02	-19.83	4.56	-9.47	14.54	-3.35	-1.04	-3.12	-3.82	-23.57	-6.78	-6.30	-5.27	-3.62	-5.19	-7.85	8.93			
Purchasing power per household in €/p.a.	xviii	41'791.10	6'999.50	30'048	70'032	36.46	7.87	17.48	-29.97	9.53	-1.59	21.55	9.67	29.71	15.47	9.28	0.56	3.16	3.19	4.68	-45.81	-44.41		
Inhabitants per household	xix	1.96	0.16	1.68	2.47	-18.77	3.68	11.62	-26.01	12.96	-4.94	1.61	2.94	27.31	7.09	4.43	-12.87	-0.21	-1.23	1.97	-40.39	-33.71	66.59	

Notes: Sample includes 570’239 observations of internet offers of rental flats in Germany from 2013-Q1 until 2016-Q4 across 412 NUTS-3 regions.

Exhibit 3: Semiparametric regression results on log rent – Secondary markets

Coefficient (t-Value)	Secondary German urban areas									
	All sample					Refurbished, as-good-as new and initial let				
	I	II	III	IV	V	I	II	III	IV	V
EPC – A+	0.017	0.023	0.038	0.041		0.002	0.016	0.036	0.040	
(ref: D)	3.741***	5.500***	11.363***	12.702***		0.475	2.843***	8.220***	9.415***	
EPC – A	0.014	0.016	0.023	0.030		0.007	0.012	0.026	0.033	
(ref: D)	5.122***	6.164***	11.224***	15.083***		1.757*	3.012***	8.104***	10.666***	
EPC – B	0.000	0.005	0.014	0.018		-0.007	-0.006	0.007	0.014	
(ref: D)	0.696	4.719***	14.32***	18.995***		-2.947***	-2.864***	4.093***	8.089***	
EPC – C	-0.007	-0.003	0.004	0.006		-0.011	-0.008	0.000	0.002	
(ref: D)	-7.327***	-4.087***	6.243***	9.571***		-5.896***	-4.600***	-0.477	2.006**	
EPC – E	0.009	0.008	0.000	0.000		0.012	0.006	-0.002	-0.003	
(ref: D)	10.297***	10.009***	0.470	-1.360		6.224***	3.693***	-1.829*	-2.455**	
EPC – F	0.011	0.010	-0.005	-0.006		0.020	0.012	-0.003	-0.005	
(ref: D)	10.291***	9.888***	-6.462***	-8.943***		8.795***	6.177***	-2.176**	-3.769***	
EPC – G	0.007	0.003	-0.013	-0.014		0.023	0.017	0.000	-0.003	
(ref: D)	4.203***	2.138**	-10.758***	-12.734***		6.621***	5.565***	-0.167	-1.404	
EPC – H	-0.010	-0.011	-0.015	-0.017		-0.008	-0.011	-0.019	-0.018	
(ref: D)	-3.838***	-4.695***	-8.302***	-9.756***		-1.433	-2.252**	-4.929***	-4.896***	
Log energy					-0.021					-0.018
consumption					-31.104***					-14.903***
Log area	-0.094	-0.121	-0.143	-0.606	-0.605	-0.081	-0.104	-0.135	-0.634	-0.634
	-54.491***	-76.805***	-112.897***	-54.124***	-54.055***	-24.087***	-34.347***	-55.776***	-29.803***	-29.783***
Age	-0.003	-0.002	-0.002	0.013	0.014	-0.001	-0.001	0.000	0.000	0.000
	-13.29***	-10.103***	-12.34***	3.429***	3.643***	-3.888***	-2.331**	-1.85*	0.112	0.159
Number of rooms	-0.021	-0.007	0.000	-0.003	-0.003	-0.018	-0.006	0.002	-0.003	-0.003
	-33.59***	-13.795***	1.960**	-7.969***	-7.961***	-14.631***	-6.086***	2.659***	-4.344***	-4.342***
Inhabitants per		-0.637	1.194	-0.194	-0.164		-0.687	0.962	-0.430	-0.441
household		-227.252***	30.99***	-0.982	-0.827		-123.483***	12.529***	-2.930***	-2.985***
Unemployment		-0.044	0.071	-0.016	-0.014		-0.046	0.055	-0.017	-0.017
rate		-284.584***	20.358***	-1.672*	-1.532		-146.679***	7.869***	-2.001**	-2.046**
Log population		0.046	0.164	0.103	0.104		0.061	0.152	0.113	0.112
		89.514***	49.885***	13.192***	13.247***		59.877***	23.843***	8.158***	8.147***
Hedonic characteristics	+	+	+	+	+	+	+	+	+	+
Construction dummies	+	+	+	+	+	+	+	+	+	+
Quarterly dummies	+	+	+	+	+	+	+	+	+	+
County dummies	-	-	+	+	+	-	-	+	+	+
Semiparametric splines	-	-	-	+	+	-	-	-	+	+
N	465’458					122’054				
R²	33.81	45.50	66.04	68.78	68.77	36.74	48.96	68.87	71.81	71.80

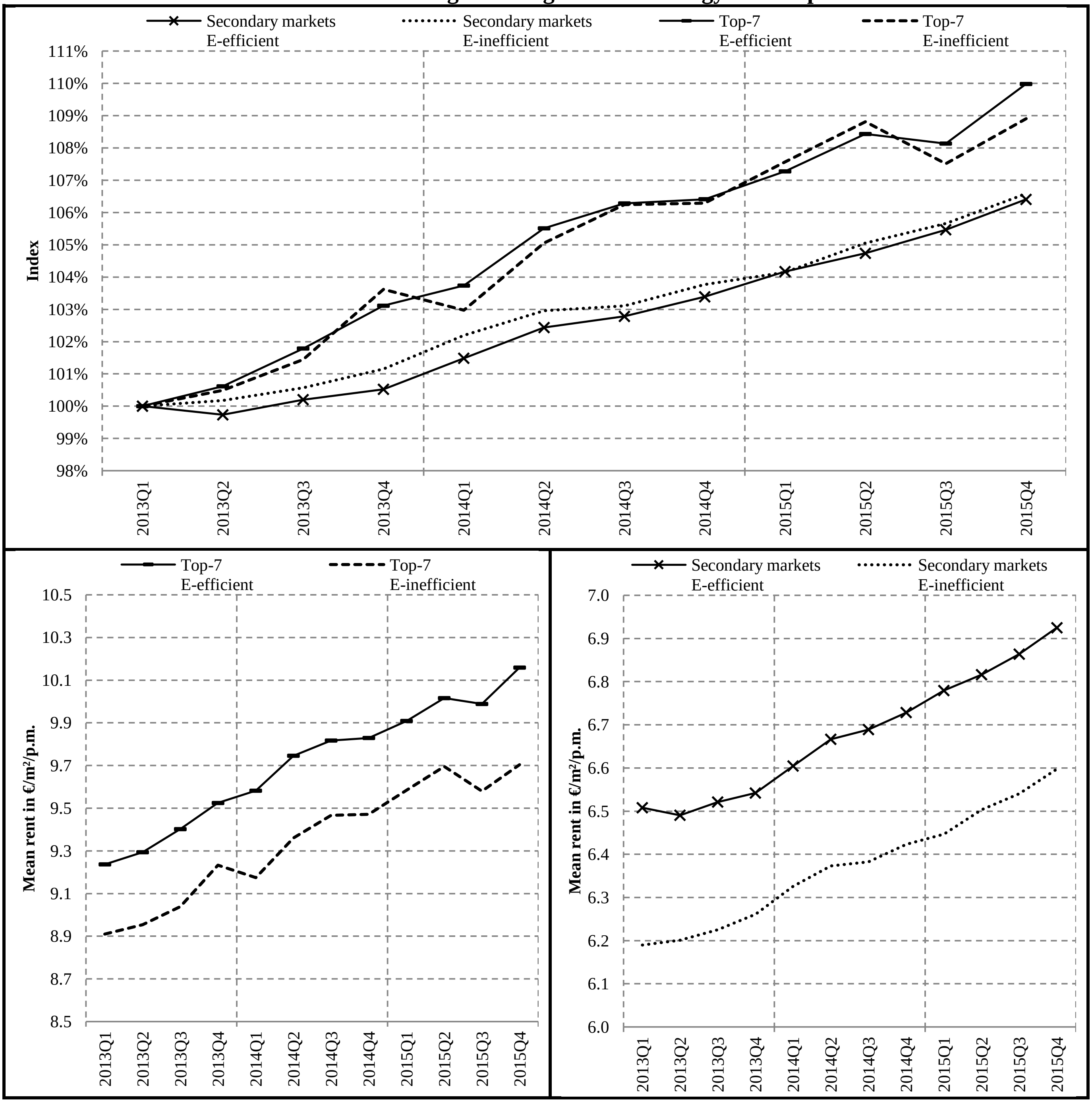
Notes: Models I estimated via OLS. Models II until V estimated via backfitting algorithm as a GAM with splines of metric. Statistical significant at: ‘*’10, ‘’**’5 and ‘***’ 1 percent levels. Subsamples generated due to RAM-allocation limitation higher than 16 GB as. Top 7 defined as Munich, Berlin, Frankfurt, Cologne, Hamburg Stuttgart and Dusseldorf.

Exhibit 4: Semiparametric regression results on log rent – Top 7 markets

Coefficient (t-Value)	Top 7 German markets									
	All sample					Refurbished, as-good-as new and initial let				
	I	II	III	IV	V	I	II	III	IV	V
EPC – A+	-0.024	-0.024	-0.028	0.007		-0.035	-0.035	-0.036	0.008	
(ref: D)	-2.400**	-2.400**	-3.099***	0.997		-2.980***	-2.980***	-3.455***	0.910	
EPC – A	-0.046	-0.046	-0.033	-0.011		-0.041	-0.041	-0.027	-0.009	
(ref: D)	-7.213***	-7.213***	-5.811***	-2.290**		-4.966***	-4.966***	-3.701***	-1.496	
EPC – B	-0.030	-0.030	-0.010	0.007		-0.030	-0.030	-0.009	0.006	
(ref: D)	-9.455***	-9.455***	-3.487***	2.974***		-5.630***	-5.630***	-1.902*	1.555	
EPC – C	-0.019	-0.019	-0.005	0.007		-0.007	-0.007	0.003	0.012	
(ref: D)	-8.587***	-8.587***	-2.881***	4.038***		-1.841*	-1.841*	0.963	4.010***	
EPC – E	0.010	0.010	0.007	0.001		0.016	0.016	0.017	0.011	
(ref: D)	5.361***	5.361***	4.135***	1.213		4.604***	4.604***	5.553***	4.143***	
EPC – F	0.013	0.013	0.007	0.001		0.014	0.014	0.010	0.003	
(ref: D)	5.912***	5.912***	3.961***	0.937		3.643***	3.643***	3.150***	1.201	
EPC – G	0.028	0.028	0.023	0.008		0.033	0.033	0.030	0.009	
(ref: D)	9.029***	9.029***	8.290***	3.587***		6.287***	6.287***	6.406***	2.334**	
EPC – H	0.045	0.045	0.038	0.008		0.071	0.071	0.058	0.015	
(ref: D)	8.875***	8.875***	8.265***	2.169**		8.543***	8.543***	7.727***	2.425**	
Log energy					0.000					0.003
consumption					0.397					1.312
Log area	-0.097	-0.097	-0.066	-0.590	-0.591	-0.075	-0.075	-0.049	-0.640	-0.641
	-28.222***	-28.222***	-21.34***	-28.873***	-28.957***	-13.354***	-13.354***	-9.706***	-21.529***	-21.559***
Age	-0.001	-0.001	-0.004	-2.565	-2.585	-0.003	-0.003	-0.006	-0.001	0.007
	-3.728***	-3.728***	-9.090***	-4.500***	-4.544***	-3.795***	-3.795***	-7.749***	-0.058	0.359
Number of rooms	0.000	0.000	-0.006	-0.009	-0.009	0.006	0.006	-0.002	-0.006	-0.006
	0.424	0.424	-5.756***	-8.619***	-8.565***	3.103***	3.103***	-1.135	-3.533***	-3.655***
Hedonic characteristics	+	+	+	+	+	+	+	+	+	+
Construction dummies	+	+	+	+	+	+	+	+	+	+
Quarterly dummies	+	+	+	+	+	+	+	+	+	+
County dummies	-	-	+	+	+	-	-	+	+	+
Semiparametric splines	-	-	-	+	+	-	-	-	+	+
N	104’781					34’472				
R^2	43.86	53.76	55.28	66.57	66.56	42.77	52.40	54.27	66.16	66.12

Notes: Models I estimated via OLS. Models II until V estimated via backfitting algorithm as a GAM with splines of metric. Statistical significant at: ‘*’10, ‘’**’5 and ‘***’ 1 percent levels. Subsamples generated due to RAM-allocation limitation higher than 16 GB as. Top 7 defined as Munich, Berlin, Frankfurt, Cologne, Hamburg Stuttgart and Dusseldorf.

Exhibit 5: Hedonic rental indices of dwellings with high and low energy consumption



Notes: Indices estimated as theoretical portfolios of energy efficient (≤ 125 kWh/m²/p.a.) and inefficient dwellings as dummy hedonic models without imputation based on the "Handbook on Residential Property Prices" of Eurostat.

Exhibit 6: Parametric survival Cox-ph regression results on time-on-market in weeks

Exp(coefficient)	Secondary German urban areas						Top 7 German markets					
Z-Value	All sample			Refurbished, as-good-as new and initial let			All sample			Refurbished, as-good-as new and initial let		
Log energy		0.940			0.975			0.943			0.986	
consumption		-10.919***			-2.646***			-5.500***			-0.845	
EPC – A			0.991			0.977			1.048			1.046
(ref: A+)			-0.310			-0.659			0.872			0.748
EPC – B			1.055			1.040			1.066			1.064
(ref: A+)			1.960**			1.193			1.305			1.138
EPC – C			1.048			1.068			1.052			1.112
(ref: A+)			1.723*			1.963**			1.028			1.874*
EPC – D			1.029			1.052			1.130			1.185
(ref: A+)			1.053			1.510			2.487**			2.995***
EPC – E			1.012			1.041			1.089			1.139
(ref: A+)			0.435			1.189			1.727*			2.286**
EPC – F			0.979			1.010			1.046			1.113
(ref: A+)			-0.782			0.293			0.910			1.863*
EPC – G			0.928			0.941			0.954			1.022
(ref: A+)			-2.615***			-1.612			-0.918			0.360
EPC – H			0.909			0.895			0.964			1.064
(ref: A+)			-3.123***			-2.441**			-0.651			0.882
Log asking rent	0.992	0.987	0.985	0.996	0.993	0.993	0.535	0.537	0.536	0.597	0.597	0.598
	-0.699	-1.111	-1.238	-0.189	-0.284	-0.296	-29.666***	-29.511***	-29.621***	-13.894***	-13.864***	-13.858***
Log area	0.993	0.993	0.993	0.994	0.994	0.994	0.993	0.993	0.993	0.994	0.994	0.993
	-17.746***	-17.798***	-17.803***	-8.871***	-8.880***	-8.889***	-13.239***	-13.177***	-13.404***	-8.510***	-8.495***	-8.615***
Age	1.000	1.001	1.000	1.009	1.009	1.009	1.011	1.011	1.011	1.017	1.017	1.017
	0.005	0.386	0.292	3.388***	3.509***	3.438***	4.007***	4.078***	4.036***	3.498***	3.520***	3.470***
Number of rooms	1.075	1.075	1.076	1.086	1.086	1.086	1.153	1.152	1.156	1.185	1.185	1.186
	20.072***	20.125***	20.239***	11.872***	11.843***	11.908***	19.966***	19.86***	20.318***	13.523***	13.507***	13.571***
Socioeconomic variables	-	-	-	-	-	-	+	+	+	+	+	+
Hedonic characteristics	+	+	+	+	+	+	+	+	+	+	+	+
Construction dummies	+	+	+	+	+	+	+	+	+	+	+	+
Quarterly dummies	-	-	-	-	-	-	-	-	-	-	-	-
County dummies	-	-	-	-	-	-	+	+	+	+	+	+
N	465'458			122'054			104'781			34'472		
Pseudo-R²	65.61%	65.63%	65.65%	66.37%	66.37%	66.40%	64.72%	64.73%	64.80%	66.25%	66.25%	66.33%

Notes: Models estimated as right censored proportional Cox-Ph models via R-package "survival" without semiparametric covariates.
Statistical significant at: '*'10, '**'5 and '***' 1 percent levels. Subsamples generated due to RAM-allocation limitation higher than 16 GB as.
Top 7 defined as Munich, Berlin, Frankfurt, Cologne, Hamburg Stuttgart and Dusseldorf.