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Real estate companies' size and the production of energy-efficient housing services: Evidence from Germany's apartment housing market

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Real estate companies' size and the production of energy-efficient housing services: Evidence from Germany's apartment housing market

Abstract

This paper investigates the effect of a housing company's size on the outcome of energetic refurbishment. We argue that economies of scale and economies of scope have an impact on the production of energy-efficient housing services. To test our hypothesis, we use unique data on 102,307 apartment houses in Germany. Besides owner characteristics and refurbishment effort, we introduce several control variables, to capture vintage, size and spatial effects. We find strong evidence for the presence of firm-specific, in particular size, effects on the energetic outcome of refurbishment. For example, large housing companies reduce real energy requirements of a building by 39.96% in the case of full refurbishment. In contrast, single-unit owners increase energy efficiency by only 15.93%. Moreover, the absolute differences between company types increase with refurbishment effort.

Keywords: green real estate, refurbishment, firm size, economies of scale, economies of scope

JEL-Classification: R31, R32, Q48

1. Introduction

While a large number of studies exist on the demand for housing services, the supply side of the market has attracted comparatively little attention in real estate research (Dipasquale, 1999; Gyourko, 2009; Rosenthal, 1999; Olsen, 1987). As Stuart S. Rosenthal states in his JREFE editorial note, “It is unlikely that lack of interest [in housing supply] is the reason. Rather, I suspect there is a widespread belief that adequate data do not exist”(Rosenthal, 1999, p. 5). Ten years later, Joseph Gyourko found in his review of the literature (Gyourko, 2009) that data availability has changed dramatically, but studies on housing supply still lag behind. However, for a complete understanding of housing markets, both, demand and supply are of crucial interest.

This study adds to the understanding of housing service production by addressing investment decisions of different types of landlords. In this context, studies on the quality of housing services regularly distinguish between two types of real estate: owner-occupied and rental housing. This paper makes a case for the impact of housing companies’ size on the outcome of refurbishment within the rental housing segment. The previous literature in this context indicates that professional housing companies, compared to private landlords, might be able to benefit from advantages due to their firms’ size in different ways. In particular, it is found that larger firms produce higher levels of housing services (see Malpezzi and Shilling, 2000), earn significantly higher rents as a result of professional portfolio management (see Hardin et al., 2009), and at the same time show a better operating performance than smaller landlords (see Benjamin et al., 2007). This outcome is found to be a result of a non-linear rent–vacancy relationship which indicates (when assuming that higher rents are paid for higher levels of housing services, and vacancy increases with rent level) the ability of large housing firms to produce housing services at lower average costs than smaller landlords. This, however, has not been confirmed empirically.

In contrast, size economies, economies of scale and scope as well as effects of organizational learning, are addressed in the literature on the construction industry (Myers, 2008). While there is a larger number of studies, building on the work of Eccles (1981), on supply chain organization (economies of scope), only a few early empirical studies deal

with the issues of economies of scale or size economies (Herzog, 1963; Maisel, 1953; Fleming, 1965, 1967; Stevens, 1975) in house building. Nevertheless, these studies indicate that larger firms have cost advantages compared to smaller construction enterprises.

In this paper, we empirically assess the effects of housing companies' size on the outcome of energetic refurbishment. From a theoretical perspective, we argue that economies of scale and scope, learning and professionalism in real estate portfolio management induce cost advantages in construction and higher revenues for larger housing companies. Against this background, we expect that, compared to single-unit owners, larger housing companies produce higher levels of energy efficiency when refurbishing a house. For the empirical analysis we use a unique sample of "energy certificates" for 102,307 apartment houses in Germany.¹

The remainder of our paper is structured as follows: in the next section we briefly outline our expectations on the effects of housing companies' size in the context of housing service production. We develop a simple theoretical model to motivate our hypothesis. The third section describes the data employed and the estimation methodology, and presents and discusses the results. Section 4 offers our conclusions.

2. Motivation and Hypothesis

This paper focuses on the comparison of energetic refurbishment outcomes of private landlords and larger housing companies. The underlying assumption is that construction costs of large and small firms differ, as has been proposed by various authors for real estate developers (see Herzog, 1963; Fleming, 1965, 1967; Stevens, 1975). Previous studies were mainly conducted on new construction projects and thus focus on activities of real estate development companies. However, in the refurbishment context private landlords and housing companies act as producers of housing services (comparable to real estate developers). They incrementally decide about the level of housing services produced by maintenance, refurbishment or new construction efforts (Arnott et al., 1983). We thus assume that most attributes that are found to affect real estate developers' cost functions

¹We are grateful to ista Germany GmbH for providing the data.

also hold for companies and private landlords that are mainly concerned with renting flats.

2.1. Economies of Scale

Economies of scale in refurbishment can be expected for larger housing companies. In contrast to private landlords or smaller firms, mostly holding only a single building or few buildings, larger companies in many cases own several buildings at one site or several buildings of a more or less identical type which can, as Stevens (1975) demonstrates for multi-family housing in the US, reduce average construction and refurbishment costs. Sources are identified in:

1. recurring project characteristics,
2. adoption of standardized construction processes, techniques and materials (Gann, 1996; Kinzy, 1992; Buzzelli and Harris, 2006),
3. quantity discount for purchasing materials and services,
4. higher flexibility in labour use (Stevens, 1975; Maisel, 1953),
5. access to financial resources (Somerville, 1999) and
6. lower capital costs (Ambrose et al., 2005; Bogdon and Ling, 1998).

Substantially similar arguments are presented for the construction sector (Ball, 2006).

2.2. Economies of Scope

Apart from the aspects mentioned, it is reasonable to assume that housing companies gain experience in energetic refurbishment over time. Presumably, due to the durability of housing, single-unit owners refurbish a dwelling once in their lifetime and thus have a 'single attempt' to achieve a desired energetic standard. A company's knowledge on how to combine different techniques and materials can be repeatedly used for other refurbishment projects and thus should enter the production function of refurbishment cost reduction, because this could allow firms to vertically integrate real estate development tasks such as planning, architectural services or supervision.

As Ronald Coase (1937) introduced in his seminal paper on transaction costs, vertical integration of processes and services allows larger firms to reduce costs of production. In the real estate refurbishment context, this might be the case when different stages

of project development can be pursued within one real estate company. It is reasonable to assume that vertical integration of, for example, project planning is rational when a company is sufficiently large and processes can be repeated within the firm. In contrast, smaller firms and private investors have to buy these services at market prices, which could lead to higher average costs of a refurbishment project. But vertical integration is not a necessary condition to realize advantages in transaction cost reduction. As Eccles (1981) proposed, Williamsonian transaction costs can be reduced by subcontracting between project developers/real estate companies and other firms (see Eccles (1981); Williamson (1979); Somerville (1999)). It is argued that ‘quasi-firms’ (Eccles, 1981) reduce costs by a higher degree of trust between contractual partners accompanied by a higher frequency of transactions and higher transaction-specific investments. This is more likely to be the case when real estate companies own a larger housing portfolio and refurbishment or renovation activities can be repeated.

2.3. Effects on Revenue

Beyond production costs, the size of housing companies might play an additional role in the energetic refurbishment context: Benjamin et al. (2007) show that branding has a positive impact on rents. Brounen and Kok (2011) demonstrated that energy labels are capitalized in higher housing prices. Given that branding is costly and pays off in the long run, large housing companies should benefit almost exclusively from such strategy. Nevertheless branding is not the predominant strategy in apartment housing markets (see Hardin et al., 2009, p. 286) but signalling quality to customers is important. In this context, signalling by energy efficiency may be an attractive substitute for a brand, since climate change is prominently discussed in politics and in the media. Given that energy efficiency is a costly housing attribute, a strategy of large companies towards long-run lettability (compared to their competitors) could trigger them to play their cost advantage against smaller competitors and to refurbish their property at a significantly higher level (Benjamin et al., 2007; Ben-Shahar, 2004).

2.4. A Theoretical Model

Summarizing the arguments lets conclude that the size of a housing company (ranging from a single unit owner to a large firm) affects the cost function of refurbishment and

construction as well as the revenue. In general, larger firms should be able to finish a project at lower costs while receiving higher revenues compared to smaller landlords. This should have an impact on the energetic outcome when the level of investment for refurbishing is chosen according to the standard optimization problem: the yield is maximized when marginal costs equal marginal revenues.

Theoretically, this relationship can be formulated as follows: let each housing firm's revenue, $R(e)$, be a function of the level of energy efficiency, e , and an additional effect of signalling, a parameter $b > 0$, where $R'(e) \geq 0$, $R''(e) \leq 0$, and $\lim_{e \rightarrow 0} R'(e) = \infty$. Let the cost of extending e be $\frac{1}{s} \cdot C(e)$, where $C'(e) > 0$ and $C''(e) > 0$. The coefficient $s > 0$ refers to the firm size. Thus a housing firm's profit function, π , is given by

$$\pi = bR(e) - \frac{1}{s} \cdot C(e). \quad (1)$$

A maximization approach for π leads to the following determination equation:

$$0 = bR'(e) - \frac{1}{s} \cdot C'(e). \quad (2)$$

Let the solution to (2) be denoted by e^* . Because $R''(e) - \frac{1}{s} \cdot C''(e^*) < 0$, e^* constitutes a unique solution.

Against this background, we derive the following proposition regarding the effect of an increasing housing firm's size on the optimal level of energy efficiency:

Proposition 1.

Larger housing firms produce higher overall energy efficiency when refurbishing a house.

Proof.

Totally differentiating (2) with respect to e and s leads to

$$\frac{de^*}{ds} = \frac{-\frac{1}{s^2} \cdot C'(e^*)}{bR''(e^*) - \frac{1}{s} \cdot C''(e^*)} > 0. \quad (3)$$

Since $C'(e) > 0$ and $bR''(e) < 0$.

Moreover, it can be expected that signalling leads to higher revenues and thus to a

higher overall energy efficiency. Consequently, Proposition 2 should hold.

Proposition 2.

Signalling leads to a higher overall energy efficiency when refurbishing a house.

Proof.

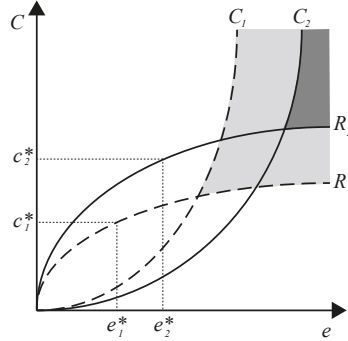
Totally differentiating (2) with respect to e and b , we get

$$\frac{de^*}{db} = \frac{-R'(e^*)}{bR''(e^*) - \frac{1}{s} \cdot C''(e^*)} > 0. \quad (4)$$

An illustration for both aspects is given in Figure 1, where two large housing companies of different sizes (s_1, s_2) face the optimization problem of refurbishment, decreasing marginal revenues and increasing marginal costs of housing service production: the steeper construction cost curve (C_1) refers to the smaller company (s_1) while C_2 refers to the larger company (s_2) which has comparative advantages in housing service production. Since in buy-to-let markets, landlords do not directly profit from energy (cost) conservation, tenants' willingness to pay for energy efficiency improvements limits the revenues. Assuming these as being largely exogenously determined while there might be a small difference due to signalling², maximizing the yield of investment should lead to different levels of energy efficiency e^* . Thus, given $s_1 < s_2$ and $b_1 < b_2$, it follows that $e_1^* < e_2^*$.

²It is implicitly assumed that the firm size does not affect revenues from investment besides the aspect mentioned, even though there is reason to believe that monopolistic power or a higher concentration of larger firms might have an impact on rents (Arnott, 1995). Moreover, it is assumed that both types of firms calculate with an identical economic lifetime of the investment and identical tax treatments.

Figure 1: optimal investment by housing companies s_1 and s_2



2.5. Hypotheses

Given these assumptions and against the background of the literature on real estate construction, we aim to test the following hypotheses on the outcome of energetic refurbishment empirically:

Hypothesis 1) In general, we expect housing companies' size to significantly affect refurbishment outcomes

More specifically:

Hypothesis 2) Refurbishment outcomes should increase with firm size

Hypothesis 3) Differences between firm-specific refurbishment outcomes should increase with project size

3. Empirical Analysis

To test the formulated hypotheses, we use a unique dataset for multi-family housing in Germany and its real energy demand. The following paragraphs describe the data used, the variables introduced to the model and the methodology employed in greater detail.

3.1. Empirical Strategy

We test our hypotheses by modelling the natural logarithm of the energy coefficient per square metre (EC)³ of a building (i) as a function of (self-reported) refurbishment efforts (R_j where $j = 1...5$, the sum of refurbished parts of a building) interacted with dummies for three firm types (F) (single-unit owner (O), small housing companies (S) and large housing companies (L); see Table 2), which are identified by the number of owned flats. Moreover, we introduce several control variables (X) to our model, including: the building's age (age in years by age-classes), its size (number of flats by size-classes) and its location (planning regions),

$$-\ln(EC)_i = \alpha + \gamma_O \cdot F_i^O + \gamma_L \cdot F_i^L + \sum_{j=1}^5 (\lambda_j \cdot R_{i,j} + \lambda_{O,j} \cdot R_{i,j} \cdot F_i^O + \lambda_{L,j} \cdot R_{i,j} \cdot F_i^L) + \beta \cdot X_i + v_i, \quad (5)$$

where $\alpha, \gamma, \lambda, \beta$ are parameters and v is the i.i.d. error component.

Hypothesis 1 is tested by directly by the coefficients λ_O and λ_L . We expect them to be jointly significantly different from zero (Wald-test), meaning that compared to small housing companies which are the base category, single-unit owners and large housing companies produce different outcomes of refurbishment ($\lambda_O \neq 0$ and $\lambda_L \neq 0$) even when it is simultaneously controlled for unobserved differences of the unrefurbished housing stock (γ_O, γ_L).

Hypothesis 2 states that refurbishment outcomes increase with firm size. In our setup, we expect the coefficient λ_L to be significantly larger or equal to zero (t-test), indicating that for each level of refurbishment effort, larger housing companies' refurbishment outcome is at least equal to the outcome of small housing companies. The opposite relation should hold for single-unit owners: the coefficient λ_O is expected to be exclusively smaller than or at least equal to zero.

Hypothesis 3 can be tested by comparing the difference in the marginal effects of the coefficients λ . Since we expect to find increasing returns to companies' size by

³To improve the readability of our results, we multiplied $\ln(EC)$ by - 1 indicating that estimated positive semi-elasticities can be interpreted as percentage increases in energy efficiency.

refurbishment effort, the difference between the marginal effects of λ_L and λ_O should increase with refurbishment intensity (the difference to the base category should increase by refurbishment effort). In non-technical words, we test the slope of energy-efficiency increases against each other.

3.2. Data and Variable Definition

To test our hypothesis we employ data mainly provided by ista Germany GmbH. In the analysis, energy billing data as well as data from energy certificates is used. Both data sources contain housing-specific information, which is used to compute the variables introduced to the estimation. Further, we use “climatic parameters” provided by the German Weather Service to account for spatial differences of climate and weather in the period of observation (2008).

Energy coefficients. The energy coefficients (EC) for each building (i) are calculated using the established procedure introduced by the Association of German Engineers (Verein Deutscher Ingenieure (VDI)) according to its guideline VDI-3807. As a basis, the raw energy measures (B) for each fuel type (F) (e.g. oil in litres, natural gas in kilowatt-hours (kWh)) for space heating are multiplied by their “heat value” (H) to derive consistent energy consumption measures in kWh per period (t). These measures are adjusted by regional “climatic parameters” (CP), which are available for 8,400 ZIP-code districts (r) and standardized by living space of the dwelling in square-metres (m^2).⁴

$$EC_{i,t} = \frac{(B_{i,t} \cdot H_F \cdot CP_{r,t})}{m^2} \quad (6)$$

EC is a measure for the annual energy requirement of a building per square metre. In our sample of 102,307 buildings, we find energy coefficients ranging from 30.13 to 399.97 kWh/m^2 (see Table 1). On average, multi-family houses in Germany require 136 kWh/m^2 for space heating annually; this is consistent with other studies relying on an identical or a comparable data basis (see Michelsen, 2009; Greller et al., 2010).

⁴For a more detailed description of the climatic parameters see www.dwd.de/klimafaktoren.

Table 1: Descriptive statistics of the dependent variable EC

Variable	Obs.	Mean	St.Dev.	Min	Max
<i>EC</i>	102,307	136.0081	4.921.512	30.13	399.97

Housing Companies' size. Size is measured by counting flats per housing company. In Germany, multi-family housing accounts for approximately 50% of the overall housing stock – roughly 75% is in the rental sector. Almost two thirds of the market for rental flats is owned by private landlords; one sixth is offered by private housing companies. The remaining stock is let by public housing companies, housing co-operatives and the church (see BBSR, 2010). Further, it can be observed that the German buy-to-let market is attracting growing attention of global real-estate investors (see Hesse and Preckwinkel, 2009).

In the literature, there is no consistent classification of firm size and characteristics apart from legal definitions (see BBSR, 2010; Veser et al., 2007). Since we do not have any information about the companies' legal status, we rely on a classification based on the number of flats owned by a company to identify whether it acts as a large housing company or private landlord. As summarized in Table 2, we define “single-unit owner” as landlords owning fewer than 21 flats. “Small housing companies” are defined in a range from 21 up to 1,000 flats. On average, this type of company owns 4.9 houses. “Large housing companies” are understood as being owners of more than 1,000 flats.⁵ In contrast to single-unit owners, we expect the latter type of housing companies to be large enough to run their business exclusively from rental income.

Refurbishment effort. Information on the refurbishment effort relies on self-reported measures of landlords. The introduction of obligatory “energy certificates” for each house, based on European Union regulation (EU, 2002), necessitates that real estate owners

⁵In this context, we face a measurement problem: exact information on firm size is not available for all companies. Large housing companies are for example classified by e.g. “owning >5,000 flats” or “owning >10,000 flats”. For this reason, we have to rely on a dummy classification rather than introducing a metric measure for firm size.

Table 2: Descriptive statistics on housing companies' size

Variable	Single	Small	Large
	unit owners	housing companies	housing companies
	< 21 flats	21-1,000 flats	> 1,000 flats
No. of firms	33,753	8,005	1,464
No. of houses owned	37,106	38,984	26,217
% of houses in sample	36.3 %	38.10%	25.6 %
Av. no. of houses in sample	1.1	4.9	17.9

provide at least raw information on the energetic standards of construction components and their refurbishment efforts respectively. Our database therefore contains information on the period of time when a specific part of a building was refurbished: for example, it is identified whether the windows of a house have been refurbished or replaced within the past 15 years, more than 15 years ago, if they are unrefurbished or if it is unknown. This information is available for the five, from the energy consumption perspective, most important construction parts of a house: roof, facade, windows, basement ceiling and heating system. Based on this information, we derived a set of dummy variables indicating the overall refurbishment effort, measured by the number of refurbished construction parts. We created 10 interaction terms by multiplying these variables with a set of dummy variables indicating whether the building is owned by a “single-unit owner” or a “large housing company” respectively. In this context, refurbishment effort of small housing companies is the base category. Table 3 summarizes frequencies of refurbishment by firm type.

Overall, we observe that nearly 11% of houses in our sample are completely unrefurbished, which means that none of the parts of the building mentioned have undergone major refurbishment “in the past 15 years”. The information was mainly gathered in the years 2008/2009 – thus the lower bound of refurbishment is the year 1993. About 8.2% of houses in our sample are completely refurbished, while about 6.6% are close to being completely refurbished (one major part missing).

Table 3: Refurbishment effort by company types

refurbishment effort	Single	Small	Large	Overall % of refurbishment types
	unit owners	housing companies	housing companies	
	< 21 flats	21-1,000 flats	> 1,000 flats	
Non-refurbished (0 parts)	3,431	4,526	2,900	10.90%
Very low effort (1 part)	7,363	5,295	3,291	15.60%
Low effort (2 parts)	7,017	3,214	1,816	11.80%
Medium effort (3 parts)	4,802	2,275	1,501	8.40%
High effort (4 parts)	2,969	2,025	1,804	6.60%
Full refurbishment (5 parts)	2,148	3,283	2,932	8.40%
Other combination*	3,038	5,865	5,601	14.50%
Built after 1993	6,338	12,501	6,372	24.60%
Total	37,106	38,984	26,217	100.0 %

*Other combinations can be houses where none of the parts were refurbished within the past 15 years while at least one construction component underwent replacement more than 15 years ago and others were reported as being unknown.

Control Variables. Besides the information mentioned in the previous paragraphs, we include several other control variables in our model. Definitions and descriptive statistics are given in Table 4. First, we include dummies indicating the spatial location of the house. This should capture possible differences in market conditions, as is proposed by several authors working on real estate investment and uncertainty (Capozza and Helsley, 1990; Capozza and Li, 2001).

Table 4: Control variables – definition and descriptive statistics

Variable	Definition	Obs.	Mean	Sd.	Min	Max
Size						
Class 2 to 6	Size of building;	47,219	4.5	1.21	2	6
Class 7 to 12	no. of flats by	29,027	9.1	1.72	7	12
Class 13 to 21	housing size classes	11,986	16.4	2.41	13	21
Class >21		14,075	44.9	3.5	22	763
Age						
Before 1919	Age of building	12,116	111.4	30.5	90	408
1919- 1948	in years by vintage	7,149	77.5	7.3	60	89
1949- 1957	classes (as of 2008)	6,056	54.3	2.5	51	59
1958- 1968		14,868	44.7	3.1	40	50
1969- 1978		16,096	35	2.6	30	39
1979- 1983		7,360	26.8	1.4	25	29
1984- 1992		13,451	19.5	2.9	16	24
1993- 2006		25,211	11.6	2.9	2	15
Refurbishment status unknown						
Roof	Dummy variables (0,1),	102,307	0.3	0.46	0	1
Facade	indicating whether the	102,307	0.31	0.46	0	1
Windows	refurbishment status is	102,307	0.29	0.45	0	1
Basement ceiling	known (base category)	102,307	0.36	0.48	0	1
Heating system	or unknown (1)	102,307	0.27	0.44	0	1

Moreover, there is evidence for differences in construction materials and techniques over time and space which have to be considered when refurbishment is analysed (Klauff et al., 2009). Thus, apart from the regional component captured in the dummies' for planning regions (ROR), we include measures for the age of housing. To account for age cohort specific housing attributes, we differentiate between vintage classes of buildings and interact them by their respective age in years. Moreover, the regional variables capture possible heterogeneity of differing housing market and socio-economic conditions, that may affect the level of refurbishment and energy consumption.

Moreover, there is evidence for differences in the refurbishment outcome according to the building's size (e.g. due to differences in the ratio of living space to the exterior surface of a building). Last but not least, we introduce dummy variables if the refurbishment

status of a specific part of the house is reported “unknown”. In total, our model consists of 141 regressors, including a constant. For clarity, we present selected results in the following subsection. The fully specified model is documented in the appendix.

3.3. Results

We estimated the model specified in Equation 1 using ordinary least squares (OLS). The results are presented in Table 6 and 10. Since the Breusch-Pagan test strongly rejects homoscedasticity ($F(140, 102,166) = 6.92$), we employ Huber-White corrected standard errors. Overall, our model has significant explanatory power for roughly 30 % ($R^2 = 0.2999$) of total variation.

Table 5: Model diagnostics

N	R^2	F-test
102,307	0.2995	$F(140, 102,166) = 312.02^{***}$

First we refer to the coefficients of the average energy-efficiency gains for different projects (see Table 6). The coefficients show the expected positive sign and significance at the 1% level. Semi-elasticities can be interpreted as average energy-efficiency gains from refurbishment. As depicted in Figure 2 and Table 7, energy conservation of projects with very low and low effort is comparatively small. On average, a 2.1% increase for very low effort and a 4.7% increase of the energy efficiency for low effort projects can be observed. In contrast, full refurbishment leads to an increase of energy efficiency of approximately 26.2%. Generally, as expected, efficiency gains increase with project size.

Additionally, based on our empirical analysis, we can draw four specific findings regarding the impact of housing companies’ size on refurbishment outcome and housings’ overall energy efficiency.

Finding 1: Company size affects refurbishment outcome. We find evidence for a company-specific influence on the energy-efficiency of refurbished apartment housing. Particularly

Table 6: Estimation results: effects of refurbishment

Variable		Coefficient		t-value	Standard Error
Average effects of	very low effort	0.0209	***	4.10	0.0051
	low effort	0.0470	***	7.60	0.0062
	medium effort	0.1228	***	16.67	0.0074
	high effort	0.1786	***	22.49	0.0079
	full refurbishment	0.2616	***	37.32	0.0070
Single-unit owner \times	very low effort	0.0102		1.56	0.0065
	low effort	- 0.0045		- 0.61	0.0074
	medium effort	- 0.0481	***	- 5.48	0.0088
	high effort	- 0.0728	***	- 7.33	0.0099
	full refurbishment	- 0.1023	***	- 9.99	0.0102
Large housing company \times	very low effort	- 0.0144	*	- 1.95	0.0074
	low effort	0.0042		0.45	0.0093
	medium effort	0.0830	***	7.62	0.0109
	high effort	0.1330	***	12.39	0.0107
	full refurbishment	0.1380	***	15.75	0.0088
	Single-unit owner	0.0474	***	13.04	0.0036
	Large housing company	- 0.0015		- 0.45	0.0034
	Constant	- 5.1489	***	- 301.42	0.0171

***, * indicate significance at 1%, 10% levels of confidence; Huber-White standard errors in parentheses.

we find that housing company's firm size has significant impact on refurbishment outcomes. According to our hypothesis 1, we expected to find the coefficients for the interaction terms of firm types and refurbishment effort to be significantly different from zero. To confirm this outcome, we jointly tested for differences between coefficients using the Wald-test (see Table 7), which strongly rejects the hypothesis of equality. Thus, our first Hypothesis can be confirmed.

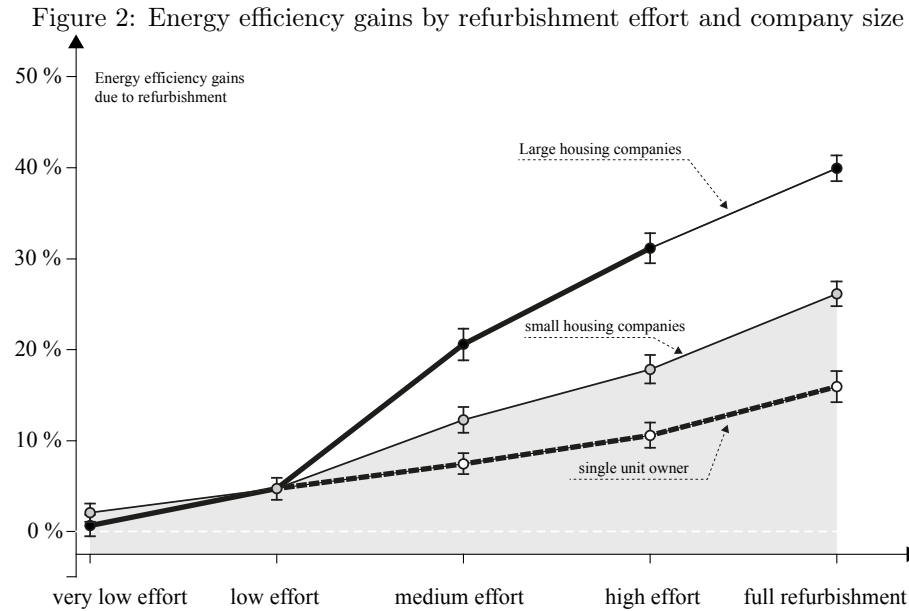
Table 7: Marginal effects (energy efficiency gains); Wald-test H_0 : marginal effect = 0

	Marginal effect	Standard error	χ^2	
Single unit owner				
very low effort	03.11 %	0.0050	38.57	***
low effort	04.25 %	0.0051	68.59	***
medium effort	07.47 %	0.0059	160.53	***
high effort	10.58 %	0.0071	223.38	***
full refurbishment	15.93 %	0.0087	338.45	***
small housing companies				
very low effort	02.09 %	0.0051	16.85	***
low effort	04.70 %	0.0062	57.73	***
medium effort	12.28 %	0.0074	278.05	***
high effort	17.86 %	0.0079	505.71	***
full refurbishment	26.16 %	0,0070	1392.73	***
large housing companies				
very low effort	00.65 %	0.0061	1.15	
low effort	05.12 %	0.0077	44.29	***
medium effort	20.58 %	0.0088	544.17	***
high effort	31.15 %	0.0085	1340.16	***
full refurbishment	39.96 %	0.0071	3133.38	***
Joint			4674.89	***

*** indicate significance at 1% level of confidence

Finding 2: Larger housing companies (mostly) produce higher energy efficiency gains. The second Hypothesis states that refurbishment outcomes should increase with firm size. More specifically, we expected to find positive coefficients for large housing companies or at least no differences (insignificant coefficients) to the base category. Indeed, we observe the expected significantly positive signs for medium effort to full refurbishment projects, while the energy efficiency gains of low effort projects do not differ compared with small housing companies (see table 6). However, in contrast to our expectations, the coefficient for very low effort projects is negative at the 10% level of confidence. This indicates that larger housing companies obviously face diseconomies of scale for these types of refurbishment projects. Additionally, the Wald-test (see Table 7) in this context

indicates that homes which undergone very low effort refurbishment by large housing companies do not have a higher energetical quality in comparison to non-refurbished dwellings (the marginal effect does not significantly differ from zero).



Whiskers represent 95% confidence bands; Insignificant coefficients are not reported. Bold lines indicate significantly deviating slopes in energy efficiency increases compared to the base category.

The opposite is expected for single-unit owners: while differences compared to the base category cannot be observed for very low and low effort projects, single-unit owners' medium, high and full refurbishment efforts produce significantly less energy-efficiency. For full refurbishment, we estimated an accumulated average efficiency gain of 15.93%, which is clearly below the outcome of large housing companies (39.96%). Similar results can be observed for high (31.16% vs. 10.58%) and medium effort (20.58% vs. 7.47%) refurbishment. To summarize, Hypothesis 2 can be confirmed for projects of medium to full refurbishment. No advantages or disadvantages to scale respectively can be observed for low and very low effort.

Finding 3: Larger housing companies (mostly) profit from increasing returns to scale by project size. As formulated in Hypothesis 3, differences between company types should

increase by refurbishment effort. As one can see (Table 6, Table 8 and Figure 2), the difference of the marginal effects increases by project size. We conclude that large housing companies benefit from the advantage of scale economies and economies of scope especially in very low to high effort projects. Small firms significantly underperform large housing companies in energetic refurbishment. This is particularly true for the energy efficiency gains between low and full refurbishment projects. While only small firm-size specific variation is observable in small projects, the difference for full refurbishment accumulates up to 24.03% (high effort: 20.58 %; medium effort: 13.11 %) between single-unit owners and large housing companies.

Table 8: Wald-test for differences in energy efficiency increases (Δ) by refurbishment effort and company size

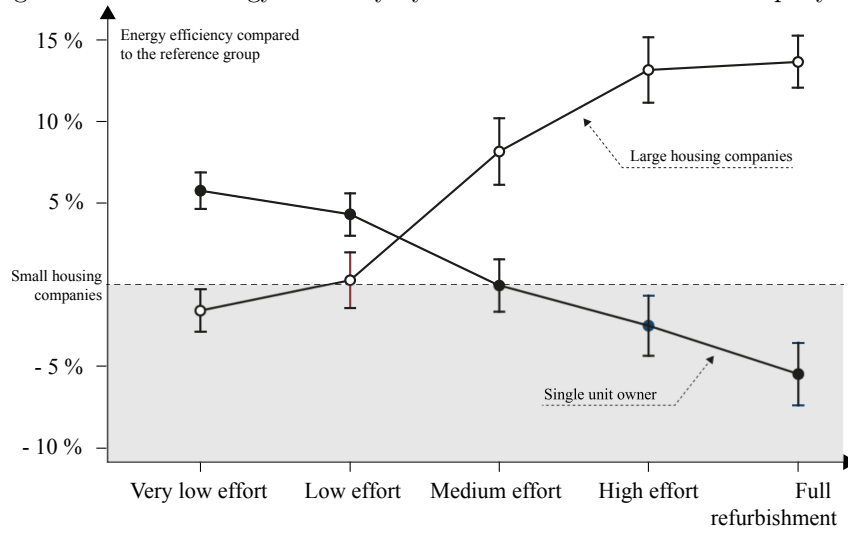
	difference	standard error	χ^2	
ΔSingle unit owners vs. Δsmall housing companies				
Δ Non-refurbished to very low effort	0.0102	0.0065	2.43	
Δ Very low effort to low effort	-0.0146	0.0085	2.97	*
Δ Low effort to medium effort	-0.0437	0.0103	17.97	***
Δ Medium effort to high effort	-0.0247	0.0122	4.06	**
Δ High effort to Full refurbishment	-0.0296	0.0133	4.93	**
ΔLarge housing companies vs. Δsmall housing companies				
Δ Non-refurbished to very low effort	-0,0144	0.0074	3.78	*
Δ Very low effort to low effort	0,0186	0.0110	2.91	*
Δ Low effort to medium effort	0,0788	0.0135	34.03	***
Δ Medium effort to high effort	0,0499	0.0144	11.97	***
Δ High effort to Full refurbishment	0,0050	0.0129	0.15	
Joint Test			1041.52	***

***, **, * indicate significance at 1%, 5%, 10% levels of confidence; differences indicate deviation from the base group (small housing companies).

Finding 4: Overall, single unit owners own “better” low quality housing, while large housing companies produce higher levels of energy efficiency in the medium to high quality segment. When comparing the overall energy efficiency (by including firm specific level effects), the disadvantages of single unit-owners are partly offset by a slightly higher

housing quality of single unit owners' non-refurbished homes. Overall, the level of energy efficiency is higher in single unit owners non-refurbished, very low and low effort refurbished houses. In contrast, the overall energy efficiency is highest in medium effort to full refurbished homes of large housing companies (see figure 3 and table 9).

Figure 3: Overall energy efficiency by refurbishment effort and company size



Whiskers represent 95% confidence bands; normalized to housing quality of small housing companies.

Table 9: Wald-test for differences in overall energy efficiency by refurbishment effort and company size

	marginal effects	standard error	χ^2	
Single unit owners vs. small housing companies				
Non-refurbished	4.74 %	0.0036	169.93	***
Very low effort	5.76 %	0.0057	103.64	***
Low effort	4.30 %	0.0066	42.04	***
Medium effort	0.67 %	0.0082	0.01	
High effort	- 2.54 %	0.0094	7.28	***
Full refurbishment	- 5.50 %	0.0097	31.99	***
Large housing companies vs. Small housing companies				
Non-refurbished	- 0.15 %	0,0034	0.20	
Very low effort	- 1.59 %	0,0066	5.74	**
Low effort	0.27 %	0,0088	0.10	
Medium effort	8.15 %	0,0104	61.30	***
High effort	13.14 %	0,0103	164.55	***
Full refurbishment	13.64 %	0,0082	280.09	***
Joint Test			1245.9	***

***, ** indicate significance at 1%, 5% levels of confidence; marginal effects indicate deviation from the base group (small housing companies).

Table 10: estimation results for control variables

Variable		Coefficient		t-value	Standard Error
Unknown refurbishment status of	roof	0.0079		1.63	0.0049
	facade	- 0.0245	***	- 5.04	0.0049
	windows	0.0019		0.42	0.0045
	basement ceiling	0.0173	***	4.40	0.0039
	heating system	0.0277	***	6.53	0.0042
Size class	class 3- 6 flats	base category			
	class 7- 12 flats	0.0207	*	1.81	0.0115
	class 13- 21 flats	0.0346		1.58	0.0219
	class > 21	0.2155	***	27.57	0.0078
Size x	Size	0.0122	***	9.47	0.0013
	class 7- 12 flats	- 0.0019		- 1.14	0.0016
	class 13- 21 flats	- 0.0052	***	- 2.87	0.0018
	class > 21	- 0.0120	***	- 9.28	0.0013
Vintage class	before 1919	base category			
	1919- 1948	0.1054	**	2.52	0.0418
	1949- 1957	- 0.1675	*	- 1.84	0.0910
	1958- 1968	0.1237	***	3.21	0.0385
	1969- 1978	0.2062	***	5.95	0.0347
	1979- 1983	0.4287	***	5.88	0.0729
	1984- 1993	0.3443	***	15.66	0.0220
	1994- 2006	0.9814	***	66.43	0.0148
Age x	Age	0.0003	***	2.65	0.0001
	1919- 1948	- 0.0013	**	- 2.41	0.0005
	1949- 1957	0.0038	**	2.30	0.0017
	1958- 1968	- 0.0013		- 1.55	0.0008
	1969- 1978	- 0.0029	***	- 3.09	0.0009
	1979- 1983	- 0.0102	***	- 3.81	0.0027
	1984- 1993	- 0.0066	***	- 7.07	0.0009
	1994- 2006	- 0.0476	***	- 65.73	0.0007

***, **, * indicate significance at 1%, 5%, 10% levels of confidence; Huber-White robust standard errors.

The control variables show the expected signs for size and age, as proposed in the previous literature (see Leth-Petersen and Togeby, 2001; Michelsen and Müller-Michelsen, 2010; Greller et al., 2010; Schröder et al., 2009; Brounen et al., 2012). Further, we find significantly lower energy coefficients for new dwellings built after 1993, which is in line with our expectations. Moreover, spatial differences are found to be present. Most of the dummy variables for planning regions show up significantly (see appendix), indicating an influence of regional (market) conditions today and in history. However, this should also be subject to further research.

4. Conclusions

In this paper we investigated the relationship between housing companies' size and the energetic outcome of refurbishment. Motivated by production theory arguments (i.e. economies of scale and economies of scope) in the context of the few available studies on housing service production, we expected refurbishment quality (energy efficiency gains) to differ between three types of housing companies (single-unit owner, small and large housing companies). As empirical basis, we employed a unique dataset (overall containing information on more than 300,000 apartment houses in Germany; after data consolidation our sample consists of 102,307 buildings) provided by the energy billing service provider ista Germany GmbH. As endogenous variable, energy coefficients, based on real energy consumption, were used as a proxy for housing quality. To test our hypothesis, we further introduced a set of variables defining the refurbishment effort and dummies for different company types according to their size. We further tested for vintage and size effects of buildings. Additionally, we controlled for spatial differences on the level of German planning regions.

Our results strongly suggest an impact of housing companies' size on refurbishment outcome. For projects with high effort, we found that energy efficiency gains differ significantly. Further, we found that energy efficiency gains increase by firm size, which allows us to conclude that the assumed effects of scale are present. Hypothesis 3 states that differences between refurbishment outcomes should diminish with decreasing effort. The comparison of the magnitude of the average energy efficiency supports our hypothesis. However, for low effort projects, differences between firm types can barely be detected.

This allows us to conclude that, in general, differences decrease by lower refurbishment effort. An interesting result is found for very low effort projects: our estimation suggests that larger housing companies produce significantly lower housing quality compared to smaller firms. This might be explained by several reasons: first, there might be differences in the maintenance effort between single unit owners and professional landlords. In many cases, single unit owners live in or close to their rental property. This might reduce the so called “rental externality”. It has been shown that in comparison to maintenance efforts undertaken by owner-occupiers, insecurity about tenants’ utilisation of the dwelling creates incentives for landlords to under maintain their property (Henderson and Ioannides, 1983; Iwata and Yamaga, 2008). Landlords might be more familiar with tenants behaviour if they get frequently in touch. Additionally, if people are more familiar with the attributes of their property (due to spatial proximity or owner-occupation), they might be more effective in finding small vulnerabilities and in fixing those with low refurbishment effort. In contrast, if large housing companies undertake low effort refurbishment, their fixed costs might be higher (e.g. if they maintain in house planning departments), which c.p. reduces the budget for construction material (the thermal quality of construction parts). Finally, it also might be that this finding is partly a result of the measurement of refurbishment effort. Possibly, respondents did not make a clear-cut distinction between maintenance and refurbishment, which should especially affect the results for low effort projects. However, this should be subject to further research.

Our findings add to the empirical literature on housing supply in general. More specifically we provide new evidence for scale economies in real estate project development and refurbishment. Moreover, we add to the broad recent literature dealing with strategies on energy conservation in the private household sector.

In this context, our results potentially have a high policy impact. First of all, we demonstrated that even after full refurbishment (under the conditions of the past fifteen years) energy conservation did not even approximately match the politically defined energy conservation targets. For example, officials in Germany announce possible energy efficiency gains up to 80% (Discher et al., 2010). Moreover, our results imply that housing companies cannot be treated equally in this context. The findings suggest that matching the political goals in climate protection (a carbon neutral housing stock until 2050, see

BMWi and BMU, 2010) is challenging, especially for single-unit owners who account for roughly 50% of the residential buy-to-let housing sector in Germany. At this point differentiated strategies should be chosen to establish an effective regime of incentives for energetic refurbishment. For instance, a strategy might be to support low cost activities for energy conservation, such as the installation of smart meters offering tenants real-time monitoring of energy consumption. In this context, other studies show encouraging results (Hargreaves et al., 2010; Burgess and Nye, 2008).

Finally, some limitations of this study and questions for future research should be addressed. First, it would be interesting to disentangle the effects of size and to explicitly measure for example the impact of experience in energetical refurbishment. Second, it would be challenging to estimate real cost functions for energetic refurbishment by different types of housing companies. Our data contains only rough measures on refurbishment efforts, and using dummy variables in this context is not satisfactory – however, extensive data on the real costs of construction, the exact nature of refurbishment activities and, for instance, revenues related to energy conservation are hard to come by.

Finally, regional market conditions, especially the specific risk structure of investment, should be addressed in the energetic refurbishment context. Since in buy-to-let markets, the changes in the net rent define the revenue of energetic refurbishment, it can be questioned to which extent landlords are able to assert a desired rent increase, if for example there is excess supply in the market. It is reasonable to assume that in markets with a high risk of vacancy, investment tends to be lower. In the firm size context, it would be worthy to investigate if, for example, larger housing companies are able to benefit from green investment by reducing their firm specific risk of vacancy and if this could be a strategy towards sustainable real estate investment.

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Appendix: Results for regional dummies

Variable		Coefficient		t-value	Standard errors
Planning region (ROR)	01	-0.0522	**	-2.08	0.0251
	02	-0.1557	***	-6.11	0.0255
	03	-0.0465	***	-2.96	0.0157
	04	-0.1443	***	-5.85	0.0247
	05	-0.1384	***	-8.81	0.0157
	06	-0.1364	***	-11.11	0.0123
	07	0.0370	**	2.43	0.0152
	08	0.1768	***	11.26	0.0157
	09	0.0046		0.30	0.0153
	10	0.0155		0.78	0.0199
	11	-0.1612	***	-12.04	0.0134
	12	-0.1961	***	-10.63	0.0184
	13	-0.1708	***	-11.08	0.0154
	14	-0.1230	***	-9.09	0.0135
	15	-0.1385	***	-9.36	0.0148
	16	-0.2002	***	-14.03	0.0143
	17	-0.1918	***	-7.78	0.0246
	18	-0.0273		-1.58	0.0172
	19	-0.0395	***	-2.99	0.0132
	20	-0.0827	***	-3.29	0.0251
	21	-0.0687	***	-3.45	0.0199
	22	-0.0187		-1.32	0.0142
	23	-0.0359	**	-2.06	0.0175
	24	0.0054		0.21	0.0252
	25	-0.0429	**	-2.55	0.0168
	26	0.0269		1.11	0.0243
	27	-0.0939	***	-4.12	0.0228

Variable	Coefficient		t-value	Standard errors
28	-0.0097		-0.64	0.0150
29	-0.1198	***	-8.11	0.0148
30	-0.1498	***	-13.28	0.0113
31	-0.0559	***	-3.54	0.0158
32	-0.0980	***	-6.01	0.0163
33	-0.0586	***	-4.05	0.0145
34	-0.0421	***	-2.94	0.0143
35	-0.0745	***	-6.21	0.0120
36	-0.0887	***	-6.70	0.0132
37	0.0027		0.08	0.0355
38	-0.0556	***	-3.32	0.0168
39	-0.0783	***	-5.95	0.0132
40	-0.0597	***	-4.69	0.0127
41	-0.1004	***	-8.21	0.0122
42	-0.1967	***	-16.20	0.0121
43	-0.1392	***	-11.44	0.0122
44	-0.2082	***	-18.36	0.0113
45	-0.0950	***	-7.32	0.0130
46	-0.1849	***	-16.21	0.0114
47	-0.1385	***	-7.21	0.0192
48	-0.0169		-1.23	0.0137
49	-0.0772	***	-5.80	0.0133
50	0.1333	***	5.73	0.0232
51	-0.1954	***	-17.46	0.0112
52	-0.1555	***	-12.02	0.0129
53	0.0175		0.57	0.0306
54	0.0412	***	2.83	0.0146
55	0.1380	***	6.96	0.0198
56	0.0124		0.65	0.0192

Variable	Coefficient		t-value	Standard errors
57	0.0262	**	2.16	0.0121
58	0.0950	***	7.77	0.0122
59	0.0553	***	3.85	0.0144
60	0.0310	**	2.46	0.0126
61	0.0686	***	5.04	0.0136
62	-0.0594	***	-4.27	0.0139
63	-0.0477	**	-2.50	0.0190
64	-0.2076	***	-12.93	0.0161
65	-0.1098	***	-5.52	0.0199
66	-0.1268	***	-8.93	0.0142
67	-0.1108	***	-7.13	0.0156
68	-0.0727	***	-6.13	0.0119
69	-0.0242		-1.41	0.0171
70	-0.0966	***	-7.13	0.0136
71	0.0324	**	2.09	0.0155
72	-0.0623	***	-5.39	0.0116
73	-0.0156		-0.99	0.0157
74	-0.0056		-0.38	0.0146
75	-0.0252	*	-1.76	0.0143
76	0.0597	***	2.78	0.0215
77	0.0267	*	1.94	0.0138
78	0.0017		0.13	0.0127
79	0.0051		0.23	0.0217
80	-0.0810	***	-4.07	0.0199
81	-0.0459	***	-2.85	0.0161
82	-0.0044		-0.32	0.0140
83	0.0183		1.05	0.0173
84	base category			
85	0.1007	***	2.97	0.0339

Variable	Coefficient		t-value	Standard errors
86	-0.0552	***	-4.46	0.0124
87	0.0239		1.05	0.0228
88	-0.1030	***	-6.31	0.0163
89	-0.0258		-1.30	0.0198
90	0.0068		0.31	0.0218
91	0.0520	***	2.82	0.0185
92	0.0005		0.03	0.0175
93	-0.0048		-0.40	0.0120
94	-0.0382	**	-2.32	0.0165
95	0.1522	***	6.88	0.0221
96	0.0774	***	4.98	0.0155
97	0.0933	***	6.26	0.0149

***, **, * indicate significance at 1%, 5%, 10% levels of confidence; Huber-White robust standard errors.