Capitalization of Energy Efficiency in the Rental Housing Market

Santiago Bohórquez Correa*

November 15, 2019

You can find the latest version of this paper here, and the online appendix here

Abstract

Using a large dataset on the Dutch rental market, I measure the extent to which energy efficiency benefits are priced in the rental housing market. Contrary to the owner-occupied market, the rental market offers the opportunity to access and assess the direct capitalization of energy cost savings into monthly rents. I exploit data on close to 430,000 addresses in both the regulated and unregulated rental market in the Netherlands, a housing market in which utility bills are high and heterogeneous across energy label classes. The full sample estimates show capitalization rates of around 50 percent and less, indicating undercapitalization. When the capitalization rate is allowed to differ between market segments and types of landlords, I find full capitalization for the regulated market segment. A result that contributes to the literature by showing that institutional settings influence the size of the investment inefficiencies in the rental market.

JEL Codes: D12, Q51, R21

Keywords: Rent Control, Social Housing, Energy Efficiency, Rent

*Corresponding author. Tilburg University, The Netherlands; s.bohorquezcorrea@tilburguniversity.edu

1 Introduction

The capitalization rate of energy efficiency is an important ingredient for financing energetic retrofits, and has therefore been thoroughly researched in the housing market - the owner-occupied housing market, that is. Harjunen and Liski (2014), Bruegge et al. (2016), Bruegge et al. (2019), Myers (2019), and Aydin et al. (2018) all use transaction data to show evidence that energy efficiency has been capitalized, at least somewhat, into home prices. Partial capitalization may well do for the owner-occupiers, as they also reap the direct benefits of the lower utility bills up until their sale of the dwelling. Hence, they can recoup their investments in energy efficiency improvements by the sum total of monthly savings and the sale premium. Moreover, full capitalization of energy efficiency is hard to measure in the owner-occupied housing market, as this depends on assumptions regarding the remaining lifetime of the house, consensus regarding future utility charges, the implied discount rates and the costs of energy efficiency investments.

In the case of the rental housing market, this is different. On the one hand, it should be more straightforward to measure the capitalization rate of energy efficiency improvements, as landlords are able to increase rents with the amount of energy costs savings. No assumptions are needed regarding the lifetime of the house, nor the discount rate used to link future benefits to current investments. Yet, the literature on the capitalization of energy efficiency for the rental housing market is scarce, mainly due to data limitations[1]. On the other hand, the rental housing market may suffer more from information asymmetries, as tenants know less about future (and past) energy charges than their landlords. To reduce this information gap, energy performance certificates (EPCs) have been introduced to enhance the flow, and even distribution, of energy efficiency consequences.

I contribute to this literature by studying the capitalization of energy efficiency benefits in the Dutch housing market. The Dutch housing market provides us with institutional settings which allow me to isolate the effects of rent regulation on capitalization rates. In the Netherlands, 40 percent of the housing market is rental, and over 70 percent of that rental market is government controlled. Rents are set and maximized by means of

[1]Rehdanz (2007), Zalejska-Jonsson (2014), Hyland et al. (2013), Kholodilin et al. (2014), and Myers (2018) reported empirical evidence for varying levels of capitalization of energy efficiency in housing rents.

a point score, up to a monthly rent level of 711 euros. The points score contains a wide variety of housing qualities, including the energy efficiency level of the house. In other words, the rent control system stipulates the size of maximum rent premia for energy label differences and improvements. In the non-regulated rental market, monthly rents are set by the landlord, including any rent differentiation related to the energy efficiency status. This unique institutional framework can help us to identify the effects of regulation on energy efficiency capitalization rates. Contrary to the existing literature, I am not limited by our data, as I have a vast database for micro data on close to 430,000 unique addresses for the period 2015 to 2018 to our disposal. I can offer new and compelling evidence regarding the capitalization rates of energy efficiency and energy costs on rental rates using unique micro data. Dutch rental homes are certified with energy labels, that consistently signal their relative energy efficiency levels. From these energy labels, I derive so-called theoretical energy use costs and compare these with the actual utility bills for each address and year. I examine the extent to which the variations and changes in both these theoretical and actual energy costs are capitalized into monthly rent levels. I also stratify the analysis across regulated and non-regulated rents, as well as, housing associations and private owners, to assess whether rent control mechanisms set by the government have helped or hindered the capitalization of energy efficiency. Finally, I contribute to the existing literature by estimating the capitalization without having to make assumptions over lifetime discounts of the properties.

I find capitalization rates of around 50 percent and less for the market as a whole, depending on model specifications and energy cost estimations. Once I differentiate for regulated and non-regulated rents, and landlord type, I find that capitalization rates are higher for regulated rents, where I estimate full capitalization, this could be thanks to the fact that Dutch rent regulations explicitly awards rent raising credits for energy efficiency gains.

In the next section, I discuss the energy efficiency paradox and state the theoretical framework along with the hypotheses with which I analyze energy efficiency in the rental market. In section 3, I explain the Dutch institutional setting and present the data. In section 4, I explain the theoretical model which I use as base for the estimation strategy. In section 5, I explain the methodology used and present the results, first for the full sample, and then separated by market segment and landlord type. After discussing the findings and implication, I conclude the paper in section 6.

2 Residential Energy Efficiency in the Rental Market

There is a rich literature regarding the effect of energy efficiency on transactions in owner-occupied housing markets. These studies generally find that dwellings certified as being energy efficient have higher transaction prices. Early studies of transaction price effects rely on relatively small samples of housing transactions, and are therefore somewhat less convincing than more recent work in this area. The first study to employ a large sample of transaction prices and systematically investigate the value consequences of energy efficiency in housing is Brounen and Kok (2011). The authors document that A-labelled homes sell at a 10.2% premium relative to otherwise similar D-labelled homes. The premiums for homes with B and C labels are 5.5% and 2.1%, respectively. Dwellings with a label below D sell at a discount. Hyland et al. (2013) perform a similar study using Irish housing transactions, but also include housing rents in the analysis. The authors study the effect of Ireland's Building Energy Rating (BER) on house prices and rents. The transaction price results are comparable to those found by Brounen and Kok (2011), both in direction and in magnitude. In addition, they find that A- and B-labelled dwellings are rented at a premium relative to C-labelled dwellings, while E, F, and G labels are associated with rental discounts. Also for Ireland, Stanley et al. (2016) measure the impact of the Energy Performance Indicator (EPI) and energy labels on the list price of homes in Dublin. The authors document that a 10% improvement in a home's EPI increases the list price by 0.87%. Their results regarding the BER are similar to Hyland et al. (2013).

Empirical studies examining the capitalization of energy efficiency in the rented sector are rare. This apparent gap in the literature is not surprising, given the inherent shortage of data of good quality. To a greater extent, previous rental market analyses have examined the effect of energy efficiency ratings in the commercial office market. This more established literature has typically relied on appraisal-based data or asking rent data to show a significant and positive link between energy efficiency ratings and office rents. For instance, an early study by Banfi et al. (2008) suggests that tenants are prepared to pay up to 13% higher rent for buildings that have adopted energy-saving measures. Similarly, Eichholtz et al. (2013) report that office buildings that were labelled energy efficient by one of the two major US rating agencies (Green Building Council and EPA's Energy Star) command a 'green' rental premium relative to office buildings that were never certified. They estimate that, holding property characteristics constant, an office building registered with LEED or Energy Star commands an average green rental premium of 3%. This green premium is found to be higher for buildings with a triple net rental contract, suggesting that tenants prefer to pay energy bills separately when leasing space in green office spaces. In related research, Fuerst et al. (2013) use a dataset containing actual contract rents and lease terms to show that UK office spaces with favorable energy performance ratings attract a significant rental premium relative to buildings with average energy performance ratings, although, this premium is largely limited to highly energy efficient, newly built buildings. However, investors and investments in the residential rental market are likely to be different from investors in commercial buildings, hence rental premia evidence cannot be generalized across sectors.

Empirical literature emerging from the rental housing market has up until now been very limited, quality concerns and suitability of available data sources are often cited limitations and there is, as yet, no clear consensus on the scale of the price effect of energy efficiency. A few case studies from Sweden, Germany and Ireland all report a positive relationship between energy efficiency ratings and residential rents. Zalejska-Jonsson (2014) uses a Swedish database that includes occupants living in green and conventional multi-family buildings to show a green premium of 5% of total rent in green buildings. However, environmental certificates are found to have a negligible effect on renting decisions. Similarly, Hyland et al. (2013) adopt a Heckman‘s selection technique to investigate the effect of energy efficiency ratings on Irish residential property values and rents. They report that relative to D-rated properties, A-rated properties have a green sale price premium of 11% and a green rent premium of 1.9%. Interestingly, not only does this study suggest a positive relationship between energy efficiency ratings and rental and sale prices, but it also suggests that buyers exhibit a stronger willingness to pay for energy efficiency than tenants. In related research,

? examined the residential rental market in Berlin and found that energy efficiency savings are generally capitalized into rental prices. Earlier, Rehdanz (2007) arrived at similar conclusions in their study of German housing markets. Some evidence therefore exists that green buildings do command higher rental prices than conventional ones.

Overall, the literature on energy efficiency in the rental market observes a gap between potential and actual energy efficiency (Allcott and Greenstone, 2012). One of the explanations for this gap is the principal-agent problem between tenant and landlord (Fisher and Rothkopf (1989), Jaffe and Stavins (1994), Gillingham et al. (2009), a.o.). Mostly, rent contracts are specified such that the landlord has to pay for energy saving investments like improved isolation, heating system, etc., whereas the savings resulting from these investments accrue to the tenant, who pays the utility bill. Only if tenants value energy efficiency of their home and are sufficiently well informed about it, can landlords recoup their investments by demanding higher rents. This so called "split incentives problem" together with asymmetric information about the investments, is one explanation for less energy efficiency in the rental housing stock. Other explanations are based on different lock-in concerns between landlords and owner-occupants, differences in search costs between tenants and owner-occupants and the relative bargaining power of owners and tenants depending on the market structure (Fuerst et al., 2015; Kholodilin et al., 2014).

3 The Dutch Housing Market and Data

3.1 The Dutch Housing Market

The Dutch Housing market has an atypical supply structure, which results from historic policy interventions. Up until the start of the 20th century, the Dutch housing market resembled that of neighboring countries. Homeownership rates were low, as mortgage financing was still in its early days. The rental market was vast but also struggling. Especially at the lower end of the market, where affordability was a constant concern. The volatile economics of the pre-war period destabilized society and put extra pressure on the lowest income groups who lacked access to affordable healthcare and housing. To contend with the housing challenges of his times, the liberal Dutch Prime Minister, Nicolaas Pierson, signed the Housing Act in 1901, which fueled the rise of Dutch social housing associations as large-scale landlords. Pierson was convinced that the Dutch rental housing market needed to be regulated in order to guarantee affordability for the working class, a necessity for stabilizing his economic outlook. The 1901 Housing Act swiftly changed the supply side of Dutch housing, as the regulated rental market grew exponentially. Growth was further enhanced after social housing associations were asked to assist in rebuilding the wrecked housing market due to bombings during the second world war. Ever since, the market share of regulated rent has been unmatched.

- Table 1 here -

Today, more than 100 years later, the Dutch housing market comprises of 7.7 million homes, of which 57 percent are owned by their occupiers. However, the most compelling effects of the old Housing Act are still to be found in the breakdown of the remaining 43 percent that is rented. Panel A of table 1 compares the housing market structure of leading European housing markets. These statistics shows that, although the overall market share enjoyed by the rental market in the Netherlands is comparable to that of France, Germany, and the UK, the share of regulated rents is surely not. Even today, the stimulating effects of old rent regulations are noticeable in the Netherlands, where 87 percent of the rental market is regulated while in the neighbouring German market this is only 12 percent. The Dutch regulations cap and specify both rent levels and rent increases by means of a point system, whenever monthly rents are below 711 euros. In Panel B of table 1, we show that these regulations do not just apply for social housing landlords, but to all types of landlords that charge less than 711 euros a month.

- Table 2 here -

The way in which regulated rents are set is specified in table 2. Every dwellings scores points on quality features such as size, heating, and sanitary and exterior space. Higher qualities lead to higher point scores, and a sum total of 140 points equals a monthly rent maximum of 711 euros. Every point less reduces the rent by a little over 4 euros. Homes with regulated rents are also restricted regarding annual rent increases, and these can not exceed more than 2.5 percent over inflation[2]. As table 2 shows, the energy efficiency standard of the home can have a vast effect on the monthly rent. In fact, in the extreme, the difference between a G- versus and A-labelled home corresponds with a gap of 36 points which is a difference of around 175 euros in rent a month.

3.2 Data

I use administrative data gathered by the Central Bureau of Statistics in the Netherlands (CBS). The data is gathered using a stratified sampling to be representative of all self-standing houses[3] in the rental market for each year. The sample is stratified in four different categories, owner type, construction type, construction year and region. The exact stratification can be seen in table 3. Each house can be classified on one of the 64 mutually exclusive categories resulting from the stratification.

- Table 3 here -

I have a sample of 429,753 unique addresses in the Netherlands for the period 2015-2018, of which approximately 89 percent are in the regulated market and 11 percent are in the non-regulated market. Table 4 shows some descriptive statistics regarding the sampled observations. We can see that, on average, the non-regulated sample consists of newer, bigger, and more expensive houses than the larger regulated sample. The sampled non-regulated homes are 26 years old (versus 46 years old regulated homes), contain a little over 90 square meters of floor space (versus less than 70 meters in regulated homes), and come at a monthly gross rent of 916 euros (versus 526 euros in the regulated sample). The average 2018 tax value[4] of non-regulated homes in our sample 199,348 euros, around 30 percent higher than the 133,995 euros of tax value in the regulated sample. At the same time, however, we also see that gas expenditures (both the theoretical and the actual) are lower in the non-regulated

[2]Regulated rents can go over 711 euros with this increases over time as long as they do not exceed the maximum rent set by the point system

[3]Self-standing houses are defined as houses with their own entry, this excludes most student housing and nurse homes from the sample

[4]Every year, every home in the Netherlands is given a so-called tax value by its municipality. These tax values are market valuations and modeled using recent comparable transactions of neighboring dwellings. The tax value primarily serves as a basis for local taxes, which are collected by the municipality as a fixed percentage of the annual tax value.

sample, despite the fact that these homes are larger. This is most likely a result of thermal quality, which better among the non-regulated homes, judging by the distribution of energy labels.

- Table 4 here -

The regulated market is referred as such because rents are not established by market forces, but by a rent table where each house is given a point score based off different characteristics. Once all points are tallied up, a maximum rent is specified and enforced to the landlord (social housing association and private investors alike) whose monthly rent is below 711 euros. At the start of the rent contract, they cannot charge above this specified rent value and may not raise rents by more than 250 basis points above annual inflation during the lifespan of the lease.

- Table 5 here -

Table 5 shows the spread by energy label of the monthly rent, gas expenditures, point score and maximum rent. As already pointed out in table 2, the energy label constitutes an important part of the point score as an "A" label awards 36 points to the house this is translated in an average of 175 euros extra in maximum rent, "B" awards 32 points and 156 euros, "C" awards 22 points and 107 euros, "D" awards 14 points and 68 euros , "E" awards 8 points and 38 euros, "F" awards 4 points and 19 euros, and "G" awards no points and no extra rent. But, as previously shown in Table 2, there is a gap between the maximum amount that landlords are allowed to charge and the amount they actually charge. Part of this can be explained by the fact that most of the regulated market is in the hands of social housing associations, whose primary objective when they were established was to offer affordable housing to low income households in the Netherlands, an objective that still marks most of their decisions today.

We can also observe that the difference in the reported rent between "A" and "G" label (632 versus 469) is less than the 175 euros of rent premium allowed for A-labeled homes. This undercapitalization could be due to variations in other quality features between the "A" and "G" groups. Variations which we will control for later in our analyses. But, an alternative explanation for this undercapitalization could also be due to the modest spread monthly gas expenditures across "A" and "G". Heating an "A" labeled dwelling requires only 38 euros less a month, savings which are easily exceeded by the difference in rent. These gas expenditures, however, are only known *ex-post*. Before the fact, most market participants (including landlords and tenants) will need to rely on the theoretical gas expenditures that are included in the energy label. In Figure 1, we plot the actual and predicted theoretical energy savings with respect to a G label. For every label class, the realized savings are less than the predicted ones which helps to explain why capitalization rates based off predicted consumption would be smaller.

- Insert Figure 1 -

4 Theoretical model

While the descriptive analysis is indicative of the different forces at play in the rental market that determine the capitalization rate, we need to introduce a more formal model to test whether energy costs in the rental housing market are fully capitalized by prospective tenants. A typical approach used by the previous literature while testing whether consumers undervalue the potentially less salient additional costs such as taxes or shipping costs is to compare the demand response of those costs versus actual costs (Chetty et al., 2009; Hossain and Morgan, 2006; Finkelstein, 2009). In this paper, we follow a similar approach, estimating how tenants trade-off between monthly rents and energy costs. The intuition is that consumers should be indifferent between paying an additional Euro of monthly rent for a home that has one Euro less monthly energy costs.

We first propose a discrete choice model where the tenant i chooses house j in region r in year t from a set of homes available for rent. Tenants derive utility from renting a home and consuming a numeraire good. Tenant i's indirect utility from home j in region r at time t can be written as:

$$u_{ijrt} = \eta \left(w_i - p_{jrt} - \gamma G_{jrt} \right) + Z'_{jrt} \tilde{\beta} + \tilde{\alpha}_{jrt} + \tilde{\xi}_{jt} + \epsilon_{ijrt} \tag{1}$$

where w_i is the budget constraint of the tenant, p_{jrt} is the rent of the home j in region r

at time t, G_{jrt} is the gas bill of the home j in region r at time t. η represents the marginal utility of money. The tenant has an outside option of not renting a home with a utility level normalized to zero. Tenants also derive utility from observable home characteristics, Z_{jrt}, unobservable home-specific characteristics, $\tilde{\alpha}_{jrt}$, neighborhood-year specific amenities, $\tilde{\xi}_{rt}$, and individual taste, ϵ_{ijrt}.

The term, γ, is our parameter of interest, which represents the valuation weight of the gas bill. If $\gamma = 1$ then consumers value the rent price and energy costs equally when choosing a house, if $\gamma < 1$ or $\gamma > 1$ then consumers overvalue or undervalue the gas costs, respectively. In other words, if $\gamma = 1$, this indicates that tenants are indifferent between additional Euro of rent and additional Euro of energy cost. If $\gamma < 1$, the tenants are less sensitive to energy costs as compared to rent cost, implying under-capitalization of energy costs in the rental housing market. This implies a higher demand for less efficient homes relative to the optimal level.

All potential tenants in region r in year t face the same choice set of homes available for rent. These prospective tenants trade off between the rent of a home versus its attributes such as size or number of bedrooms and age. We assume a traditional consumer logit model where ϵ_{ijrt} is distributed i.i.d extreme value. Integrating over ϵ_{ijrt} and taking the natural logarithm of both sides leads to the following choice probability model.

$$\frac{1}{\eta}\left(\ln s_{jrt} - \ln s_{0rt}\right) = p_{jrt} - \gamma G_{jrt} + Z'_{jrt}\beta + \alpha_{jrt} + \xi_{jt} \tag{2}$$

The left hand side of the equation represents the choice probability of renting a house, s_{jrt}, relative to probability of choosing the outside option, s_{0rt}, which is not renting a house. Dividing by η leads to the new variables $Z'_{jrt}\beta$, α_{jrt} and ξ_{jt}, which can be interpreted as the monetary value of the utility components represented by $Z'_{jrt}\tilde{\beta}$, $\tilde{\alpha}_{jrt}$ and $\tilde{\xi}_{jt}$. Equation (2) can be transformed into an empirical model of rent price as a function of gas costs, house attributes and a set of fixed effects as follows:

$$p_{jrt} = \gamma G_{jrt} + Z'_{jrt}\beta + \alpha_{jrt} + \xi_{jt} + \epsilon_{ijrt} \tag{3}$$

where p_{jrt} is the monthly rent of the home, Z'_{jrt} is a vector of observable home attributes,

α_{jrt} is the home specific fixed-effects, ξ_{jt} is the unobserved region-year specific factors that might affect house rents and ϵ_{ijrt} represents the idiosyncratic differences in the preferences for a particular house and is assumed to be independent of the monthly gas costs.

My approach is similar to Grigolon et al. (2018), Allcott and Wozny (2014) and Myers (2019) who follow the attention weight models as in Chetty et al. (2009) and DellaVigna (2009). Unlike our approach, in the Allcott and Wozny (2014), Grigolon et al. (2018) and Myers (2019) empirical settings, G_{jt} instead represents the net present value of the expected life-time energy cost resulting from the consumption of the durable good. The advantage of my approach is that, since the home is not owned by the consumer, we do not need to calculate the life-time energy costs. This requires assumptions regarding the discount parameter, the life time of the durable good and the expected future energy prices. As mentioned by Allcott and Wozny (2014), the estimated capitalization rate that is based on life-time energy cost calculations will be highly sensitive to these assumptions.[5] Therefore, my approach is able to eliminate any potential bias resulting from invalid assumptions.

5 Estimation and Results

5.1 OLS and IV Approaches

I first estimate equation (3) using ordinary least squares (OLS), assuming that the monthly gas bill (G_{jrt}) is independent of the unobserved determinants of the rent ($\alpha_{jrt} + \epsilon_{ijrt}$). We expect negative coefficients (γ), as a decrease in gas expenditures should be carried over to an increased rent, in order to compensate landlords for their investments in the enhanced standard of energy efficiency. From an economics point of view, these capitalization coefficients should equal unity, as rational tenants ought to be indifferent between paying for rent or gas. As long as the sum total is the same, tenants would not object to rent increases or differences that are completely offset by a reduction in gas charges. In practice, one could argue for rational oscillations from unity. For one, we could reason that social

[5]In our case the tenant can change the address at any point as the regulation in the Netherlands protects renters from long term rent contracts, usually requiring only one month notice before moving out. This implies that the only energy saving that matters for tenants is the saving that they are going to incur during the contract period. Therefore we do not need to estimate a discounted present value of the gas savings and we can take the current price as the cost for the household.

housing landlords – who do not aim to make profits – would be satisfied with a rent increase that covers their underlying energy efficiency investment. In some cases, this may well be recouped by only charging a part of the consequential reductions in gas expenditures. In that case, for not-for-profit landlords it would be rational to observe less than unitary capitalization coefficients. On the other hand, we may also expect coefficients of more than one, as energy efficiency improvements lead to more than gas savings alone[6]. Green labeled dwellings offer more comfort and quality, for which tenants may well be willing to pay a small rental premium that exceeds their reduction in gas expenditures.

Table 6 reports the estimated capitalization rates for various estimation specifications. In all three columns we start with the capitalization rates of actual gas expenditures on net rent. All regressions in Table 6 contain time fixed effects to control for variables that are constant across entities but vary over time, like gas prices. We estimate and present capitalization rates for the full sample of 965,969 observations. In our first column of Table 6, including the G_{jrt} as the sole regressor, the estimated capitalization parameter (γ) is positive, which is a result contrary to economic theory. These OLS estimates, however, suffer from different measurement errors, endogeneity issues and regression attenuation. Hence, we repeat the same analysis, but using alternative econometric procedures that can help to improve the accuracy of our results. Since the gas bill might be correlated with some home attributes that affect the rent, in column (2), we control for house characteristics (Z'_{jrt}) such as the type of dwelling, construction year, and the size, tax value and interior spaces as measured by the point system[7]. Controlling for home characteristics leads to a change in the sign of the coefficient to one in line with our expected results. Finally, in column (3) we additionally control for the location and ownership characteristics. Overall, based on the full specification in column (3), I report that there is under-capitalization of energy savings as only 2.4 cents per euro saved returns to the landlord via higher rents.

- Insert Table 6 here -

This result should be taken with caution as there could still be some methodological

[6]See Yang et al. (2014) review on thermal comfort and the implications on energy use, and Brounen et al. (2012) for an analysis on the Dutch market

[7]Control variables are omitted from the table. Detailed estimation results are provided in Appendix Table A.1. The estimated coefficients for the control variables are in line with expectations.

problems that might cause a bias in the estimation of the capitalization parameter (γ). Although we use a large, representative sample and control for detailed dwelling characteristics in the OLS estimations, there is a potential bias in the estimated capitalization rate, the presence of unobserved determinants of home rents that are varying over time and may be correlated with the gas expenditures, influencing the estimated coefficient. Depending on the direction of the correlation between these unobserved factors and rents, and between the unobserved factors and the gas bill, this can either be a downward or an upward bias. Furthermore, multicollinearity between the construction year and gas bill may increase the magnitude of a bias when controlling for the construction year in the OLS estimates.[8]

Another more important econometric issue that may cause a biased estimate is the presence of measurement error in the expected gas bill. It could be the case that the gas bill include a random measurement error, because it also reflects the household behavior. We assume that the actual gas bill G_{jrt} is a combination of the true value (G^*_{jrt}) that is related to home's energy efficiency level and a random error component (e) that has a mean value equal to zero and that is not correlated with the true energy efficiency level. In this case, the OLS assumption that the G_{jrt} is independent of the error term (ϵ_{ijrt}) may not be valid. The presence of this random measurement error leads to a downward bias in the OLS estimate of γ.[9]

In order to overcome the potential bias originating from unobserved factors and measurement error, a common approach is to use an instrumental variable (IV) method. Such IV needs to be correlated with the true energy efficiency level (G^*_{jrt}), but has to be independent of both the measurement error (e) and the unobserved determinants of home rents (ϵ_{ijrt}).

One potential IV candidate that can satisfy these two conditions is the theoretical gas consumption that is predicted by an engineering model. Mandated by EU regulation, all leasing and sales transactions in the housing market of every EU Member State need to

[8]See Atkinson and Halvorsen (1984) for a discussion of multicollinearity problem in the estimation of hedonic models.

[9]Hausman (2001) states that the magnitude of a parameter estimate is usually smaller than expected because of the measurement error problem, even in studies using seemingly high quality data. In our case, the measurement error problem would make us more likely to underestimate the capitalization rate.

be accompanied by an energy performance certificate (EPC). Professionally trained and certified assessors issue the certificates using standardized software. In order to classify the dwelling into one of the energy efficiency rating categories, an engineer visits a dwelling and inspects its physical characteristics (e.g., size, quality of insulation, type of windows, etc.). The collected information is then used to predict the total gas and electricity consumption of the dwelling. Dwellings that have been constructed after 1999, or that are classified as monuments, are exempted from mandatory disclosure of the energy performance certificate[10].

In order to identify the capitalization rate on home rents using an IV approach, we first exploit the predicted gas consumption of homes, which is provided by the EPC, since it can be considered as a measure of energy costs that is related only to home energy efficiency characteristics, not to occupant behavior. The first column of Table 7 reports the IV results using the predicted gas consumption as an IV for actual gas bill. Under the IV specification there is a return of almost 45 cents per euro saved to the landlord. Results that, while bigger than the estimated in Table 6 as they solve the attenuation bias of the previous estimations, still estimate less than full capitalization in the rental market.

- Insert Table 7 here -

Another potential IV candidate is the over-time variation in building regulations which is related to thermal quality of new constructions. Starting in 1965, the Dutch government introduced minimum legal requirements for the thermal efficiency level of newly constructed homes. The legislation set a maximum allowable U-value for each component (walls, windows, floor and roof) of the dwelling, where the U-value is defined as the amount of heat loss through a single square meter of material, for every degree difference in temperature at either side of the material.[11] Appendix Figure 1 presents the over-time variation in the maximum allowable U-value requirements for external walls of newly constructed homes in the Netherlands. In order to reach the goal of zero energy buildings by 2020, these requirements have been strengthened over time. Column (2) of Table 7 document the

[10]Importantly, if the tenant of the dwelling signs a waiver, the landlord is also exempt from providing the certificate. The real estate agent typically offers such a waiver.

[11]For example, one square meter of a standard single glazed window transmits about 5.6 watts of energy for each degree difference at either side of the window, and thus has a U-Value of 5.6 W/m^2. A standard double glazed window has a U-value of 2.8 W/m^2.

IV estimation results that are based on the evolution of U-value requirements for external walls of newly constructed homes, respectively. According to the estimated capitalization parameter under the IV estimation 34 cents for every euro saved goes back to the landlord, but we still find less than full capitalization under both cases.

5.2 Grouping Estimator

While the previous results control for the presence of unobserved determinants of home rents that are varying over time and may be correlated with the gas expenditures, we also need to consider the potential unobserved home characteristics as a source of bias. The usual procedure for these cases would be to estimate a fixed-effects (FE) estimation approach to address the potential correlation between G_{jrt} and α_{jrt}. However, given that our data does not follow specific houses during the sample period, a FE estimation is not an option. In order to solve this problem Blundell et al. (1998) propose a generalized Wald (1940) estimator. To make use of the estimator we need to define groups of houses sharing common characteristics, and they need to be defined in such a way that each house is a member of one, and only one group, and this group does not change over time. This is the exact description of the groups used to stratify our data for sampling, therefore, a natural grouping is to use the ones as described in table 3. With this we can estimate equation 3, using weighted least squares, as:

$$\bar{p_{gt}} = \gamma \bar{G_{gt}} + \bar{Z'_{gt}}\beta + \alpha_g + m_t + \epsilon_{gt} \tag{4}$$

where $\bar{x_{gt}}$ means the average of variable x by group and year. And the identifying assumptions being that $E(\alpha_{jrt}|g,t) = \alpha_g + m_t$[12] i.e. the unobserved differences between groups can be summarized by a group effect and an additive time effect. And that the gas bill changes differently across time for the different groups. With these assumptions the estimator of γ is:

$$\hat{\gamma} = \frac{\sum_g \sum_t \widetilde{p_{gt}} * \widetilde{G_{gt}}/n_{gt}}{\sum_g \sum_t \widetilde{G_{gt}}^2/n_{gt}} \tag{5}$$

[12]Notice that ξ_{jt} disappears from the estimation equation as we group over regions and include time effects

where $\widetilde{x}_{gt} = \bar{x_{gt}} - \bar{x_g} - \bar{x_t}$ and n_{gt} is the number of observation in group g at time t. Which, as shown by Moffitt (1993), is equivalent to an IV estimation of the individual level data using the group and time dummies interacted as instruments for the gas bill.

As in any IV regression, these instruments need to fulfil the exogeneity and relevance assumptions. For the exogeneity assumption, we need sufficiently large groups such that the individual effect is averaged out, for our estimation we drop two groups that have less than 50 observation in at least one group*time cell. With this the minimum value in any cell is 68 and the median cell has 1.651 observations. As for relevance we need that the gas bill changes differently across our strata variables. The first stratification variable is the type of landlord, social housing associations tend to rent to the low-income classes while private owners rent to middle- and high-income classes, as point out by De Cian et al. (2019) thermal comfort requirements are different across income classes, therefore, changes in gas prices across time should affect them differently. In terms of construction type, and construction year, figure 2 shows the variations of energy use for apartments and houses constructed in different periods, showing that the current variation of gas bills is still a function of the building codes that applied during the year of construction. Until today, homes built before 1990 require 60 percent more gas to maintain the same level of thermal comfort. Moreover, the average apartment needs half the gas for the same heating requirements, which is mainly due to the lower portion of outer wall exposure within apartment buildings.

- Insert Figure 2 here -

In terms of regional variations, we also documented relevant winter temperature differences across the Netherlands in our period of study. Figure 3 shows the regional variations in January of each sample year, with warmer winter at the coast. While we have reasons to believe that both assumptions are fulfilled, we will do formal tests on these assumptions later on.

- Insert Figure 3 here -

I proceed with the estimation of equation 4 using the IV method, the advantage of using this method with respect to the WLS is that it allows to calculate the standard errors of the coefficients including the first stage errors. Column (3) of table 7 shows the results using this grouping estimator, a capitalization rate of around 53 cents per euro, which still falls significantly short of full capitalization.

The calculation of this capitalization rate - as one for the market as a whole - could be masking different mechanisms at work, where agents with different objectives make decisions in two differentiated markets. Therefore, a more granular sub-sample analysis of these forces is needed to identify these effects.

5.3 Sub-sample Analysis

5.3.1 Housing Associations and Regulation

One possible explanation for this less than full capitalization is the presence of the not-for-profit housing associations. As previously mentioned in Table 1, these are major players in the market and have other considerations than profit maximization when setting their rents. Amongst these considerations is a Dutch government mandate to make their dwellings more sustainable and supply affordable housing to lower income brackets. Alongside them, there are also profit-seeking private and institutional investors[13], with both types of landlords acting in the regulated and non-regulated market. In Table 8 panel A we show the distribution of ownership and market segment for the dwellings in our sample in the year 2018[14]. Housing association mainly operate in the regulated market while private owners are evenly distributed between the regulated and non-regulated market.

- Insert Table 8 here -

To see whether the presence of these different types of ownership and the separation between regulated and non-regulated market segments affects the capitalization of energy efficiency we separate the sample in four and estimate the capitalization rates. Specifically, owned by a housing association and in the regulated market at time t ($\gamma^{h,r}$), owned by a housing association and in the non-regulated market at time t ($\gamma^{h,n}$), privately owned in the

[13]From here on, we refer to both of them simply as private actors

[14]Dwellings can change between the regulated and non-regulated market between years when a tenant leaves. And while technically possible we do not observe any sells between the housing association and private actors.

regulated market at time t ($\gamma^{p,r}$), and privately owned in the non-regulated market at time t ($\gamma^{p,n}$).

I focus my attention on the dwellings owned by housing association and that are part of regulated market as it comprises the biggest segment of the rental market. In Table 8 panel B we show the estimated capitalization rates using the grouping estimator, separated by landlord type and market type. For $\gamma^{h,r}$, the results show higher capitalization rates across all specifications w.r.t. the ones estimated for the full sample, while a test of $\gamma^{h,r} \leq -1$, that is at least full capitalization, can not be rejected at the 1% level. This implies that housing associations are taking advantage of the regulation for higher rents when investing on energy features. This, however, opens the question as to whether the other market segments are being under capitalized as the total capitalization rate is closer to zero.

I report the results for this segments in table 8 panel B. These results show smaller capitalization than the ones found for housing associations in the regulated market under the same specifications. These results, while surprising as the private owners are supposed to be profit maximizers, could be explained by the fact that private landlords might not know the energy characteristics of the dwelling relative to other dwellings as well as housing associations that have a bigger portfolio of houses. And the renters on the non-regulated market may also have the option to buy instead, making it harder for landlords to appropriate the energy savings, while tenants on the regulated market tend to have lower income making the possibility of obtaining a mortgage to buy a house less likely.

5.3.2 Label Effect

To analyse the effect of information on the capitalization, we examine the difference that energy labels have for dwellings with similar energy efficiency. We take dwellings with similar energy index values that are close to the cut-off point where the enerry label value changes. Formally,

$$p_{jrt} = \beta_0 + \beta_1 EI_{jt} + \beta_2 I(EI_{jt} > C_{lab}) + Z'_{jrt}\delta \tag{6}$$

where EI_{jt} is the energy index associated with the dwelling, $I(EI_{jt} > C_{lab})$ is an indicator of whether the energy index is higher than the threshold value to assign a worse label, and Z'_{jrt} are covariates associated with the dwelling. So, β_2 is the local average treatment effect (LATE) of decreasing one label, as higher EI indicates lower energy efficiency.

We should expect to find no significant effect for β_2 if all information contained in the energy index is being incorporated by the landlord when setting the rent. However, if what landlords observe is the value of the label only, because this information is more salient and easier to interpret, then we should observe a negative LATE. In table 9 we show the results for the LATE for changes for every label from A to G. We find a negative and significant effect at the usual levels for three of the changes, A to B, B to C, and E to F. While, two others are not significant at any of the usual levels and the change for D to E has a positive sign. These results point to landlords not using all of the information contained in the labels, only the most salient one.

- Insert Table 9 here -

5.3.3 Renovations

Finally, I make use of a small dataset of houses that have been renovated in the period 2015-2018. While regulations stipulate that rents can only be raised once a year, special dispensation is made when dwellings undergo a renovation as landlords can immediately raise the rent once the renovation is finished. We observe 5,977 dwellings that were renovated and the changes in point value. I separate the gains made in energy efficiency and quality increases so I can measure the immediate impact of energy efficiency gains. Table 10 shows full capitalization in those cases, this could be due to the fact that when renovations happen the gas expenditures savings are made more salient and landlords can then recoup their investments.

- Insert Table 10 here -

6 Conclusions

In this paper, I have studied the capitalization of energy efficiency benefits in the rental housing market. I examine to what extent energy efficiency benefits – lower energy expenditure – are accompanied by proportional differentiations in monthly rents. In theory, landlords can increase rents by the amounts that tenants save on their utility bills, and as such recoup their intended investment in upgrading the energy quality of their dwellings. In practice, this capitalization of energy benefits is less obvious, as a result of informational asymmetries across tenants and landlords. The former know less about future (and past) energy charges, and therefore, the latter are sometimes reluctant to adequately adjust rents.

I make good use of high-quality micro data on nearly 430,000 addresses in the Dutch rental housing market for the period 2015 to 2018. A rental housing market, of which 87 percent is regulated by government rent controls, and in which energy efficiency information is disseminated by means of energy performance certificates. The rich data allows me to control for endogeneity and regression attenuation in our estimations, and to stratify our analysis of energy efficiency capitalization rates across regulated and non-regulated rents, while controlling for different types of landlords.

The full sample estimates show capitalization rates of 53 percent and less, indicating undercapitalization. These estimates, however, depend strongly on model specification and energy cost estimations. The results show that simple OLS regression estimates suffer from measurement errors in energy expenditures and unobserved rent determinants. Using instrumental variable methods and grouping estimators, I obtain more accurate and robust estimates. The capitalization rates tend to be higher for regulated rents by social housing landlords, where I estimate full capitalization. This may well be the result of the rent regulations in place that explicitly award rent raising credits for energy efficiency gains. Credits which appear to be set to appropriate levels for enhancing full energy capitalization. In the non-regulated rental market, I find lower capitalization rates. In the case of the Dutch rental housing market, this may well be due to the fact that non-regulated rents compete with the owner-occupied market and this hampers landlords from raising their rents for fear of competition.

These findings contribute to the existing literature by offering robust large sample results that show the influence that institutional settings – rent regulations and landlord characteristics – have on energy efficiency capitalization. These results have important implications for landlords and policymakers who are concerned with energy efficiency efforts in the housing market. I show that rent controls can help elevate capitalization rates to levels close to unity and can stimulate the agility of reluctant landlords to invest in enhancing the energy efficiency of their housing portfolio.

References

Allcott, H. and M. Greenstone (2012). Is there an energy efficiency gap? *Journal of Economic Perspectives 26*(1), 3–28.

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

Atkinson, S. E. and R. Halvorsen (1984). A new hedonic technique for estimating attribute demand: An application to the demand for automobile fuel efficiency. *The Review of Economics and Statistics 66*(3), pp. 417–426.

Aydin, E., D. Brounen, and N. Kok (2018). Information asymmetry and energy efficiency: Evidence from the housing market.

Banfi, S., M. Farsi, M. Filippini, and M. Jakob (2008). Willingness to pay for energy-saving measures in residential buildings. *Energy economics 30*(2), 503–516.

Blundell, R., A. Duncan, and C. Meghir (1998). Estimating labor supply responses using tax reforms. *Econometrica*, 827–861.

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.

Brounen, D., N. Kok, and J. M. Quigley (2012). Residential energy use and conservation: Economics and demographics. *European Economic Review 56*(5), 931 – 945. Green Building, the Economy, and Public Policy.

Bruegge, C., C. Carrión-Flores, and J. C. Pope (2016). Does the housing market value energy efficient homes? evidence from the energy star program. *Regional Science and Urban Economics 57*, 63–76.

Bruegge, C., T. Deryugina, and E. Myers (2019). The distributional effects of building energy codes. *Journal of the Association of Environmental and Resource Economists 6*(S1), S95–S127.

Chetty, R., A. Looney, and K. Kroft (2009, September). Salience and taxation: Theory and evidence. *American Economic Review 99*(4), 1145–77.

De Cian, E., F. Pavanello, T. Randazzo, M. Mistry, and M. Davide (2019). Does climate influence households' thermal comfort decisions? *University Ca'Foscari of Venice, Dept. of Economics Research Paper Series No 2*.

DellaVigna, S. (2009). Psychology and economics: Evidence from the field. *Journal of Economic literature 47*(2), 315–72.

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

Finkelstein, A. (2009). E-ztax: Tax salience and tax rates. *The Quarterly Journal of Economics 124*(3), 969–1010.

Fisher, A. C. and M. H. Rothkopf (1989). Market failure and energy policy a rationale for selective conservation. *Energy policy 17*(4), 397–406.

Fuerst, F., P. M. McAllister, A. Nanda, and P. Wyatt (2015). Variations in the implicit pricing of energy performance by dwelling type and tenure: A study of wales. *Available at SSRN 2633539*.

Fuerst, F., J. Van de Wetering, and P. Wyatt (2013). Is intrinsic energy efficiency reflected in the pricing of office leases? *Building Research & Information 41*(4), 373–383.

Gillingham, K., R. G. Newell, and K. Palmer (2009). Energy efficiency economics and policy. *Annu. Rev. Resour. Econ. 1*(1), 597–620.

Grigolon, L., M. Reynaert, and F. Verboven (2018, August). Consumer valuation of fuel costs and tax policy: Evidence from the european car market. *American Economic Journal: Economic Policy 10*(3), 193–225.

Harjunen, O. and M. Liski (2014). Not so myopic consumers-evidence on capitalization of energy technologies in a housing market.

Hausman, J. (2001). Mismeasured variables in econometric analysis: problems from the right and problems from the left. *Journal of Economic perspectives 15*(4), 57–67.

Hossain, T. and J. Morgan (2006). ... plus shipping and handling: Revenue (non) equivalence in field experiments on ebay. *Advances in Economic Analysis & Policy 5*(2).

Hyland, M., R. C. Lyons, and S. Lyons (2013). The value of domestic building energy efficiency—evidence from ireland. *Energy economics 40*, 943–952.

Jaffe, A. B. and R. N. Stavins (1994). The energy paradox and the diffusion of conservation technology. *Resource and Energy Economics 16*(2), 91 – 122.

Kholodilin, K. A., C. Michelsen, and D. Ulbricht (2014). Speculative price bubbles in urban housing markets in germany.

Moffitt, R. (1993). Identification and estimation of dynamic models with a time series of repeated cross-sections. *Journal of Econometrics 59*(1), 99 – 123.

Myers, E. (2018). Asymmetric information in residential rental markets: Implications for the energy efficiency gap.

Myers, E. (2019, May). Are home buyers inattentive? evidence from capitalization of energy costs. *American Economic Journal: Economic Policy 11*(2), 165–88.

Rehdanz, K. (2007). Determinants of residential space heating expenditures in germany. *Energy Economics 29*(2), 167–182.

Stanley, S., R. C. Lyons, and S. Lyons (2016). The price effect of building energy ratings in the dublin residential market. *Energy Efficiency 9*(4), 875–885.

Wald, A. (1940). The fitting of straight lines if both variables are subject to error. *The Annals of Mathematical Statistics 11*(3), 284–300.

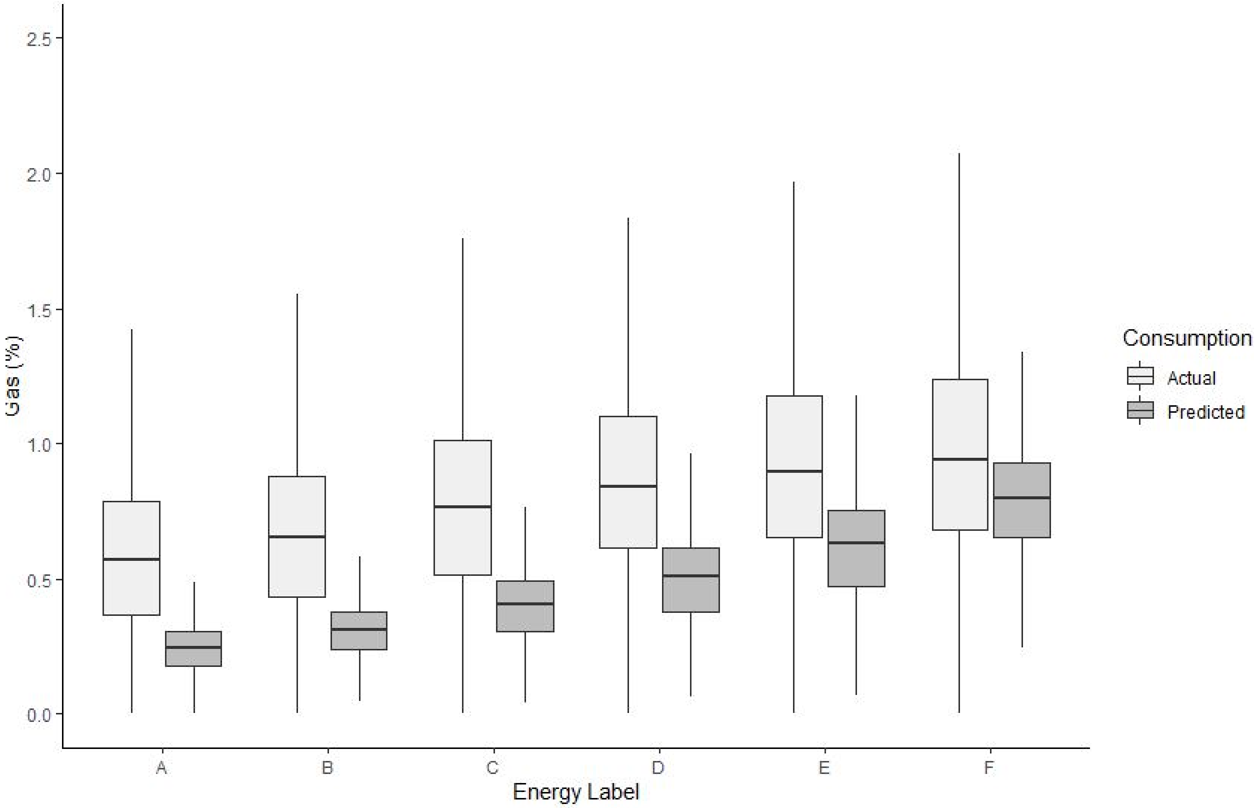
White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica 48*(4), 817–838.

White, H. (1982). Instrumental variables regression with independent observations. *Econometrica 50*(2), 483–499.

Yang, L., H. Yan, and J. C. Lam (2014). Thermal comfort and building energy consumption implications – a review. *Applied Energy 115*, 164 – 173.

Zalejska-Jonsson, A. (2014). Stated WTP and rational WTP: Willingness to pay for green apartments in Sweden. *Sustainable Cities and Society 13*, 46–56.

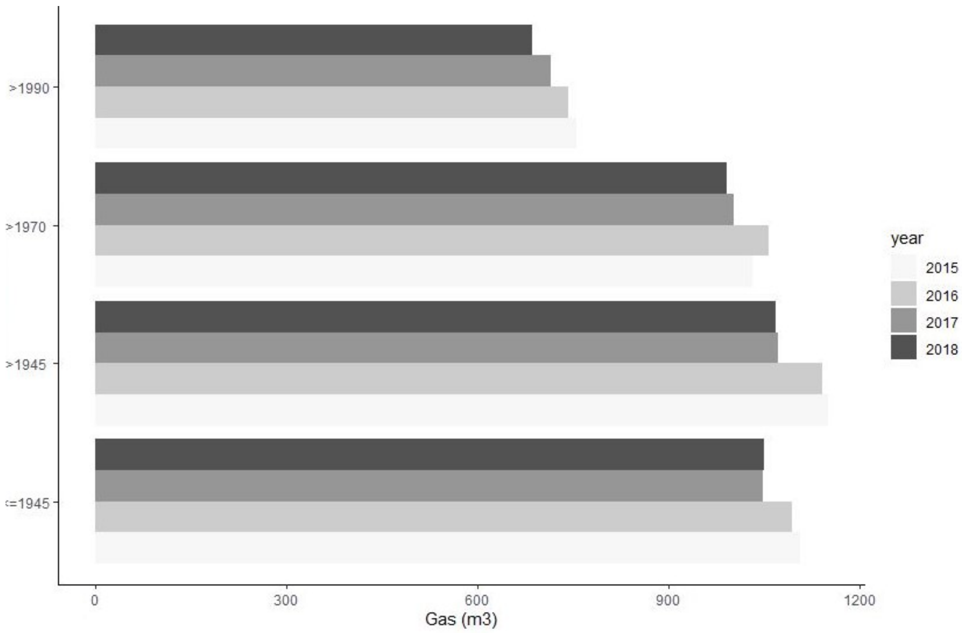
Figure 1: Consumption Relative to an average G Label



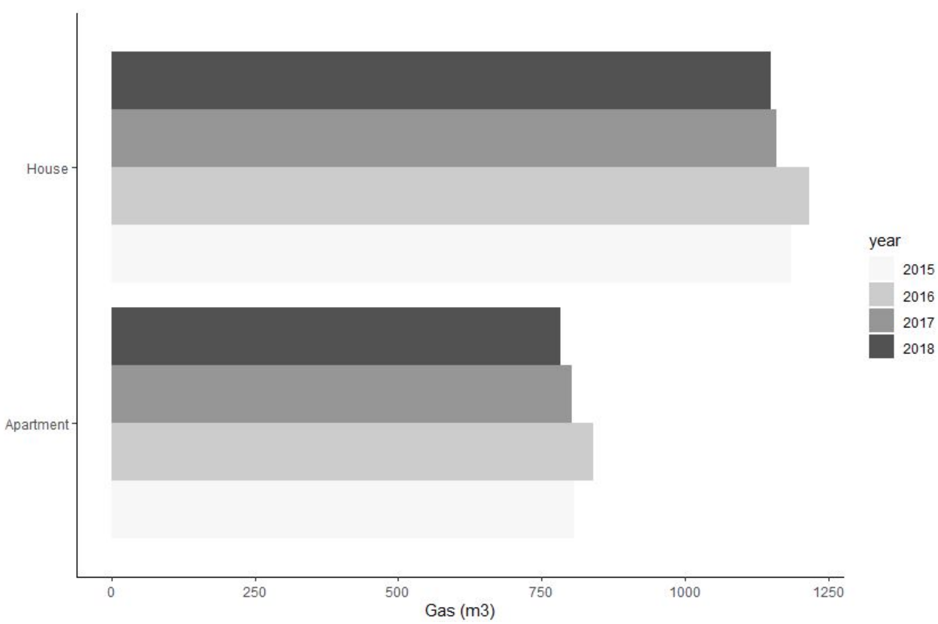
Notes: The predicted consumption is given by an engineer when the label is awarded. The consumption is relative to the average predicted and actual consumption of a G labeled dwelling, respectively. Data from CBS and RVO

Figure 2: Gas consumption by Construction year and type

(a) Construction Year



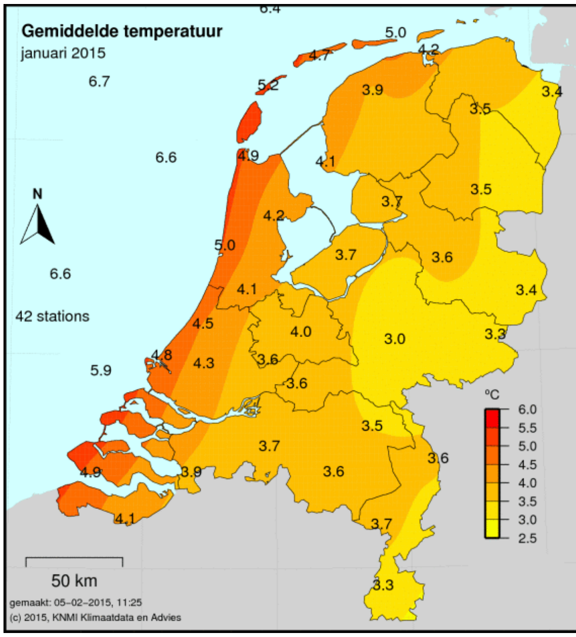
(b) Construction type



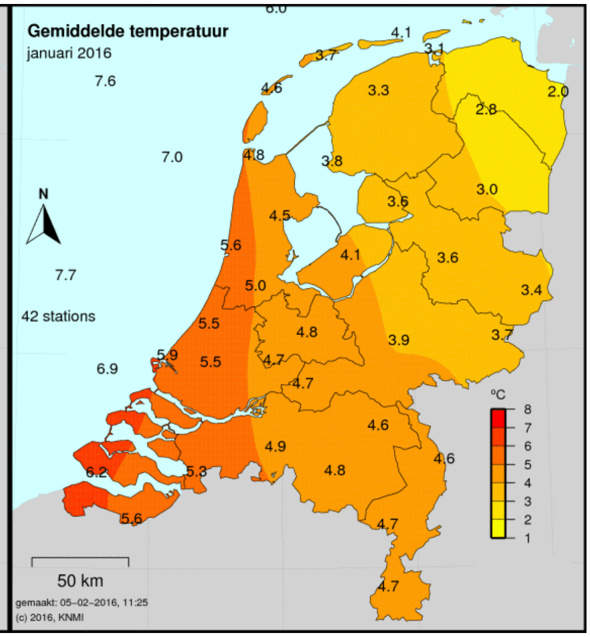
Notes: Consumption of gas in m3 per year of construction and type of dwelling. Data from CBS

Figure 3: Average temperature in the Netherlands by province

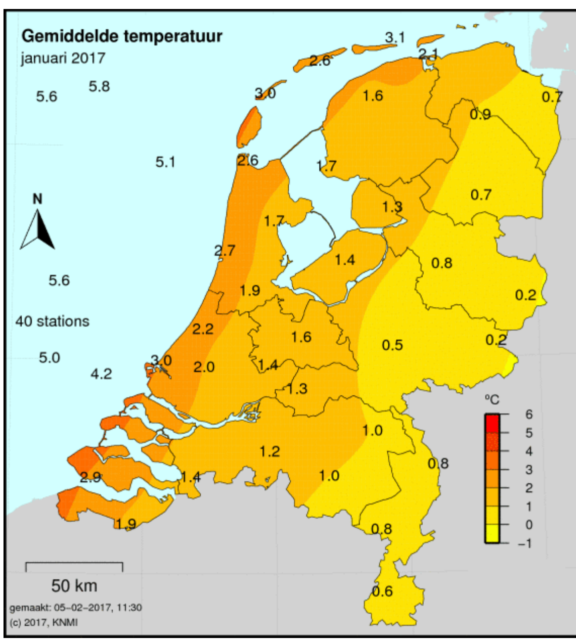
(a) 2015



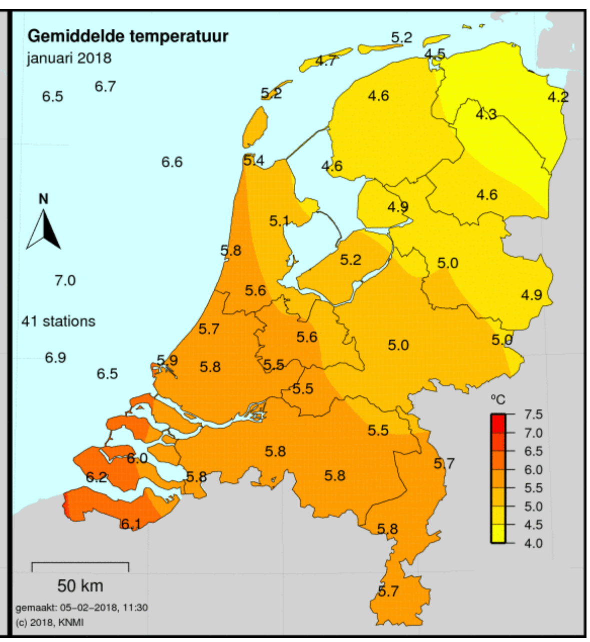
(b) 2016



(c) 2017



(d) 2018



Source: Koninklijk Nederlands Meteorologisch Instituut (KNMI)

Table 1: Housing market supply side market shares

A: International housing market breakdown	The Netherlands	United Kingdom	Germany	France
Owner - occupied	57%	62%	43%	56%
Rental	43 %	48%	57%	44%
of which Regulated	87%	51%	12%	36%

B: Dutch rental market breakdown	Social housing associations (2.3 mln units)	Commercial Investors (1 mln units)	
		Institutional investors (185.000 units)	Private investors (815.000 units)
Regulated rent	95%	43%	78%
Non-regulated rent	5%	57%	22%

Notes: Panel A: Distribution of owner and rental market in four of the biggest markets in Europe. Panel B: Distribution by type of landlord and market segment of the rental market in the Netherlands.

Table 2: The Dutch regulated rent point system

Quality feature	Points assigned
Living surface area	1 point for each sqmeter
Non-living surface area	0.75 point for each sqmeter
Heating	2 points for each living room
	1 point for each non-living room
Energy label	36 points for A
	32 point for B
	22 points for C
	14 points for D
	8 points for E
	4 points for F
	0 points for G
In the absence of energy label	
built after 2002	36 points
built after 2000	32 points
built after 1992	22 points
built after 1984	14 points
built after 1979	8 points
built after 1977	4 points
built before 1977	0 points
Kitchen	0 points if countertop <1 meter
	4 points if countertop is between 1 and 2 meters
	7 points if countertop is over 2 meters
Sanitary	3 point for a toilet
	1 point for a sink
	4 points for a shower
	6 points for a bath
	7 points for a batch/shower
Exterior space (garden/balcony)	2 points if less than 25 sqmeters
	4 points if less than 50 sqmeters
	6 points if less than 75 sqmeters
	8 points if less than 100 sqmeters
	10 points if more than 100 sqmeters
	2 points for a carport
Tax value	1 point for every 8747 euros of tax value
Renovation	0.2 points for every 1000 euros spent (5 years max)
Monument	50 points

Source: Huur commissie, De Rijksoverheid. Voor Nederland

Table 3: Sampling Strategy

Category	Description
Owner type	Social Housing
	Private
Construction Type	House
	Apartment
Construction Year	≤ 1945
	> 1945 and ≤ 1970
	> 1970 and ≤ 1990
	> 1990
Region	North
	Middle
	South
	G4[†]

[†] G4 refers to the four biggest cities in the Netherlands: Amsterdam, Rotterdam, the Hague and Utrecht
Source: CBS

Table 4: Descriptive Statistics

	Regulated	Non-regulated
Rent	526	916
M^2	69.21	91.95
Tax Value	133,995	199,348
Year of Construction	1973	1993
Apartment (%)	51.94	57.88
Gas Expenditures:		
Theoretical	114.58	76.90
Actual	75.81	66.41
Year (%)		
2015	23.76	11.30
2016	25.26	24.41
2017	24.27	27.00
2018	26.70	37.28
Energy Label (%)		
A	4.71	19.87
B	14.08	23.11
C	32.79	33.58
D	24.45	13.91
E	13.93	5.61
F	7.37	2.76
G	2.66	1.15
N	1'136,193	91,144
n	399,930	45,282
T	1-4	1-4

Notes: Rent, refers to the monthly rent in euros. Tax Value is the latest available valuation in euros. Gas expenditures is the theoretical and actual monthly expense in euros.

Table 5: Descriptive statistics Regulated market

	Rent	Point Score	Rent / Max Rent	Gas Expenditures
A	609	173	0.7081	55.4
B	551	159	0.7093	62.0
C	536	149	0.7282	72.0
D	518	142	0.7410	80.6
E	498	135	0.7511	86.5
F	479	130	0.7520	91.4
G	458	123	0.7620	94.0
Total	526	146	0.7306	75.8

Notes: All values calculated for 2018. Gas expenditures is the monthly expense in euros. Rent/Max Rent is calculated using the equivalent value in euros for the average point score for each label. Non-regulated rents are excluded as they do not need to follow the point system when setting the rent value.

Table 6: Regression Results

	(1) OLS	(2) OLS	(3) OLS
γ	0.114***	-0.041***	-0.024***
	(0.003)	(0.002)	(0.002)
Time effects	Yes	Yes	Yes
House characteristics	No	Yes	Yes
Location characteristics	No	No	Yes
N	958,461	958,461	958,461

Notes: Dependent variable is the monthly rent of the house. Standard errors are estimated using White (1980) method for OLS.
*** p<0.01, ** p<0.05, * p<0.1.

Table 7: IV Estimations

	Theoretical (1) IV	uValue (2) IV	Grouping Estimator (3) IV
γ	-0.445***	-0.343***	-0.529***
	(0.009)	(0.065)	(0.048)
Time effects	Yes	Yes	Yes
House characteristics	Yes	Yes	Yes
Location characteristics	Yes	Yes	Yes
N	483,917	882,651	1’089.617

Notes: Dependent variable is the monthly rent of the house. Standard errors are estimated using White (1982) method for IV reported in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table 8: Regression by type of landlord and market segment

A: Sample Distribution - 2018	Housing Association	Privately Owned
Regulated	197,399	14,085
Non-regulated	9,415	13,222

B: Regression Results	Housing Association	Privately Owned	
Regulated	- 0.821***	0.063	-0.546***
	(0.193)	(0.236)	(0.125)
Non-regulated	- 0.549***	-0.269*	-0.490***
	(0.176)	(0.152)	(0.101)
Landlord Type	-0.765 ***	-0.133	
	(0.086)	(0.118)	

Notes: Panel A: Distribution of dwellings in 2018. Panel B: Dependent variable is the monthly rent of the house. Standard errors are estimated using White (1982) method for IV, reported in parentheses. Sample is estimated separately for Housing associations and private landlords.
*** p<0.01, ** p<0.05, * p<0.1.

Table 9: RD Estimations

	A-B	B-C	C-D	D-E	E-F	F-G
	(1)	(2)	(3)	(4)	(5)	(6)
LATE	-5.454***	-7.125***	-0.663	5.763***	-8.850***	-2.590
	(1.723)	(1.168)	(1.501)	(1.762)	(2.315)	(3.564)
N	116,375	189,103	96,813	70,033	38,169	19,725

Notes: Dependent variable is the monthly rent of the house. LATE is calculated using a bandwidth of 0.03, for reference EI can only increase by 0.01 and the average label range is 0.6. Standard errors are estimated using White (1982) method for IV reported in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table 10: Regression Results

	(1) OLS
γ^{ren}	-1.824*** (0.533)
N	5,977

Notes: Dependent variable is the change in the monthly rent of the house after renovation. Column (1) calculates the change in points due to a change in label and column (2) calculates the change in predicted gas bills after the renovation. Controls include the year of renovation and change in points not related to change in energy label. Standard errors are reported in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.