Discussion Papers in Economics

No. 10/2018

What is the Information Value of Energy Efficiency Certificates in Buildings?

Andreas Mense
University of Erlangen-Nürnberg

ISSN 1867-6707

Friedrich-Alexander-Universität Erlangen-Nürnberg
Institute for Economics
https://www.iwf.rw.fau.de/research/iwf-discussion-paper-series/

What is the Information Value of Energy Efficiency Certificates in Buildings?[1]

Andreas Mense

School of Business and Economics, University of Erlangen-Nuremberg, Findelgasse 7, 90402 Nuremberg, Germany, andreas.mense@fau.de

Abstract

I study the information value of energy efficiency certificates. By using data on repeatedly observed buildings, I separate the rent premium for certified energy efficiency from the premium for readily observable energy efficiency. The buildings were observed before, in-between and after two consecutive law changes that first made certification compulsory and then introduced fines for non-compliers. The strategy allows to control for time-fixed effects of the buildings and for changes in energy efficiency premia over time. I find a precisely measured, but economically and statistically insignificant effect of certification. Supplementary analysis suggests that consumers do value energy efficiency per se, and that energy cost savings translate into higher rents 1-by-1. Further, in a simple theoretical framework, I study the channels through which certification of buildings affects energy consumption. One implication from theory is that compulsory certification is unlikely to be welfare-increasing, even if certificates carry additional information. Given the empirical results of this paper, it is almost certainly welfare-decreasing.

Keywords: certification; energy efficiency; information asymmetry; value of information.

1. Introduction

In recent years, there has been great interest in policies that aim to inform agents who make sub-optimal economic choices. Proponents of this view stress the great potential to realize large welfare gains at incredibly small costs (Allcott and Mullainathan, 2010). However, there has been a vivid debate around the central assumption, namely that choices are misinformed (Gerarden et al., 2017). In many instances, empirical results are fully consistent with the conventional view of rationally deciding consumers when it comes to energy efficiency

[1] I thank Ines Kusmenko for excellent research assistance.

investments in buildings (Fowlie et al., 2018; Levinson, 2016; Allcott and Greenstone, 2017; Sandler, 2018) or fuel economy of cars (Busse et al., 2013; Sallee et al., 2016; Allcott and Knittel, 2017)[1].

This paper studies the information value of energy efficiency certificates in rental housing. The existing literature has analyzed energy efficiency labels without controlling for the extent to which energy efficiency is observable to buyers or renters, irrespective of certification. Recent examples include Eichholtz et al. (2010, 2013), Brounen and Kok (2011), Mense (ming), and Walls et al. (2017). While these papers find large premia for certified relative to uncertified units, they cannot differentiate between premia for energy efficiency and for the certificate per se. For instance, a potential tenant inspecting a unit offered for rent can observe whether windows are single- or double-glazed. Clearly, the information value of the certificate will be lower in cases where many other indicators for energy efficiency are readily observable.[2]

I focus on two consecutive law changes in Germany. The first change in May 2014 made certification compulsory when offering housing units for rent. The second change in May 2015 introduced fines for non-compliance. Both led to sharp increases in the share of units offered with a certificate. Figure 1 below plots the evolution of the share of certified units among rental units offered on three large online market places for rental housing in Germany.[3] The two dashed vertical lines indicate the dates of the law changes, in May 2014 and May 2015. The share jumped two months before the second law change, which is sensible since landlords have to take into account marketing time.

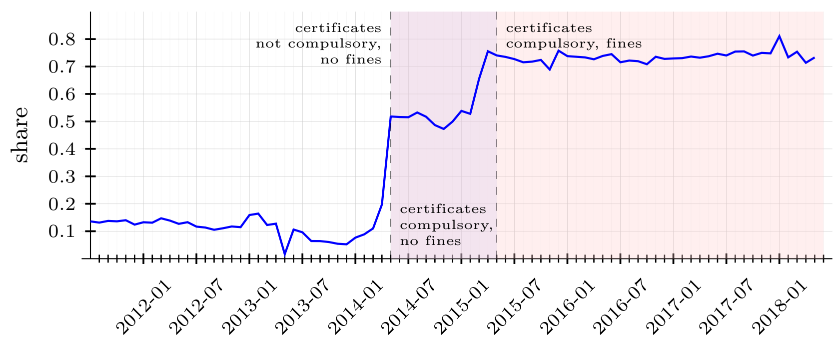
The empirical strategy exploits within-building variation and compares the rent premia for certified and non-certified energy requirement in the three re-

[1] In contrast to Busse et al. (2013), Allcott and Wozny (2014) find price premia for fuel efficiency that are smaller than the present value of potential cost savings, although this reading depends much on assumptions about discount rates and remaining lifetimes.

[2] In case all relevant characteristics are readily observable, a certification premium could still result from salience effects.

[3] I restricted the sample to units that were offered with a valid address and a year of construction. The shares are lower when other units are considered as well, but the pattern is very similar.

Figure 1: Share of offers with an energy efficiency certificate



The shares are calculated among offers that indicate the exact address and the year of construction.

sulting cases, by focussing on buildings for which at least one housing unit was offered before certificates became compulsory, when they were compulsory without enforcement through fines, and after fines were introduced. I condition on buildings for which I observe a certificate in the third period, which allows me to assign energy requirement levels also to units that were offered without a certificate in the other periods. The strategy is akin to a difference-in-differences specification, where early-certified and late-certified buildings serve as comparison groups for buildings that first appeared with a certificate in the period in-between the law changes. I can thus control for time-constant building attributes, and for the change in the valuation of certified and uncertified energy efficiency over time. This allows to disentangle the effect of *certified* energy efficiency from the effect of uncertified energy efficiency. The latter might be observable for the renter at least partly even without a certificate. Because both rents and energy costs are flow variables, energy cost-related premia are readily comparable to potential energy cost savings.

One drawback of the empirical strategy is that it does not control for the negative relationship between energy efficiency and building age (see Levinson, 2016). Because buildings in the sample are certified at different points in time, certification at a later point in time under-estimates true energy efficiency at the beginning of the sample period. However, the period under consideration is very narrow (7/2011–3/2018), and I can control perfectly for time-constant effects of baseline energy efficiency through first-differencing. Therefore, the problem should be of minor importance for the results. Secondly, building characteristics are correlated with certification date. In other words, buildings certified under different regimes are different from each other. Again, most differences are stripped off by first-differencing. What I cannot rule out completely is that certificied energy efficiency is valued differently in buildings of different types, which essentially means that the control for *changes* in the valuation is imperfect.

To motivate the empirical analysis, I propose a simple framework that identifies main channels through which voluntary and compulsory energy efficiency certification of buildings influences welfare. Compulsory certification is widespread. Among other EU countries, the UK, Sweden, Portugal, Greece, Poland, and Germany require an energy performace certificate when units are turned over, and certificates expire after ten years. In case certificates are a useful source of information, the general possibility to certify housing units reduces the level of energy required in newly constructed units (absent minimum standards). It also reduces the vintage at which buildings are re-constructed. Assuming that developers of new buildings find it optimal to certify their unit, making certification compulsory does not alter the energy requirement of newly constructed units. However, it shifts up the average vintage of buildings ripe for reconstruction. Total energy required from compulsory certification does not need to decrease in this case, making welfare gains from compulsory certification unlikely even if externalities from energy consumption are quantitatively important.

The paper connects to the literature on (mis-)informed economic agents, policies of information provision, and energy efficiency. It adds to the existing literature in at least three important ways. First, to the best of my knowledge, it is the first attempt to disentangle the information value from certification and the premium for uncertified energy efficiency. I show that the rent premium for reducing the unit's certified energy requirement by one kilowatt hour per square meter and month (kWh/[m$^2 \cdot$ month]) is very close to zero. Even the upper bound of the 95% confidence interval amounts to less than one tenth of the typical energy costs per kWh. Results from supplementary regressions are consistent with the view that potential tenants are able to learn about a unit's energy requirement through other channels, making inattention to energy costs in general unlikely. These results are important because certificates were designed under the assumption that agents cannot learn enough about a unit's energy requirement without having access to a certificate. While this might be true for more complex products such as computers, it does not need to hold for buildings. If certificates for buildings are less useful than previously thought, such policies need not be welfare-enhancing even if its costs are moderate.

Second, I use building fixed effects to identify the rent premium for certified energy efficiency. Even the best of the previous studies suffer from endogenous unobserved building quality. To the extent that this quality is constant over the study period, the strategy of this paper allows to rule out such bias. One drawback of this strategy is that it is not possible to identify the premium for (time-constant) uncertified energy efficiency.

Third, I provide a theoretical framework that deals with the channels through which certification of buildings influences welfare. The special nature of buildings makes it necessary to treat them differently than relatively short-lived consumption goods such as light bulbs, where allmost all units available on the market are replaced by newer models every several years, and where there is no rental market.

While this paper studies rent instead of sales price premia, the main channels should be at work in owner-occupied housing, too. Most importanty, buyers typically inspect houses much more thoroughly than renters. They should thus be able to assemble more relevant information on the unit's energy requirement than renters, so that certificates carry less additional information. The theoretical framework predicts – at best – small effects from making certification compulsory. Under current building regulation, or if there are sizable subsidies for very efficient buildings, the additional effects are likely to be even smaller.

These conclusions are crucial, as policy makers seem to have great hopes that information provision alone can prevent climate change[4] – diminishing their motivation to take more radical action.

The rest of the paper proceeds as follows: The next section lays out the theoretical framework. Section 3 contains the results from the empirical analysis, followed by a short discussion in Section 4. The appendix provides additional material about the data.

2. Theoretical Framework

2.1. Effects on rents

Housing units are characterized by their energy use E that is drawn from a continuous distribution Φ with density ϕ and support $[0, \bar{e}]$. For technical reasons, I assume $\mathbb{P}(E = e) = 0 \; \forall e \in [0, \bar{e}]$. Households gain utility $v - e$ when living in a housing unit that uses energy e.

The owner of an e-housing unit knows the unit's energy demand e, while the renter can only observe e if the owner has acquired an energy efficiency certificate, at fixed administrative cost $a > 0$. Otherwise, the renter observes the distribution of housing units that are offered with a certificate. Let N be the set of energy consumption levels of all non-certified units. A renter has a willingness to pay

$$WTP = \begin{cases} v - e & \text{if the unit has a certificate,} \\ v - \mathbb{E}[E|E \in N] & \text{otherwise.} \end{cases} \tag{1}$$

Equation (1) summarizes the – almost trivial – relationship between (certified) energy efficiency, and prices. If heating costs are observable, prices net of heating costs should decrease with heating costs. Otherwise, prices should not

[4] See, for instance, the energy efficiency directive of the European Union, https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive.

depend on heating costs. The main idea behind certification is to make heating costs observable (and salient), so that they can influence prices.

2.2. Welfare implications of certification schemes

It is worthwhile to study more precisely the welfare implications of energy certification schemes. On the negative side, compulsory certification produces administrative costs. It may have positive effects through reducing externalities related to energy consumption: Owning an inefficient rental unit becomes less attractive due to a reduced stream of future rental income. Hence, older buildings will be demolished and replaced by more efficient ones earlier.

2.2.1. Administrative costs

The mechanism behind the cost side is simply that making certification compulsory triggers redistribution of benefits both within the group of renters and of owners, but it is not cost-free. Formally, for an optimally choosing e-owner without a certificate, it must be that $e + a \geq \mathbb{E}[E|E \in N]$, and vice versa.

Lemma 1. *Let $e \leq e'$ and assume that owners are rational. Owners of e-units always choose to obtain a certificate if there exists a certified e'-unit.*

Proof. First, note that for any $x \in [0, \bar{e}]$, we assumed $\mathbb{P}(\{x\}) = 0$. This implies that $\mathbb{E}[E|E \in N] = \mathbb{E}[E|E \in N \setminus \{x\}]$.

We have $e + a \leq e' + a \leq \mathbb{E}[E|E \in N]$, where the second inequality follows because the e'-unit is certified. Hence, the owner of the e-unit should also obtain a certificate. □

Clearly, there exist distributions Φ and $a > 0$ such that $N \neq \{\bar{e}\}$, and $\mathbb{E}[E|E \in N] = a + e^*$ for some $e^* \in [0, \bar{e})$. From Lemma 1, it follows directly that $N = (e^*, \bar{e}]$.

Consider a policy that requires owners to obtain a certificate at cost a. This affects owners of units with $e \in N$.

Lemma 2. *Let* $N = (e^*, \bar{e}]$. *Under compulsory certification, aggregate owner utility* W *decreases by* $\Delta W = (1 - \Phi(e^*))a$. *Aggregate renter utility* V *remains constant.*

Proof. Let $e \in N$. A renter who happened to rent an e-unit paid a price $p = v - \mathbb{E}[E|E \in N]$ without certification, and $p' = v - e$ with compulsory certification, to gain utility $v - e$.

$$\begin{aligned} \Delta V &= \int_N \mathbb{E}[E|E \in N]\phi(z)dz - \int_N z\phi(z)dz \\ &= (1 - \Phi(e^*))\mathbb{E}[E|E \in N] - (1 - \Phi(e^*))\mathbb{E}[E|E \in N] = 0. \end{aligned} \tag{2}$$

The owner of the e-unit faces an analogous price change that cancels out the renter's utility differential. Furthermore, the owner has to pay a cost a. The aggregate cost is thus $(1 - \Phi(e^*))a$. □

Thus, the immediate consequence of a policy that requires compulsory certification is a welfare loss, as long as certificates are costly to obtain. The welfare loss will be small if certification is not so costly, or if only few units are affected.

Assume that, despite the regulation, owners can still decide to offer units without a certificate. If they get caught, they have to pay a fine f, which happens with probability q. The optimally choosing e-owner certifies if $e + a < \mathbb{E}[E|E \in N] + qf$. From the perspective of the owner, the fine represents an increase of the opportunity costs of evading certification (as compared to the situation with voluntary certification), making certification more likely. Hence, e^* decreases with q and f.

Lemma 3. *Let* $N_e = (e, \bar{e}]$ *for* $e \in [0, \bar{e}]$, *and let there be a fine* $f > 0$ *and a detection probability* q *under compulsory certification. Assume further that fines are redistributed. The utility loss is equal to*

$$\Delta = [\Phi(\tilde{e}^*) - \Phi(e^*)]a, \tag{3}$$

where $\tilde{e}^* > e^*$ *is the solution to* $e + a = \mathbb{E}[E|E \in N_e] + qf$.

Proof. Now, owning a unit without a certificate has become less attractive, as at least some e-units with $e + a \geq \mathbb{E}[E|E \in N_{e^*}]$ face the situation $e + a < \mathbb{E}[E|E \in N_{e^*}] + qf$, so that $\tilde{e^*} > e^*$ eventually. The arguments from Lemma 2 apply, which completes the proof. □

The two Lemmas 2 and 3 clearly show that compulsory certification imposes a welfare cost on owners. In the longer run, however, the resulting change in the willingness to pay for energy efficiency might alter the speed at which buildings are demolished and re-constructed. We now study this possibility.

2.3. Dynamic housing supply response

The preceding section has shown that, from the perspective of the owner, compulsory certification reduces the net revenue stream from very inefficient housing units. In this section, I consider a framework where owners face a stream of revenues r that decrease with building age z, of the form

$$r_e(z) = u \exp(-vz) - e, \qquad u, v > 0, \tag{4}$$

where e represents the discount of a unit with energy efficiency e. For simplicity, we assume that e does not vary with building age, but only with year of construction (through technological progress).[5]

Owners can always choose to rebuild their housing unit at energy level $\tilde{e} < e$, by paying a cost $c(\tilde{e})$, where $c' < 0$, and $c \to \infty$ as $e \to 0$. They discount the future by a factor $1 > \beta > 0$ and maximize their stream of total revenues. Total revenues from a housing unit of age z and energy efficiency e are

$$\int_{t=0}^{\infty} (u \exp(-v(z+t)) - e) \exp(-\beta t) dt. \tag{5}$$

[5] Clearly, this is a simplification. However, in the framework presented here, this assumption is only relevant for the effect of compulsory certification on the date of re-construction. The evidence compiled in Levinson (2016) shows that the relationship between energy efficiency and building age is flat for buildings of older vintage (i.e., around the time they are ripe for demolition).

New construction of an $\tilde{e}$-unit leads to total revenues

$$\int_{t=0}^{\infty} (u \exp(-vt) - \tilde{e}) \exp(-\beta t) dt - c(\tilde{e}). \tag{6}$$

The owner chooses the building age at which to rebuild, $\tilde{z}$, by setting equal the streams of revenues from a new and the existing building. She chooses the new unit's energy requirement by offsetting the negative impact of lower $\tilde{e}$ from construction costs c and the positive impact from reduced rent income, i.e, $\tilde{e}$ solves $1 = -\beta c'(e)$. From (5) and (6),

$$\tilde{z} = -\frac{1}{v} \ln \left\{ 1 - \frac{v+\beta}{u\beta} [\tilde{e} + \beta c(\tilde{e}) - e] \right\}. \tag{7}$$

Conditional on $\tilde{e}$, this is the age at which the stream of revenues from an existing unit equals the stream of revenues from a new unit, net of construction costs. Since the latter term is constant in z, the owner of the building can only lose from postponing reconstruction.

The solution is sensible if the term in curly brackets lies between zero and one, which requires $e > \tilde{e} + \beta c(\tilde{e})$. Intuitively, reconstruction costs net of the discounted stream of energy cost savings need to offset the reduced revenues from having aged $\tilde{z}$ years.

If energy consumption cannot be observed by renters, it does not reduce the rental income stream.[6] Denote the maximum possible energy requirement in new construction by $\bar{e}$, and the average existing unit's energy efficiency by e_m. Then, equation (7) reads

$$\bar{z} = -\frac{1}{v} \ln \left\{ 1 - \frac{v+\beta}{u\beta} [\bar{e} + \beta c(\bar{e}) - e_m] \right\}. \tag{8}$$

Suppose that certificates are available to signal the energy efficiency level. Unless the existing, inefficient unit is certified, the optimal reconstruction age

[6] This is, renters form expectations, so that developers do not have an incentive to provide housing with energy efficiency better than this expected value.

is given by

$$\hat{z} = -\frac{1}{v} \ln \left\{ 1 - \frac{v+\beta}{u\beta} [\hat{e} + \beta c(\hat{e}) - e_m] \right\}, \tag{9}$$

where $\hat{e}$ is the solution to $-c(e) = 1/\beta$. $\hat{e}$ is a unique minimum of the function $e \mapsto e + \beta c(e)$, whereas $\bar{e}$ is not. Hence, $\hat{e} + \beta c(\hat{e}) < \bar{e} + \beta c(\bar{e})$. Because the function $f : x \mapsto -\ln(1-x)$ is strictly increasing in x, it follows that $\hat{z} < \bar{z}$, i.e. buildings get rebuilt earlier. This implies that, in this case, it is optimal to demolish buildings with a higher net present value (as compared to baseline). Voluntary certification of new buildings will be the norm if this difference is large enough to justify the total costs of certification.

Compulsory certification changes the e_m term in (9) to e. The optimal reconstruction age now depends on the individual e, and thus on its distribution in the stock of existing buildings. Since the energy requirement of new units will not be affected by voluntary certification, any effect on total energy consumption can only come from changes in reconstruction dates. Somewhat counterintuitively, the average age at reconstruction cannot decrease:

Lemma 4. *Consider the setting described above, and let $E > \hat{e}$ be a random variable that determines the energy requirement of existing units, where we assume that E is not almost surely constant. If newly constructed units get certified voluntarily, compulsory certification increases the average age at which units are reconstructed.*

Proof. Consider the function $z : e \mapsto B \ln(A + Ce)$ on $(0, \infty)$, where $A, C > 0$. For $B < 0$, z is strictly convex. Jensen's Inequality for strictly convex functions and a random variable that is not almost surely constant states that $\mathbb{E}[z(E)] > z(\mathbb{E}[E])$. □

Clearly, this does not preclude a reduction of total energy consumption. Lemma 4 simply states that the average building will be older when demolished. The fact that certification helps to sort out the least efficient buildings – these will be reconstructed earlier, while more efficient ones will be rebuilt later than before – works in favor of lowering total energy use. Using the notation from the preceding lemma, the net effect is given by the sum of the differences in reconstruction ages, $z(e) - z(\mathbb{E}[E])$, times the energy cost reductions from reconstruction, $e - \hat{e} > 0$:[7]

$$\Delta Q = \int_{e_0}^{e_1} \left[z(e) - z(\mathbb{E}[E])\right](e - \hat{e})\phi(e)de, \tag{10}$$

where the distribution of energy costs in existing buildings around the critical age has support (e_0, e_1). In general, this sum can be positive or negative. In any case, compulsory certification of existing units can only have this effect if it provides important information to potential tenants. The next section is devoted to this empirical question.

3. Empirical Analysis

The most basic question with respect to energy efficiency certificates is this: Do the certificates really provide information to potential buyers? It might well be that the energy use of a dwelling can credibly be signalled by other means, so that a certificate is not necessary. This section attempts to answer this question.

3.1. Setting and Data

The empirical analysis relies on web-scraped rental data, collected between July 2011 and March 2018, from three large online real estate market places that cover Germany as a whole.[8] Roughly 50% of the data points have an address and a house number in a valid format. For a sub-sample of locations (North-Rhine Westphalia, Hamburg, Berlin, parts of Bavaria), official address directories were available that allow to check the consistency of the addresses. 90 to 95% of the addresses from these locations could be confirmed by consulting address directories, based on an exact comparison of standardized address strings. This sub-sample lends itself to verifying the robustness of the results to errors in the addresses.

[7] We assume that this difference is always positive, because of technological progress.
[8] These are Immobilienscout24, Immonet, and Immowelt.

The data contain a long list of housing characteristics, most of which are related to the housing unit itself. The most important ones for the present study are the offered net rent, heating costs (reported in about half of the cases), the living area, the address, the year of construction, and the energy efficiency certificate. The certificate includes an estimate of energy required in kWh/[$m^2\cdot$ month], which is used as the main explanatory variable.

The empirical strategy (described further below) relies on the fact that some buildings in the sample are observed repeatedly, and that energy efficiency certificates are specific to the building, not the individual housing units. It is thus possible to rule out most types of biases from time-constant building attributes. To do so, I restrict the sample to offers that report a building age, and to buildings constructed not later than 2011. Matching was done by comparing standardized address strings. All units observed in a given building were assigned to one of the three periods before May 2014 (pre), May 2014–February 2015 (mid), and March 2015 or later (post). As a consistency check and to identify reconstructions, the algorithm checked whether the difference between year of construction and the year of observation as reported in the post period equaled the building age in the pre- and the mid-periods. The building's energy requirement was set to the energy requirement of the first unit observed in the post-period, in order to further reduce the danger of missing reconstructions.

Then, each unit from the pre-period was matched to a unit from the mid-period (without replacement), by minimizing the variance-scaled distance on the variables number of rooms, living area, floor, balcony, and second bathroom as well as a time difference variable. This variable equaled zero when the units were observed at a time difference of two years, and increased linearly in both directions from that point.

Summary statistic for the full and matched samples are reported in Table 5 in the Appendix. From July 2011 to February 2015, 1 333 007 units with a valid address were observed in Germany. Of these, $2 \times 45\ 324$ could be matched. When compared to their level means, the mean covariate differences in the matched sample are very small, except for the building age. The latter variable indicates that buildings were roughly 1.76 years older when observed for the second time. The exact number based on the time difference in months is 22.3 months, or 1.86 years (not reported in the table). Further details about the data are relegated to Section 5.1 in the appendix.

3.2. Empirical Strategy

I consider buildings for which we observe housing units offered for rent both before and after May 2014, when energy efficiency certificates became compulsory. I condition on buildings for which I observe at least one housing unit in each of the two periods July 2011 – April 2014 and May 2014 – February 2015. Buildings that did not have a certificate in these two periods had to be observed an additional time, between March 2015 and March 2018. Furthermore, all buildings that did not have a unit offered with an energy efficiency certificate until March 2018 were also dropped. Because individual housing unit are observed at least twice, but the certificate refers to the whole building, the building's energy efficiency is known for all units in this sample, whether, at a given point in time, it was offered with or without a certificate. This allows to disentangle the effect of the energy efficiency level as observed without a certificate, and the effect of the label itself.

In the estimation, I focus on the first two periods and consider three cases: units that do not hold a certificate in either period 1 or 2, units that hold a certificate in both periods 1 and 2, and units that obtained a certificate in period 2.

More specifically, assume the rent per square meter of unit i at date t, p_{it}, is a linear function of covariates x_{it}, its energy efficiency level e_i, and its certificate status z_{it}, where $z_{it} = 1$ iff unit i is offered with a certificate at date t:

$$p_{it} = \beta x_{it} + \gamma_t e_i + \delta_t e_i z_{it} + \psi_t + \phi_i. \tag{11}$$

ψ_t and ϕ_i are time- and unit- fixed effects. Equation (11) assumes that the valuation of energy efficiency and of the label are time-varying. Now consider the difference between dates t_0 and t_1 (omitting the time dependency):

$$\Delta p_i = \beta \Delta x_i + \Delta\psi + \begin{cases} \Delta\gamma e_i & \text{if } z_{it_0} = z_{it_1} = 0, \\ (\Delta\gamma + \tilde{\gamma}_{t_1}) e_i & \text{if } z_{it_0} = 0,\ z_{it_1} = 1, \\ (\Delta\gamma + \Delta\tilde{\gamma}) e_i & \text{if } z_{it_0} = z_{it_1} = 1. \end{cases} \tag{12}$$

A regression of the price change on the change in covariates, repeated-sales time dummies, the building's energy efficiency level, and the energy efficiency level interacted with two dummies that capture the certification pattern, thus allows to identify the parameters of interest $\Delta\gamma$, $\Delta\tilde{\gamma}$, and $\tilde{\gamma}_{t_1}$ from equation (12). In this regression, $\tilde{\gamma}_{t_1}$ captures the valuation of the information from the label, $\Delta\tilde{\gamma}$ is the change in this valuation across periods (arguably: from making certificates compulsory), and $\Delta\gamma$ is the change in the valuation of the building's energy efficiency level in offers that do not provide information im form of a certificate.

3.3. Results

3.3.1. Did compulsory certification shift the distribution of reported energy efficiency?

According to the theoretical considerations laid out above, compulsory certification and the introduction of fines should shift the distribution of certified energy efficiency. Figure 2a plots esimates of building-level[9] quantile regressions of the energy requirement on dummies that indicate whether the building had a certificate before May 2014 (in red), or whether it was observed without a certificate before May 2014, but with a certificate between May 2014 and February 2015 (in blue). The omitted category are buildings that were observed without a certificate in the second period, but with a certificate after February 2015.

Clearly, buildings certified already in the first period had much lower energy requirements across the whole distribution. Strikingly, the difference is

[9] This is, each address only appears once in the data. There are 33 535 distinct addresses in the sample.

largest for very inefficient buildings. The picture is more mixed for buildings that appeared with a certificate in the second period for the first time. Here, the difference is slightly positive for more efficient buildings, but again strongly negative for the least efficient buildings. This suggests that compulsory certification and fines predominantly helped to convince owners of very inefficient buildings to obtain a certificate, in line with theory. A similar conclusion follows from Figure 2b that contains kernel density estimates of the energy requirement across the three periods.

3.3.2. Do energy efficiency certificates correlate with reported heating costs?

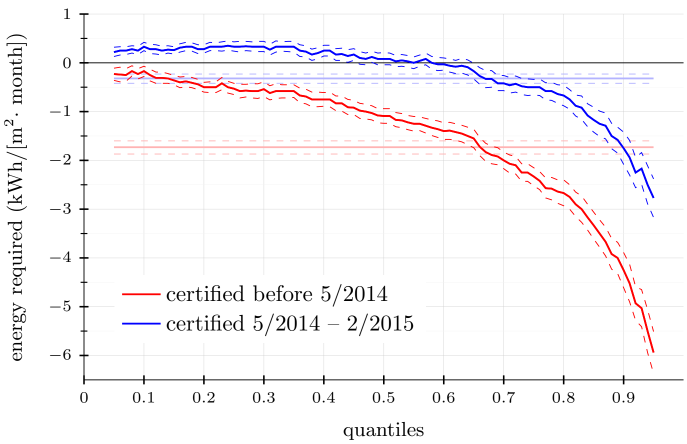
Approximately half of the offers report past heating costs, based on individual assessments by the landlord. For instance, providers typically deliver energy to the building as a whole, which is then distributed among the units. In such a case, the owners of the individual housing units simply pass the costs on to their renters. However, since the way of reporting information about heating costs in this way is not regulated, landlords might understate true energy costs.

Table 1 contains results from regressions of reported energy cost per square meter and month, on energy required per square meter and month (according to the energy efficiency certificate). When considering all units, an increase in energy required by 1 kWh/[$m^2\cdot$ month] increases heating costs by about 2.6 cents (column 1). This is somehwat below the price per kWh of gas (≈ 5 cents), heating oil ($\approx 5-6$ cents), and district heating ($\approx 7-10$ cents).[10] When interacting the energy requirement with these heating types (reference category: gas heating) in column 2, the interaction effect for oil-fueled heating goes into the expected direction, while the interaction effect for district heating is insignificant. The relationship is somewhat stronger if the certificate is based on past energy use (column 3) instead of a model prediction of energy use

[10]Potential reasons are the rebound effect, under-reporting of reported energy costs, but also climate-normalization of energy efficiency scores. Moreover, the energy required measure is calculated per square meter of total use area, which includes staircases, the building entrance, etc., and thus is greater than the building's living area.

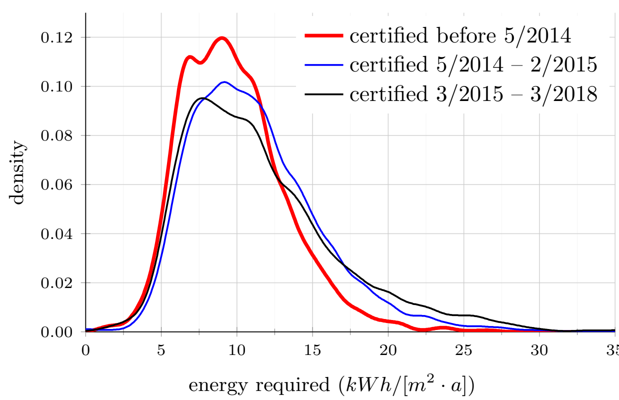
Figure 2: Shifts in the distribution of energy required in the three periods

(a) Quantile regression estimates



The figure plots quantile regression estimates. The horizontal thin lines represent the respective shifts in conditional means; the dashed lines are 95% confidence intervals. The reference category are units that were offered without a certificate before 2/2015, but with a certificate after 2/2015. The red lines refer to units offered with a certificate before 5/2014; the blue lines refer to units first offered with a certificate between 5/2014 and 2/2015.

(b) Kernel density estimates



The red line refer to units offered with a certificate before 5/2014; the blue line refer to units first offered with a certificate between 5/2014 and 2/2015. The black line refers to units that were offered without a certificate before 2/2015, but with a certificate after 2/2015.

(column 4). The adjusted R^2's suggest that the unexplained variation between energy required and reported heating costs is substantial. Potential reasons could be poor performance of energy efficiency certificates to predict energy use, heterogeneity in preferences and energy usage, the rebound effect, and manipulation of reported energy costs (i.e., unter-reporting). In any case, the estimates presented in this table serve as a baseline to which the willingness to pay for certified energy requirement can be compared.

Table 1: Certified energy requirement and reported heating costs

Dependent variable	*heating costs (euro/[$m^2\cdot$ month])*			
	all	all	use-based	model-based
	(1)	(2)	(3)	(4)
energy required	0.026***	0.023***	0.029***	0.019***
(kWh/[$m^2\cdot$ month])	(0.001)	(0.002)	(0.001)	(0.001)
energy required × oil fueled heating		0.010*		
		(0.004)		
energy required × district heating		0.000		
		(0.002)		
energy required × other/NA heating fuels		0.005**		
		(0.002)		
oil fueled heating		-0.120*		
		(0.056)		
district heating		0.065*		
		(0.027)		
other/NA heating fuels		0.002		
		(0.023)		
Observations	25009	25009	19805	5204
Residual standard error	0.37	0.37	0.36	0.40
Adjusted R^2	0.081	0.085	0.090	0.060

The heating type reference category is gas heating. Heteroskedasticity-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

3.3.3. Regression in levels

Setting aside omitted variable concerns, equation (11) is interesting in its own right, because it allows to separate the correlation between the energy efficiency of a unit and its rent from additional effects due to certification. Table 2 presents estimates of equation (11), separately for the two periods.[11] The regression in column 1 controls for zip code an time fixed effects (months) as well as unit characteristics. It suggests that net rents per square meter decrease by 2.8 cents per kWh required, irrespectively of whether the building held a certificate or not. This point estimate is remarkably close to the correlation between reported energy costs and energy required. The two interaction effects are very close to zero, suggesting that the correlation between energy required and rents was similar in units offered with and without a certificate. When

[11] Covariate results can be found in Table 6 in Appendix 5.2.

adding a third-order polynomial in year of construction (column 2), the correlation between non-certified energy required and rents shrinks drastically. This is in line with the idea that the price mechanism aggregates readily observable information about the building in a very efficient way, which includes information about its energy requirement.

Columns 3 and 4 repeat the exercise for the sub-sample of offers in the second period, with very similar results. In column 5, this sub-sample is further restricted to units offered without an indication of reported heating costs, but this does not seem to matter for the valuation of certified energy efficiency.

Table 2: Regression in levels: Do certificates matter?

	Dependent variable: rent per sqm				
Sample period	before 5/2014		5/2014–2/2015		
	(1)	(2)	(3)	(4)	(5)
energy required × certified May 2014–Feb 2015	-0.003	-0.003	-0.004	-0.004	-0.001
	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)
energy required (kWh/[$m^2\cdot$ month])	-0.028***	-0.012**	-0.027***	-0.012**	-0.012
	(0.004)	(0.004)	(0.004)	(0.005)	(0.007)
energy required × certified before May 2014	-0.003	0.005	-0.004	0.005	0.003
	(0.010)	(0.009)	(0.011)	(0.010)	(0.012)
certified before May 2014	0.088	0.028	0.067	-0.021	-0.051
	(0.118)	(0.112)	(0.135)	(0.125)	(0.151)
certified May 2014–Feb 2015	-0.005	0.030	-0.048	-0.014	-0.106
	(0.066)	(0.065)	(0.071)	(0.070)	(0.097)
year of construction, linear term		29.867***		26.180***	27.304***
		(3.477)		(3.489)	(3.313)
year of construction, quadratic term		58.613***		58.459***	42.876***
		(3.501)		(3.589)	(3.419)
year of construction, cubic term		30.612***		31.907***	23.726***
		(3.757)		(3.888)	(3.809)
Zip code FE	yes	yes	yes	yes	yes
time FE	yes	yes	yes	yes	yes
heating costs reported	yes/no	yes/no	yes/no	yes/no	no
Observations	43951	43951	43951	43951	18804
Residual standard error	0.93	0.91	0.96	0.94	0.98
Adjusted R^2	0.808	0.819	0.811	0.821	0.838

The polynomial in year of construction uses an orthogonal base. Zip code cluster-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

3.3.4. Regression in differences

Table 3 displays the main estimation results for the differences equation (12). Coefficient estimates for the control variables in regressions (2)–(6) can be found in Table 7 in Appendix 5.2. The first three rows of table 3 show the coefficient estimates for $\tilde{\gamma}_{t_1}$, and $\Delta\tilde{\gamma}$, and $\Delta\gamma$, respectively.

Table 3: The willingness to pay for certified energy efficiency

	Dependent variable: difference in rent per sqm					
	(1)	(2)	(3)	(4)	(5)	(6)
energy required [$\Delta\gamma$]	0.002	0.003	0.003	0.001	0.003	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)
energy required × certified before May 2014 [$\Delta\tilde{\gamma}$]	0.002	0.000	-0.000	0.002	-0.007	0.007
	(0.004)	(0.004)	(0.004)	(0.005)	(0.013)	(0.005)
energy required × certified May 2014–Feb 2015 [$\tilde{\gamma}_{t_1}$]	0.001	-0.000	-0.000	0.001	-0.001	0.003
	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)	(0.004)
certified before May 2014	-0.145***	-0.125**	-0.102*	-0.132*	-0.049	-0.157**
	(0.043)	(0.040)	(0.041)	(0.061)	(0.137)	(0.056)
certified May 2014–Feb 2015	-0.049	-0.033	-0.036	-0.057	0.002	-0.057
	(0.026)	(0.025)	(0.026)	(0.039)	(0.061)	(0.044)
time difference: 13–24 months	0.077***	0.085***				
	(0.019)	(0.018)				
time difference: 25–36 months	0.248***	0.252***				
	(0.019)	(0.018)				
time difference: >36 months	0.393***	0.394***				
	(0.019)	(0.018)				
Zip code FE	yes	yes	yes	yes	yes	yes
district × time difference FE	no	no	yes	yes	yes	yes
controls for unit characteristics	no	yes	yes	yes	yes	yes
Observations	43951	43951	43951	20823	9098	33756
Residual standard error	0.73	0.70	0.70	0.72	0.72	0.68
Adjusted R^2	0.137	0.196	0.207	0.194	0.241	0.215

Heteroskedasticity-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

When controlling only for the zip code's average price increase between the periods and the time difference between the offers, the main coefficients are all statistically insignificant. Additionally, they are very precisely estimated. The estimate of main interest, $\tilde{\gamma}_{t_1}$, is estimated to be smaller than 0.0005 in column (1), suggesting that the additional willingness to pay for reducing energy use by 1 kWh/m^2 when the building is certified is smaller than 0.005 cents. Even after substracting twice the standard error of 0.2 cents, the additional willingness to pay is only about 0.4 cents per kWh. Relative to the price of heating gas of approximately 5 cents per kWh, even this upper bound is tiny. This suggests that sellers were able to signal credibly the dwelling's energy requirement even without the certificate.

The two coefficients that capture changes in the valuation of uncertified energy efficiency, $\Delta\gamma$, and of certified energy efficiency, $\Delta\tilde{\gamma}$, are likewise precisely estimated, but small and insignificant. For instance, the estimate for $\Delta\gamma$ suggests that the willingness to pay for a reduction of energy required by 1 kWh/[$m^2\cdot$ month] decreased by 0.3 cents, irrespectively of whether the building was certified or not.

I added two indicator variables to the regression to capture a potentially uniform effect on rents when certifying a unit (regardless of its energy efficiency level) as well as differences in trends between the groups. There are slight differences in price trends between buildings certified in the pre-period and the two post-periods. According to these coefficients, rents per square meter increased by 14.5 cents less in dwellings that obtained their certificate before May 2014, while they increased by 4.9 cents less if the certificate was present only after May 2014 (both relative to a unit that was offered with a certificate only after February 2015).

The three coeficient estimates for the time differences reflect the rising rent level in Germany during that time, with more positive rent differences as the period between observing the unit gets larger.[12]

The picture just described is very robust to the inclusion of additional controls (column 2) and the inclusion of district $\times$ time difference fixed effects (column 3). In column 4, the sample is restricted to buildings with an address that appears in the State's official address directory (available for Berlin, Hamburg, Northrhine-Westfalia and Middle Franconia (Bavaria)). This should reduce errors in the data that might lead to attrition bias. Reassuringly, the coefficients remain stable. The regression in column 5 uses only buildings where the energy requirement calculation was based on an engineering model (*Bedarfsausweis*), whereas the sample in column 6 consists of buildings with certicicates that rely on reported past energy use (*Verbrauchsausweis*). If at all, the results only change marginally.

3.3.5. Are reported heating costs a substitute for certificates?

One particular reason why certificates do not matter on average might be the self-reported heating costs discussed in Section 3.3.2. If reported heating costs are seen as valid substitute for certified energy requirement, renters and

[12] Since the period in which these units are observed for the second time is quite narrow, the time difference also serves as an indicator of when the unit was observed for the first time.

owners might use them instead. Table 4 reproduces the main specifications from Table 3 separately for the sub-samples of units that were always (never) offered with heating costs reported.

Table 4: Reported heating costs and the willingness to pay for certified energy efficiency

	Dependent variable: difference in rent per sqm					
heating costs	not reported			reported		
	(1)	(2)	(3)	(4)	(5)	(6)
energy required [$\Delta\gamma$]	0.006*	0.007**	0.007*	0.002	0.003	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
energy required × certified before May 2014 [$\Delta\tilde{\gamma}$]	-0.007	-0.006	-0.006	0.010	0.005	0.004
	(0.005)	(0.005)	(0.005)	(0.008)	(0.008)	(0.008)
energy required × certified May 2014–Feb 2015 [$\tilde{\gamma}_{t_1}$]	-0.000	-0.002	-0.002	0.001	0.000	0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
certified before May 2014	-0.012	-0.018	-0.005	-0.223*	-0.166	-0.109
	(0.057)	(0.055)	(0.057)	(0.093)	(0.087)	(0.090)
certified May 2014–Feb 2015	-0.020	0.000	0.007	-0.022	-0.022	-0.043
	(0.039)	(0.038)	(0.039)	(0.046)	(0.045)	(0.046)
time difference: 13–24 months	0.084**	0.078**		0.093**	0.101***	
	(0.029)	(0.028)		(0.031)	(0.030)	
time difference: 25–36 months	0.258***	0.248***		0.266***	0.269***	
	(0.030)	(0.029)		(0.031)	(0.030)	
time difference: >36 months	0.422***	0.413***		0.382***	0.382***	
	(0.030)	(0.029)		(0.031)	(0.030)	
Zip code FE	yes	yes	yes	yes	yes	yes
district × time difference FE	no	no	yes	no	no	yes
controls for unit characteristics	no	yes	yes	no	yes	yes
Observations	18804	18804	18804	16184	16184	16184
Residual standard error	0.75	0.72	0.71	0.66	0.64	0.63
Adjusted R^2	0.142	0.201	0.212	0.180	0.230	0.237

Heteroskedasticity-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

When considering offers that do not provide information on heating costs (columns 1–3), the coefficient of main interest, $\tilde{\gamma}_{t_1}$, remains insignificant and very small, suggesting that the certificate was not necessary even in cases where heating costs were not reported. The valuation of energy efficiency irrespective of certification ($\Delta\gamma$) decreased significantly, but only slightly. In units that were certified already before May 2014, this decrease was offset completely. It must be noted that the coefficient estimates for $\Delta\tilde{\gamma}$ and $\tilde{\gamma}_{t_1}$ are difficult to reconcile, because absent biases, $\Delta\tilde{\gamma}$ measures the change in the valuation of certified energy efficiency, while $\tilde{\gamma}_{t_1}$ is the post-level (which should not be smaller in magnitude than the change). Setting aside this issue, the results confirm the idea that observable building characteristics allow to learn enough about the energy requirement of a housing unit so that certificates are not necessary.

Finally, in the sample of housing units that always reported past heating costs (columns 4–6), none of the main coefficients is significant, irrespective of the specification. Please note that the residual standard error and the R^2's suggests that the housing characteristics of these observations contain more precise information about the unit's price.

4. Conclusion

Energy efficiency certificates are wide-spread around the globe. For instance, the European Union's Energy Efficiency Directive obliges its member states to carry out a wide array of measures designed to empower households and other economic agents to better manage their energy consumption. Such policies are built on the premise that agents are malinformed, and that markets are themselves unable to provide enough relevant information. This paper has shown that such premises should be tested, as it is far from clear that missing information is a real problem. The results suggest that the information aggregated by rental prices in the residential market captures energy cost-related premia even without providing such information.

This paper adds to the emerging literature that challenges the view that "soft" information provision policies help to reduce energy consumption. After all, economic agents do not seem to be as misinformed or irrational as assumed. Besides the administrative costs of certification, the real danger behind such policies is that they prevent policy makers from choosing more costly measures, if the soft, but ineffective measures help to reduce public pressure to take action.

References

Allcott, H. and M. Greenstone (2017). Measuring the Welfare Eects of Residential Energy Eciency Programs with Self-Selection into Program Participation. Becker Friedman Institute for Research in Economics Working Paper.

Allcott, H. and C. Knittel (2017). Are Consumers Poorly Informed about Fuel

Economy? Evidence from Two Experiments. NBER Working Paper No. 23076.

Allcott, H. and S. Mullainathan (2010). Behavioral Science and Energy Policy. *Science 327*(5970), 1204–1205.

Allcott, H. and N. Wozny (2014). Gasoline prices, fuel economy, and the energy paradox. *Review of Economics and Statistics 96*(5), 779–795.

Brounen, D. and N. Kok (2011). On the economics of energy labels in the housing market. *Journal of Environmental Economics and Management 62*(2), 166–179.

Busse, M. R., C. R. Knittel, and F. Zettelmeyer (2013). Are Consumers Myopic? Evidence from New and Used Car Purchases. *The American Economic Review 103*(1), 220–256.

Eichholtz, P., N. Kok, and J. M. Quigley (2010). Doing Well by Doing Good? Green Office Buildings. *The American Economic Review 100*(5), 2492–2509.

Eichholtz, P., N. Kok, and J. M. Quigley (2013). The Economics of Green Building. *The Review of Economics and Statistics 95*(1), 50–63.

Fowlie, M., M. Greenstone, and C. Wolfram (2018). Do energy efficiency investments deliver? Evidence from the weatherization assistance program. *Quarterly Journal of Economics 133*(3), 1597–1644.

Gerarden, T. D., R. G. Newell, R. N. Stavins, and R. C. Stowe (2017). Assessing the Energy-Efficiency Gap. *Journal of Economic Literature 55*(4), 1486–1525.

Levinson, A. (2016). How Much Energy Do Building Energy Codes Save? Evidence from California Houses. *American Economic Review 106*(10), 2867–2894.

Mense, A. (forthcoming). The Value of Energy Efficiency and the Role of Expected Heating Costs. *Environmental and Resource Economics*.

Sallee, J. M., S. E. West, and W. Fan (2016). Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations. *Journal of Public Economics 135*, 61–73.

Sandler, R. (2018). You can't take it with you: Appliance choices and the energy efficiency gap. *Journal of Environmental Economics and Management 88*, 327–344.

Walls, M., K. L. Palmer, and T. Gerarden (2017). Is Energy Efficiency Capitalized into Home Prices? Evidence from Three US Cities. *Journal of Environmental Economics and Management 82*, 104–12.

5. Appendix

5.1. Rental housing data

5.1.1. Data description

Table 5 lists the variables used in the regressions. While the differences in the covariates are small in the matched sample, there are some notable differences between the full and the matched sample. Net rents are slightly higher in the full sample, by about 50 to 80 cents per sqm. There are less gas-fueled units in the matched sample, but only because there are more NA cases for the heating fuel variable. Units in the full sample were (re-)constructed about six to seven years later, are slightly larger, and on a lower floor. They are also more likely to have parking. Units in the full sample are more likely to be first-use, retrofitted, and renovated. Part of these differences are artificial, because I excluded units with condition “first-use” or “retrofitted” from the May 2014 – February 2015 period to prevent measuring the effect of upgrading energy efficiency of the building. They also seem to be of higher quality. One explanation for these differences could be that tenants want to move out sooner than later if the unit’s quality is low, making it more likely that the unit re-appears in the data after one or two years. The average length of stay of renters in Germany amounts to approximately ten years.

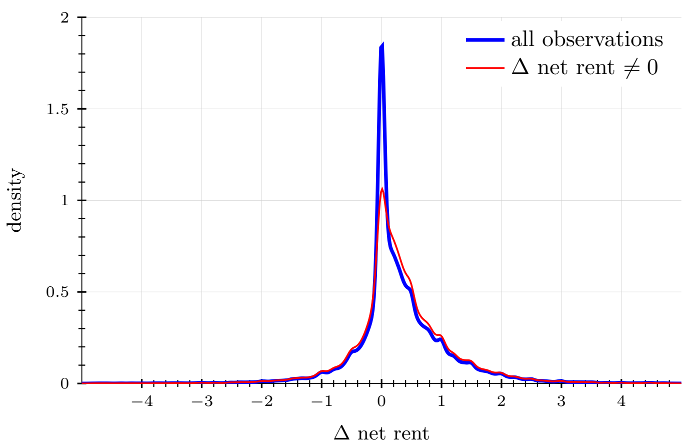
Figure 3 plots a kernel density estimate of the difference in net rents in the matched sample. The blue line refers to the full sample, while the red line conditions on the change being different from zero. The distributions are skewed to the right, indicating rising rents in Germany during that time. However, there also is a sizable share of units/buildings that experienced rent decreases.

Table 5: Summary statistics

	full sample		matched sample					
			before 5/2014		5/2014 – 2/2015		Differences	
	M	SD	M	SD	M	SD	M	SD
net rent per sqm	6.96	(2.78)	6.16	(2.13)	6.46	(2.21)	0.30	(0.78)
heating costs per sqm	1.17	(0.38)	1.19	(0.39)	1.20	(0.39)	-0.00	(0.35)
energy required per sqm	10.55	(4.28)	9.81	(3.46)	11.01	(4.15)	-0.00	(0.07)
gas fueled heating	0.25	(0.43)	0.16	(0.36)	0.16	(0.37)	0.00	(0.12)
oil fueled heating	0.04	(0.20)	0.03	(0.16)	0.03	(0.16)	0.00	(0.05)
district heating	0.12	(0.33)	0.12	(0.33)	0.14	(0.34)	0.01	(0.16)
other/NA heating fuels	0.59	(0.49)	0.69	(0.46)	0.70	(0.46)	0.01	(0.23)
year of construction	1966	(33.3)	1968	(25.3)	1968	(25.2)	-0.0	(4.2)
years since (re-)constr.	37.03	(33.02)	43.23	(25.27)	44.99	(25.23)	1.76	(1.12)
living area	68.67	(25.51)	63.86	(20.49)	63.51	(20.55)	-0.36	(14.40)
number of rooms	2.59	(0.92)	2.53	(0.88)	2.52	(0.88)	-0.02	(0.67)
floor	1.99	(2.03)	2.35	(2.37)	2.35	(2.34)	-0.01	(2.28)
floor NA	0.15	(0.36)	0.14	(0.35)	0.10	(0.30)	-0.05	(0.37)
fitted kitchen	0.23	(0.42)	0.19	(0.39)	0.07	(0.25)	-0.13	(0.40)
balcony	0.52	(0.50)	0.51	(0.50)	0.59	(0.49)	0.08	(0.50)
parking	0.31	(0.46)	0.18	(0.38)	0.15	(0.36)	-0.03	(0.33)
condition: first use	0.11	(0.31)	0.02	(0.14)	0.00	(0.00)	-0.02	(0.14)
condition: retrofitted	0.14	(0.34)	0.04	(0.19)	0.00	(0.00)	-0.04	(0.19)
condition: renovated	0.16	(0.37)	0.11	(0.32)	0.11	(0.32)	-0.00	(0.32)
condition: needs renov.	0.01	(0.09)	0.01	(0.09)	0.01	(0.08)	-0.00	(0.11)
second bathroom	0.13	(0.33)	0.06	(0.24)	0.07	(0.26)	0.01	(0.24)
quality: luxurious	0.01	(0.12)	0.00	(0.06)	0.00	(0.05)	-0.00	(0.05)
quality: elevated	0.15	(0.35)	0.05	(0.22)	0.05	(0.21)	-0.00	(0.19)
quality: simple	0.01	(0.08)	0.00	(0.05)	0.00	(0.06)	0.00	(0.07)
type: roof storey	0.10	(0.30)	0.06	(0.24)	0.07	(0.25)	0.00	(0.28)
type: ground floor	0.16	(0.37)	0.15	(0.36)	0.17	(0.38)	0.02	(0.46)
type: terraced	0.01	(0.11)	0.00	(0.07)	0.01	(0.07)	0.00	(0.09)
type: souterrain	0.01	(0.07)	0.00	(0.05)	0.00	(0.06)	0.00	(0.06)
type: maisonette	0.02	(0.15)	0.01	(0.11)	0.01	(0.11)	-0.00	(0.11)
type: loft/penthouse	0.01	(0.09)	0.00	(0.05)	0.00	(0.05)	0.00	(0.06)
Observations	1 333 007		45 324					

The table shows means (M) and standard deviations (SD) for the most important variables in the full and the address-matched sample (7/2011 – 2/2015). Means and standard deviations of non-dummy variables were calculated by dropping NA cases; the variables *heating costs per sqm*, *energy required per sqm*, and *floor* contain NAs.

Figure 3: Differences in rent per square meter in the matched sample



There are 4748 observations (10.5%) that did not experience a change in rents.

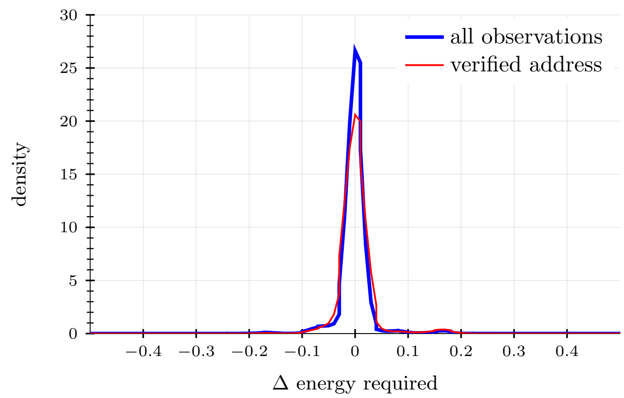
5.1.2. Measurement error in energy requirement

The main analysis of energy efficiency certificates in this paper relies on housing units from repeatedly observed buildings that were offered with and without certificates at different points in time. If the energy efficiency level was altered in the meantime (due to retrofitting) or if there is measurement error in the assignment of buildings to addresses, there might be differences in energy efficiency for different units observed in a single building at different points in time. Here, I consider units from buildings that obtained a certificate already before May 2014 and compare the energy requirement as reported before May 2014 to the energy requirement as reported between May 2014 and February 2015. Figure 4a plots the kernel density estimate for the difference, zoomed in to ± 0.4 kWh/[m$^2\cdot$ month]. The two lines refer to the full sample (blue) and to the sample of verified addresses (red), which are quite similar (apart from a higher peak at zero in the full sample). Allmost all observations have deviations smaller than 0.1 kWh/[m$^2\cdot$ month] ($\approx 1\%$ of the mean energy requirement in this part of the sample). Such deviations are likely to stem from rounding.

There are also a few instances of greater deviations, the largest being 2.58. Figure 4b plots various thresholds from 0 to 2.6 against the share of housing units with positive absolute differences greater than the threshold. This again shows that about 98% of the housing units in this sample had differences less than 0.1, and for approximately 99.8%, the difference was less than 0.2. There are a few units with a difference of about 0.8, and only four of the 4818 units have differences greater than 1.0. Taken as a whole, this suggests that measurement error-induced bias from missed retrofittings or wrongly assigned addresses is negligible.

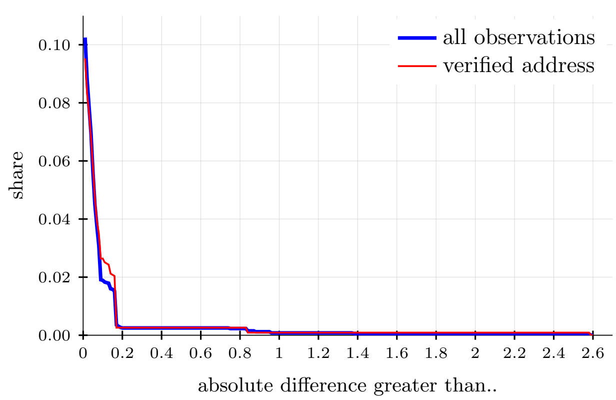
Figure 4: Differences in energy requirement in repeatedly observed buildings

(a) Kernel density estimate



The unit of the horizontal axis is kWh/[$m^2\cdot$ month]. The average energy required in units offered with a certificate before 5/2014 is 9.81 kWh/[$m^2\cdot$ month].

(b) Shares of observations with positive absolute differences



The unit of the horizontal axis is kWh/[$m^2\cdot$ month]. The average energy required in units offered with a certificate before 5/2014 is 9.81 kWh/[$m^2\cdot$ month].

5.2. Covariate tables

Table 6: Control variables for regressions from Table 2

Dependent variable:	rent per sqm	
	(2)	(4)
living area	-0.010***	-0.009***
	(0.001)	(0.001)
number of rooms	-0.105***	-0.121***
	(0.022)	(0.023)
floor	-0.046***	-0.048***
	(0.005)	(0.006)
floor NA	-0.047*	0.045
	(0.022)	(0.035)
fitted kitchen	0.507***	0.465***
	(0.035)	(0.055)
balcony	-0.019	0.031
	(0.016)	(0.020)
second bathroom	0.353***	0.313***
	(0.041)	(0.035)
parking	0.230***	0.328***
	(0.030)	(0.036)
condition:	0.546***	NaNNA
first use	(0.074)	(0.000)
condition:	0.076	NaNNA
refurbished	(0.041)	(0.000)
condition:	0.087**	0.119***
renovated	(0.029)	(0.032)
condition:	-0.415***	-0.390***
needs renovation	(0.075)	(0.069)
quality:	2.377***	2.058***
luxurious	(0.230)	(0.351)
quality:	0.861***	0.887***
elevated	(0.055)	(0.055)
quality:	-0.296*	-0.448***
simple	(0.142)	(0.111)
type:	0.091**	0.043
roof storey	(0.029)	(0.034)
type:	-0.066***	-0.050**
ground floor	(0.018)	(0.019)
type:	0.033	0.043
terraced	(0.109)	(0.110)
type:	-0.455**	-0.337*
souterrain	(0.143)	(0.137)
type:	0.373***	0.306***
maisonette	(0.084)	(0.077)
type:	1.187***	1.118***
loft/penthouse	(0.217)	(0.179)

Zip code cluster-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

Table 7: Control variables for regressions from Table 3

Dependent variable:	difference in rent per sqm				
	(2)	(3)	(4)	(5)	(6)
Δ living area	-0.015***	-0.014***	-0.014***	-0.016***	-0.014***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Δ number of rooms	0.029*	0.025*	0.026	0.033	0.018
	(0.012)	(0.013)	(0.019)	(0.030)	(0.014)
Δ floor	0.002	0.001	0.004	0.006	-0.001
	(0.002)	(0.002)	(0.003)	(0.004)	(0.002)
Δ floor NA	-0.021	-0.021	-0.008	-0.003	-0.021
	(0.011)	(0.011)	(0.016)	(0.025)	(0.013)
Δ fitted kitchen	0.000	0.017	0.010	-0.007	0.018
	(0.011)	(0.012)	(0.017)	(0.034)	(0.013)
Δ balcony	0.011	0.012	0.011	0.015	0.011
	(0.008)	(0.008)	(0.011)	(0.020)	(0.009)
Δ second bathroom	0.097***	0.101***	0.123***	0.068	0.103***
	(0.017)	(0.018)	(0.022)	(0.053)	(0.019)
Δ parking	0.028*	0.033*	0.053**	0.061	0.027
	(0.013)	(0.013)	(0.019)	(0.052)	(0.014)
Δ condition: first use	0.057	0.072	0.136*	0.065	0.088*
	(0.039)	(0.040)	(0.065)	(0.114)	(0.045)
Δ condition: refurbished	0.053*	0.050*	-0.013	0.103	0.051*
	(0.024)	(0.024)	(0.057)	(0.083)	(0.026)
Δ condition: renovated	0.058***	0.060***	0.062**	0.009	0.070***
	(0.013)	(0.013)	(0.021)	(0.036)	(0.014)
Δ condition: needs renovation	-0.153***	-0.140***	-0.168**	-0.346***	-0.082*
	(0.034)	(0.034)	(0.052)	(0.093)	(0.037)
Δ quality: luxurious	0.360*	0.313*	0.326	0.382	0.290
	(0.149)	(0.151)	(0.197)	(0.304)	(0.196)
Δ quality: elevated	0.139***	0.130***	0.189***	0.051	0.135***
	(0.027)	(0.028)	(0.039)	(0.084)	(0.031)
Δ quality: simple	-0.131*	-0.132*	-0.170*	-0.168	-0.109
	(0.064)	(0.066)	(0.086)	(0.174)	(0.077)
Δ type: roof storey	0.004	0.009	0.016	0.035	0.010
	(0.015)	(0.015)	(0.024)	(0.044)	(0.017)
Δ type: ground floor	-0.017	-0.014	-0.020	0.016	-0.020
	(0.009)	(0.009)	(0.013)	(0.020)	(0.010)
Δ type: terraced	-0.026	-0.019	-0.090	-0.069	-0.030
	(0.058)	(0.058)	(0.067)	(0.238)	(0.060)
Δ type: souterrain	-0.406***	-0.390***	-0.334*	-0.060	-0.448***
	(0.101)	(0.102)	(0.148)	(0.160)	(0.115)
Δ type: maisonette	-0.006	0.001	-0.081	0.029	0.005
	(0.047)	(0.047)	(0.067)	(0.185)	(0.051)
Δ type: loft/penthouse	0.652***	0.657***	0.433**	0.971***	0.536***
	(0.105)	(0.109)	(0.156)	(0.220)	(0.133)

Heteroskedasticity-robust standard errors in parentheses; $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$