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The capitalization of energy efficiency

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The capitalization of energy efficiency: Evidence from the housing market

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A B S T R A C T

This paper investigates how private consumers capitalize energy efficiency in the housing market, and the extent to which the provision of an energy performance certificate (EPC) affects such capitalization. We explicitly address methodological lacunae in the literature, using an exhaustive battery of identification strategies. The results indicate that energy efficiency is indeed capitalized into home prices, with OLS estimates biased downwards. Using an IV approach, we find that as the level of energy efficiency increases by ten percent, the market value of the dwelling increases by around 2.2 percent – quite a precise reflection of both the required capital outlay and future energy savings. These results are confirmed in a repeat-sales analysis. Importantly, examining the role of energy performance certificates (EPCs), we document that the extent of capitalization of energy efficiency is not affected by information provision, questioning the continued need for government-imposed certification programs.

1. Introduction

In today's debate on climate change, and the carbon externality from energy consumption, energy efficiency seems the panacea that is globally embraced by policy makers. The building stock represents an important target for public policy, due to its sizable share of global energy use and its significant potential for efficiency improvements. For example, the European Union aims for a 20 percent reduction in energy consumption by 2020, based solely on "cost effective" measures that are paid back by reductions in utility bills. China has included energy efficiency as a cornerstone of its current five-year plan, with the ambition to retrofit four million square feet of non-residential space. And while the U.S. lacks comprehensive federal policy aimed at reducing energy consumption in buildings, individual states have passed legislation to do just that. Most prominently, under California's Global Warming Solutions Act (also known as AB 32), 50 percent of existing commercial buildings will need to be retrofitted to "zero net energy" by 2030. But of course, the success of such policies critically depends on the ability of homeowners, developers, and commercial real estate investors to identify efficiency opportunities and their willingness to invest in energy efficiency retrofits.

Economists have long recognized that market barriers and market failures can lead to what has been termed the "energy efficiency gap" – the difference between the socially optimal level of energy efficiency investments and the level that is actually achieved (Allcott and Greenstone, 2012). Explanations for this gap vary between hidden costs of energy efficiency investments, principal-agent problems and behavioral failures such as inattention, while others argue that the energy efficiency gap is merely an artifact of overly optimistic engineering assumptions (see Gillingham et al., 2014, for a discussion).

Another potential market barrier that may lead to underinvestment in energy efficiency is a lack of transparency, especially in the opaque real estate market. Homebuyers may be unable to accurately assess the energy efficiency of a home, as some features are imperfectly visible. Indeed, following Akerlof (1970)'s "lemons" model, information asymmetry between seller and buyer is generally accepted as one of the main reasons leading to underinvestment in energy efficiency in the housing market (Gillingham et al., 2009). In the absence of perfect information, potential buyers are unable to incorporate future energy expenditures into their purchasing decisions, and therefore (current) homeowners prefer not to invest in energy efficiency improvements. In recent years, energy certificates and labels have been proposed as a remedy – comparable

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[2] Starting with Hausman (1979), many studies have shown that the present value of future energy savings exceeds the initial costs of energy efficiency investments.

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to food labels (Bollinger et al., 2011) and restaurant hygiene scorecards (Jin et al., 2003). For instance, EU member states have been required since 2009 to implement energy performance certification (EPC) schemes for residential dwellings.[3] By providing information to market participants regarding the energy performance of buildings, policy makers expect differentiation in demand based on energy characteristics of the dwellings, which in return may lead to higher investments in energy efficiency. The effectiveness of this policy of course hinges on the extent to which buyers are willing to pay for increased energy efficiency.

The academic literature provides some empirical evidence on the relationship between energy efficiency and real estate prices, but most research focuses on the commercial real estate sector, which arguably represents a more efficient market with more rational agents (see Eichholtz et al., 2010, 2013). For the residential market, using a sample of dwellings with energy performance certificates (EPCs), Brounen and Kok (2011) document that consumers pay a four percent premium for homes labeled as “efficient” (labels A, B or C) in the Netherlands. Kahn and Kok (2014), using transaction data from the California housing market, document that homes labeled with a “green” certificate are sold at a small price premium as compared to non-labeled homes. As energy labels are not necessarily available in other countries, researchers have also used alternative approaches to identify the market value of energy efficiency. Zheng et al. (2012) document that “green” buildings, which are identified based on an index created using Google search, are sold at a price premium during the pre-sale stage. In the same spirit, Dastrup et al. (2012) find that solar panel installations in California are capitalized into house prices at a 3.5 percent price premium.

While this body of literature is significant and growing, a common methodological drawback is the potential bias that may arise from the omission of unobserved dwelling characteristics correlated with measures of energy efficiency.[4] Typically, in order to minimize the omitted variable bias, the empirical strategy is to include a detailed set of observable characteristics into hedonic pricing models. However, this strategy does not completely rule out the presence of unobservable factors, and multicollinearity among the observed characteristics often leads to imprecise and sometimes implausible estimates of attribute prices. Indeed, Atkinson and Halvorsen (1984) document that the difficulties caused by multicollinearity are more apparent when analyzing energy efficiency, leading to insignificant or theoretically incorrect estimates.

Besides these methodological challenges, the available literature on residential energy efficiency has not been able to distinguish between the impact of certification policies (i.e. information provision) and the energy efficiency of the home itself, as observable to the buyer in the absence of energy certificates. Private consumers might already be incorporating the energy efficiency of a dwelling into their purchasing decisions, independent of the availability of additional information. From a policy perspective, it is important to assess whether energy policies based on information provision are effective, given that considerable resources are devoted to, for example, increasing the diffusion of home energy certification programs.

This study is the first to directly examine the capitalization of energy efficiency improvements in the housing market, including the role of information provision. Using a large, representative dataset from the Netherlands, we employ a variety of estimation strategies to identify the capitalization of energy efficiency in the housing market, and the extent to which information asymmetry affects such capitalization. The analysis benefits from a continuous measure of energy efficiency provided by engineering estimates. These engineering estimates form the base for widely adopted energy performance certificates, enabling us to estimate the elasticity of home prices with respect to their energy efficiency. In addition to including detailed dwelling characteristics in the hedonic model, we use an instrumental variable approach to address the issue of omitted variable bias. We exploit the 1973-74 oil crisis, which creates an exogenous discontinuity in the energy efficiency level of dwellings constructed before and after this event, and the evolution of building codes as instruments for energy efficiency. Finally, we employ a repeated sales analysis as an alternative identification strategy.

Our results indicate that energy efficiency is capitalized into home prices, but that OLS estimates are biased downwards. Using an IV approach, we find that as the level of predicted energy efficiency increases by ten percent, the market value of the dwelling increases by around 2.2 percent, for an average dwelling in the Dutch housing market. Using a repeated sales analysis, based on a sample of homes that experienced energy efficiency improvements between consecutive sales, we show that the change in the level of energy efficiency is capitalized quite precisely in the second transaction. The estimated price effect is comparable to the IV estimates.

In order to assess whether the capitalization of energy efficiency varies with information provision, we create a common energy efficiency measure, based on actual energy consumption for a set of homes that are labeled with an energy performance certificate and a control group that is not labeled. We document that the market value of a change in actual gas consumption is close to the value of a change in the engineering estimate of energy efficiency indicator, as provided by energy performance certificate. Our findings do not provide evidence of a different capitalization rate for homes that transacted with an energy performance certificate. We also employ a regression discontinuity approach to test whether the actual label rating (ranging from A to G) has market implications. Our results do not provide an indication of a significant change in the transaction price at the threshold energy efficiency level that is used to assign homes into different label classifications. This finding implies that, after controlling for the continuous energy efficiency level of a home, the EU energy label does not seem to lead to a significant change in the buyer’s valuation of the energy efficiency of a dwelling.

The results of this paper have important policy implications, particularly for energy efficiency programs. One reason for households not to undertake seemingly profitable investments in energy efficiency may be the uncertainty regarding the financial return, as upgrading a dwelling to improve its energy efficiency typically involves a significant upfront investment. For instance, from the homeowner’s point of view, the expected length of tenure may not be sufficient to offset the cost of the investment by the reduction in energy costs. The willingness to invest in energy efficiency may be even lower for institutional investors, as they typically lease out their investment properties, and therefore do not directly benefit from the reduction in utility bills.[5]

For homeowners and institutional investors to better assess the total return on investments in energy efficiency, it is therefore important to understand both the immediate returns through lower utility bills as well as the indirect, future returns through capitalization of energy efficiency improvement in the sales price of the building. Our findings suggest that energy efficiency is capitalized quite precisely in the housing market (in addition to the immediate financial benefits from lower energy expenses).

As discussed by Allcott and Greenstone (2012), information campaigns can play an important role in the diffusion of energy efficiency investments. However, the results in this paper do not provide evidence for the intangible effects of energy labels on transaction prices. Given the significant efforts put into energy certification programs, further research is needed into their effectiveness – perhaps the increased salience of energy costs and energy efficiency now obviates the need for

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[3] Owners of commercial real estate assets in a number of cities across the U.S. have to report standardized energy consumption data to the local governments, which is subsequently made public.

[4] See Klier and Linn (2012) for a discussion of similar issues when analyzing the capitalization of energy efficiency in the automobile sector.

[5] See Kahn et al. (2014) for a discussion of energy consumption and the split incentive problem in commercial real estate.

such programs. These programs may be more useful as public awareness campaigns that highlight the financial benefits that households and investors can derive from energy efficiency, as for example highlighted by this study.

The remainder of this paper is organized as follows. The next section describes the data used in the various parts of the analysis. In Section 3, we present the methodology and the results. Section 4 provides a brief conclusion.

2. Data

This paper exploits detailed transaction data provided by the National Association of Realtors (NVM) in the Netherlands. The NVM tracks about 75 percent of all transactions in the Netherlands, through their affiliate broker network.[6] The data contains information on the detailed characteristics of all dwellings transacted, as well as their transaction price. We restrict our sample to single-family homes, which account for nearly 70 percent of the total transactions.[7]

2.1. Sample of homes transacted with EPC

Following the EU directive 2002/91/EC on the energy performance of buildings, energy performance certification for homes was introduced in the Netherlands in January 2008.[8] The energy performance certificate is issued by a professionally trained expert. Obtaining the certificate requires an investment of approximately € 200, which is incurred by the owner of the dwelling. The expert visits the dwelling and inspects its physical characteristics such as size, structure, quality of insulation, heating installation, ventilation, solar systems, and built-in lighting. The collected information is then used to predict the total energy consumption of the home through an automated engineering model (see also Aydin et al. (2017)). These "asset rating" engineering models are based on standard usage patterns, a standard set of operating parameters (e.g., for thermostat settings) and climatic conditions that do not depend on occupant behavior, actual weather and indoor conditions, and are developed to rate the building and not the occupant. The predicted total energy consumption is a combination of predicted gas and electricity consumption.[9] The electricity component does not include the electricity consumption from household appliances, which are expected to make up nearly 40 percent of total residential electricity consumption. After scaling by the size and heating loss area of the dwelling, the prediction is transformed into an energy performance index (EPI), a continuous measure used to assign the dwelling to a certain label class, ranging from "A+ +" for exceptionally energy-efficient homes, to "G" for highly inefficient homes. Appendix Figure A.1 provides a stylized example of the energy label in the Netherlands, which is comparable across the EU.[10]

In order to analyze the predicted energy efficiency of homes, we match the NVM transaction data set with the energy performance certificate (EPC) database managed by Netherlands Enterprise Agency (RVO) – a governmental body responsible for subsidies and regulations related to energy efficiency and innovation (including renewable energy, patents, etc.). We exclude homes that were constructed before 1900 or after 1999, as these are exempt from mandatory disclosure of an EPC. We eliminate outliers that are detected based on the sample distribution of the energy performance index – the upper and lower boundaries for the outliers are set at the first and 99th percentile. The final sample includes 30,036 single-family homes that transacted during the 2008-2011 period with an energy performance index.[11]

Fig. 1 presents the distribution of transaction price, energy performance index and construction year of the dwellings in this sample. A higher energy performance index (EPI) indicates a lower level of energy efficiency. According to this simple graph, most of the homes in the sample have an EPI value between 1-3, were constructed after 1950, and sold at a price ranging from € 100,000 to € 300,000. Columns (1) and (2) in Table 1 further document the summary statistics for some of the main characteristics of the sample, distinguishing between "energy efficient" (EPI $<$ median) and "inefficient" (EPI $>$ median) homes. According to these statistics, energy efficient homes are sold at a slightly higher price, are larger in size, and are younger than less efficient homes.

As a first analysis of the relationship between energy efficiency and home prices, Fig. 2 plots the observed home prices for varying levels of energy efficiency. In Panel A, using raw, unadjusted prices, we obtain a quadratic relationship between the EPI and the value of the dwelling, which is not fully in line with expectations. This, however, may well be due to the omission of other determinants of home prices, which are correlated with energy efficiency (such as dwelling type, location, construction year, etc.). In panel B, we adjust for all observable determinants of home prices, except the EPI. In order to calculate the adjusted house prices, we use the covariate adjustment approach described by Cattaneo et al. (2019).[12] We observe a more intuitive relationship in

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[6] Comparing the descriptive statistics of our sample to descriptive statistics on the owner-occupied market in the Netherlands more broadly, we find that homes in our sample are somewhat smaller (the average size of owner-occupied homes in the Netherlands is 139 m^2 with 4.32 rooms per home versus 125 m^2 and 4.8 rooms in our sample).

[7] Bailey (1966) notes that, compared to single-family dwellings, apartment units may present idiosyncratic difficulties of specification and measurement, and differences in the valuation of attributes between these two types of dwellings may exist. Similarly, Ridker and Henning (1967) and Kahn and Kok (2014) focus on single-family dwellings in their analysis of energy efficiency and home prices.

[8] Dwellings that have been constructed after 1999, or that are registered as monuments, are exempted from mandatory disclosure of the energy performance certificate. If the buyer of the dwelling signs a waiver, the seller is also exempt from providing the certificate. That is why, around 80 percent of homes in the NVM database has been transacted without EPC. In order to examine the impact of information provision, we also analyze the sample of these non-certified homes in Section 3.4.

[9] The predicted gas use is assumed to be a combination of gas used for space heating and water heating. The gas used for space heating is calculated based on the efficiency of the distribution and installation systems. Any potential gains from use of a solar boiler and the additional energy used for pilot flame are also accounted for in the prediction. In order to calculate the demand for heating, the transmission and ventilation losses are summed up, and the internal and solar heating gains are deducted from this aggregate. The transmission loss component is calculated based on a weighting factor for surface, which ranges from 0 to 1 depending on the position of the surface, the area of the surface and the U-value of that surface (an indication of its isolation quality). The heating season duration is assumed to be 212 days. The average indoor and outdoor temperatures are assumed to be 18 degrees Celsius and 5.64 degrees Celsius, respectively. The prediction also accounts for the loss of energy through ventilation, which is calculated based on the type of ventilation and the infiltration rate. The second component of the residential gas consumption is the gas used for water heating, which is a combination of the gas used by the main boiler and the kitchen boiler. The gas consumed by the main hot water installation is calculated based on a conversion factor, the quantity of hot water consumed in a day, the efficiency of the boiler, type of boiler, the circulation loss depending on the insulation level. The quantity of the hot water is a combination of hot water used in kitchen, quantity used for basins, quantity used for showering and quantity used for bath. The assumption on the number of people living in the house is based on the dwelling size. The gas used for cooking is not included in the calculations, as it strongly depends on household behavior, and it typically represents just three percent of the total residential gas consumption.

[10] We exploit the energy performance index in the first part of the analysis, while the corresponding label class is used in the second part of the paper.

[11] For the repeated sales analysis, we extend the sample period by including transactions between 2012 and 2015, but at the time of writing, energy consumption data (which will be used later for comparison purposes) was not available for this period, yet.

[12] The covariates that are included in this model (except the EPI) can be retrieved from Column 4 of Table A.1 in the Appendix.

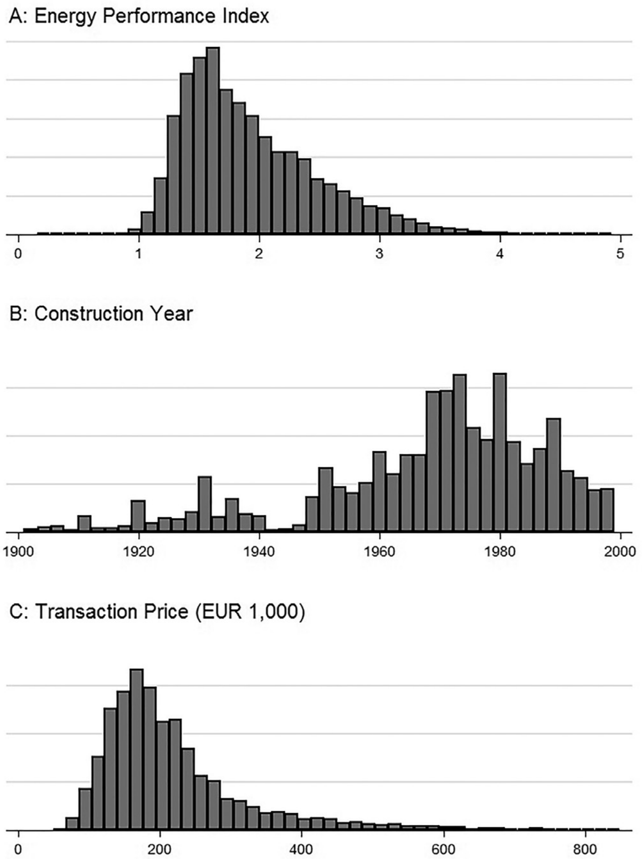

Fig. 1. Distribution of the Energy Performance Index, Construction Year, and Transaction Price. *Notes:* Figure 1 shows the sample distribution of the energy performance index (EPI), construction year and the transaction price. The distributions are based on the sample of single-family dwellings that were sold between 2008 and 2011 with an EPC. We exclude homes that were constructed before 1900 or after 1999. We eliminate outliers that are detected based on the sample distribution of size, price, and the energy performance index – the upper and lower boundaries for the outliers are set at the first and 99th percentile. This leads to a sample of 30,036 single-family homes that were transacted with an EPC during the 2008-2011 period.

this graph, indicating that as the energy efficiency of a home decreases, the transaction price decreases as well.[13]

2.2. Repeated sales with EPC

A second approach to identify the capitalization of energy efficiency is to measure the change in home prices associated with the change in energy efficiency occurring between repeated sales. Therefore, we create another sample that includes only the homes that were sold repeatedly with an EPC. In order to obtain a sufficient number of repeat observations, we extend the sample period by adding homes that were transacted between 2012 and 2015.[14] We limit the sample to homes that are sold twice between 2008 and 2015 (N=1,938). We exclude homes that are sold repeatedly within one year, as this type of high frequency transaction tends to be speculative and/or tax-driven, and therefore lacks a common economic price mechanism (N=1,848). We also exclude outliers based on the distribution of over-time changes in transaction price (the upper and lower boundaries for the outliers are set at the first and 99th percentile, N=1,810). The final sample of homes with improved energy efficiency that are sold twice between 2008 and 2015 consists of 155 single-family homes. These homes had a lower energy performance index for the second sale as compared to the first transaction.[15] In order to isolate other time-varying factors, we use the remaining part of the repeated sales sample as a control group, including 1,655 single-family homes that transacted twice between

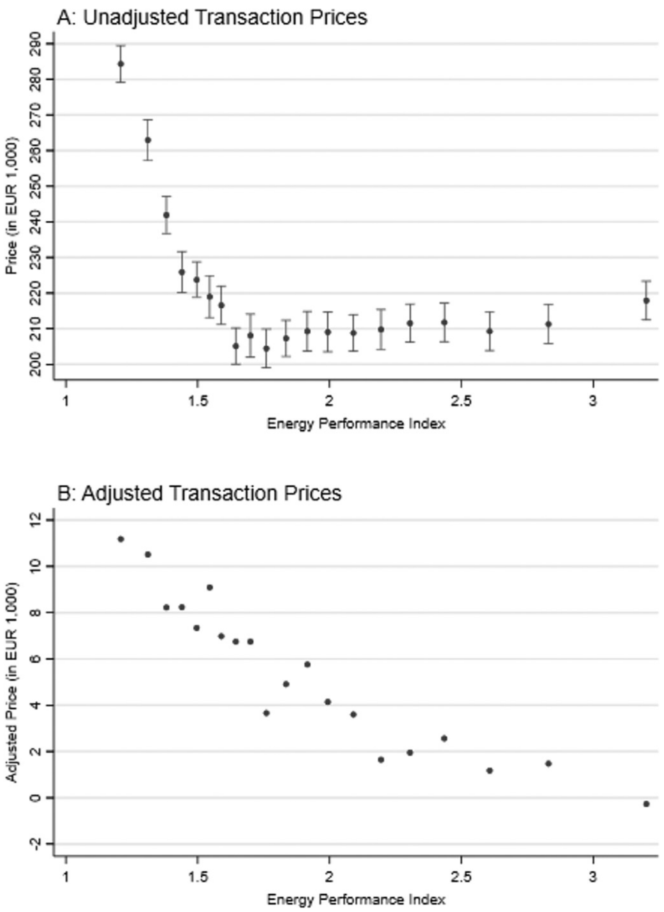

Fig. 2. Transaction Prices and the Level of Energy Efficiency. *Notes:* Panel A presents a figure relating home prices to the energy performance index (EPI). In Panel B, we adjust for all determinants of home prices except the EPI. In order to calculate the adjusted house prices, we use the covariate adjustment approach described by Cattaneo et al. (2019). The covariates that are included in this model (except the EPI) can be retrieved from Column 4 of Table A.1 in the Appendix. In both panels, the data is divided into J = 15 bins according to the empirical quantiles of observed EPI scores. Within each bin a single dot is plotted at the mean of house price (or adjusted house price) for observations falling in the bin. The vertical lines represent the 95 percent confidence intervals for adjusted/unadjusted house prices for the group of homes in each bin.

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[13] Note that Fig. 2, Panel B does not include confidence intervals. These confidence intervals are reported in Appendix Figure A.2, but the increased scale of the y-axis makes this graph harder to interpret.

[14] We are unable to use the extended sample in other analyses, as the information on household characteristics and energy consumption is not yet available for the period after 2011.

[15] There are also homes for which we observe an increase in EPI score, which indicates decreasing energy efficiency level between two transactions. We excluded these homes from the analysis. These homes represent around 25 percent of the homes that realized a change in EPI between two transactions. However, we note that these observations are more likely to be the result of minor differences in the calculation of EPI by different experts, as a large fraction of these changes in EPI are relatively small (the median change in EPI for these homes is +0.1 while it is -0.24 for the homes that realized a decrease in EPI). Because of assumptions made in the calculation procedure and potential mistakes made during the inspection, it is possible that the engineering predictions of energy efficiency include a random measurement error, which might lead to differences in the prediction of EPI between two sales. In the subsequent analysis, we also take this potential measurement error problem into account.

Table 1
Descriptive Statistics.

Variables	EPC Sample		Repeated Sales Sample						Certified and Non-certified Samples	
	$EPI \leq 1.8$	$EPI > 1.8$	Improved Homes			Control Group			Non-Certified Homes	Certified Homes
			1^{st} Sale	2^{nd} Sale	% Δ	1^{st} Sale	2^{nd} Sale	% Δ		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Transaction Price (€ 1,000)	229.3	210.8	179.8	185.6	3.23	209.6	201.0	-4.10	257.0	214.5
	(108.3)	(109.6)	(83.0)	(87.9)		(85.4)	(82.4)		(113.3)	(100.1)
Log (Transaction Price)	5.35	5.25	12.02	12.05		12.2	12.1		5.47	5.28
	(0.41)	(0.42)	(0.36)	(0.37)		(0.36)	(0.36)		(0.39)	(0.40)
Energy Performance Index (EPI)	1.507	2.342	2.11	1.70	-19.4	1.94	1.94	0.00		1.92
	(0.171)	(0.417)	(0.57)	(0.43)		(0.55)	(0.55)			(0.52)
Log (Energy Performance Index)	0.40	0.84	0.71	0.50		0.62	0.62			0.62
	(0.12)	(0.17)	(0.27)	(0.24)		(0.27)	(0.27)			(0.26)
Gas Consumption (m^3)									1,795	1,647
									(646)	(581)
Log (Gas Consumption)									7.43	7.35
									(0.36)	(0.35)
Number of Insulation Measures	2.53	1.35	1.66	1.96	18.1	2.06	2.18	5.8	2.24	1.92
	(1.72)	(1.05)	(1.47)	(1.47)		(1.58)	(1.56)		(1.65)	(1.51)
Internal Maintenance (1=excellent, 9=bad)	6.76	6.39	6.50	7.13	9.7	6.76	7.12	5.3	6.83	6.58
	(0.95)	(1.15)	(0.99)	(1.09)		(0.98)	(0.88)		(1.04)	(1.07)
External Maintenance (1=excellent, 9=bad)	6.92	6.64	6.73	7.05	4.8	6.89	7.04	2.2	6.90	6.78
	(0.75)	(0.92)	(0.86)	(0.94)		(0.77)	(0.82)		(0.93)	(0.84)
Size (m^2)	122.9	116.3	107.6			115.1			126.9	117.5
	(34.2)	(33.4)	(26.1)			(28.9)			(31.1)	(29.8)
Gas Consumption Intensity (m^3/m^2)									14.44	14.35
									(4.82)	(4.67)
Log (Gas Consumption Intensity)									2.61	2.61
									(0.34)	(0.33)
Number of Rooms	4.822	4.835	4.60			4.71			4.976	4.807
	(1.050)	(1.077)	(1.23)			(1.37)			(1.073)	(1.032)
Number of Floors	2.750	2.750	2.75			2.76			2.790	2.756
	(0.545)	(0.592)	(0.55)			(0.56)			(0.556)	(0.560)
Year of Construction(Median)	1981	1965	1970			1972			1965	1968
Type (fraction)										
Corner	0.249	0.257	0.33			0.22			0.205	0.258
Semi-detached	0.103	0.139	0.03			0.02			0.164	0.121
Between or Townhouse	0.552	0.508	0.63			0.69			0.490	0.537
Detached	0.096	0.096	0.01			0.07			0.141	0.084
Household Characteristics										
Number of Household Members									2.405	2.270
									(1.011)	(0.934)
Number of Elderly (Age > 65)									0.343	0.332
									(0.547)	(0.513)
Number of Children (Age < 18)									0.597	0.529
									(0.774)	(0.696)
Number of Female Household Members									1.209	1.158
									(0.625)	(0.585)
Household Income (€ 1000)									35.34	31.21
									(14.74)	(13.32)
Transaction Year (fraction)										
2008	0.435	0.425	0.27	0.00		0.50	0.00		0.277	0.434
2009	0.206	0.218	0.23	0.00		0.20	0.00		0.230	0.205
2010	0.172	0.176	0.19	0.00		0.16	0.00		0.257	0.173
2011	0.187	0.181	0.23	0.00		0.11	0.01		0.236	0.188
2012			0.03	0.10		0.02	0.21			
2013			0.04	0.17		0.01	0.14			
2014			0.01	0.39		0.00	0.31			
2015			0.00	0.34		0.00	0.33			
Number of Observations	15,170	14,866	155	155	155	1,655	1,655	1,655	103,834	23,187

Notes: The statistics for the "EPC sample" (columns 1 and 2) are based on the sample of single-family dwellings that are sold between 2008 and 2011 with an EPC. These statistics are provided separately for homes that have an energy performance index (EPI) that is smaller ("energy-efficient") and larger ("energy-inefficient") than the median energy performance index (1.8). Columns (3) to (8) report the descriptive statistics for the single-family homes that were sold twice between 2008 and 2015. For this sample, we provide the statistics separately for the homes with a lower energy performance index prior to the second sale and for the homes that were sold with the same energy performance index in the second sale. We exclude outliers based on the distribution of over-time changes in transaction price and energy efficiency. We also exclude the homes that are sold repeatedly within one year. Finally, the last two columns report the descriptive statistics for EPC-certified and non-certified dwellings. Average household characteristics and gas consumption are calculated based on the households that reside in each dwelling between 2004-2011 (gas consumption data is not available for the years 2005 and 2007). In calculating the average gas consumption level for each home, we correct for annual heating degree days and exclude the year of transaction. For all samples, we exclude the homes that were constructed before 1900 or after 1999. We eliminate outliers that are detected based on the sample distribution of size, price, and the energy performance index – the upper and lower boundaries for the outliers are set at the first and 99th percentile.

2008 and 2015. These homes had an energy performance index prior to the first sale and had the same index value in the second transaction.

In columns (3) to (8) of Table 1, we present the descriptive statistics for the sample of homes with improved energy efficiency and for the control group, separately for the first and second sales. The statistics indicate that the sample of improved homes are sold at a slightly lower price at both the first and the second sale, as compared to the control sample. However, the price gap decreases in the second sale. We also observe that the initial level of energy efficiency of the improved homes is lower as compared to the control sample. Assuming that there is no change in the energy efficiency of the homes in the control group, we observe that a 19.4 percent change in energy efficiency corresponds to a change in home prices of around 7.33 percent (3.23 + 4.10). This simple calculation implies that the elasticity of home prices with respect to energy efficiency is around 38 percent. But of course, this calculation does not control for macroeconomic changes in the housing market.

Using the information provided by NVM data, we also check whether there are changes in the (subjective) internal and external quality measures of homes between the first and second sales. The statistics in Table 1 indicate that the average home quality decreases over time for both sub-samples. This depreciation is larger for the homes that achieved energy efficiency improvements, and this can be considered as evidence that there is no positive correlation between changes in energy efficiency and the changes in other quality characteristics of the home. As expected, the change in the number of insulation measures is higher for the improved homes as compared to the control sample. It is important to note that there is also an increase in the number of insulation measures for the control group, although these homes did not show a revised energy performance index prior to the second sale. Therefore, we take this factor into account in the analysis, as it might lead to a downward bias in the estimated elasticity parameter.

2.3. *Sample of homes transacted without EPC*

In order to test whether the capitalization of energy efficiency varies with the disclosure of an energy performance certificate (EPC), we also analyze the homes that are transacted without EPC. For comparability, we create a common energy efficiency measure for both certified and non-certified homes. Since the energy performance index underlying the EPC is not available for non-certified homes, we exploit the variation in actual energy consumption. We match the NVM data set (for the years between 2008-2011) with annual gas consumption data provided by the Central Bureau of Statistics (CBS).[16] We calculate the average annual gas consumption per m^2 (between 2004-2011) for each home and use this as a proxy for the energy efficiency level of that dwelling. Fig. 3, Panel A shows the relationship between gas consumption per m^2 and the EPI.[17] CBS also provides information on household characteristics, including household composition and income level. We calculate the average characteristics of the households that reside in each dwelling between 2004-2011. We include these average household characteristics in the model as control variables, as they might be correlated with gas consumption (Brounen et al., 2012). In order to obtain information on the year of construction of non-certified dwellings, we merge our data set with the housing data provided by CBS. Finally, we exclude outliers detected based on the sample distribution of gas consumption per m^2, transaction price, house size and household income level (the upper and lower boundaries for the outliers are set at the first and 99th percentile). The complete sample includes 103,834 dwellings that transacted, without EPC, between 2008-2011.

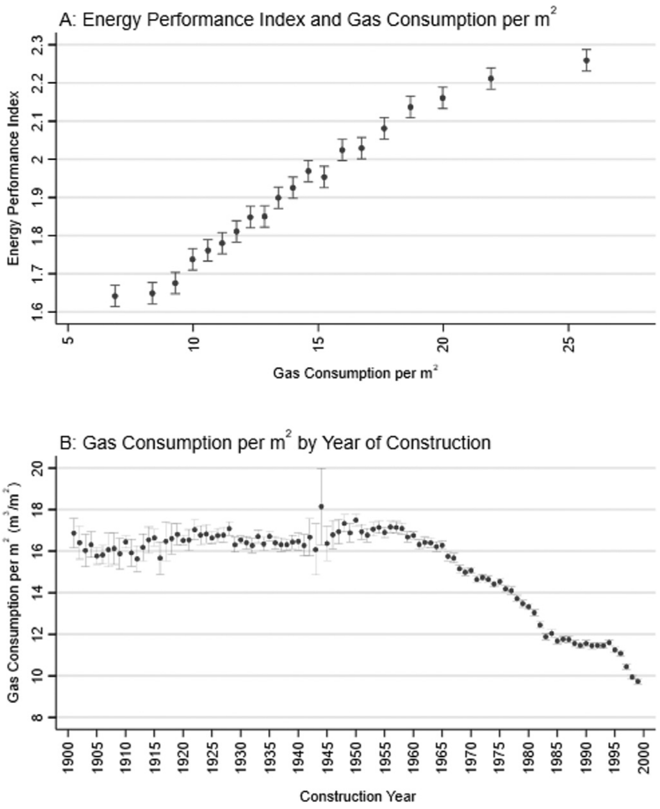

Fig. 3. Gas Consumption, Energy Performance Index and Year of Construction. *Notes:* Panel A presents the relationship between the energy performance index (EPI) and annual gas consumption per m^2. We calculate the average annual gas consumption per m^2 for the households that reside in each dwelling between 2004-2011 (the gas consumption data is not available for the years 2005 and 2007). In calculating the average annual gas consumption level for each home, we correct for annual heating degree days and exclude the years of transaction. In Panel A, the data is divided into J = 20 bins according to the empirical quantiles of observed annual gas consumption per m^2. Within each bin a single dot is plotted at the mean of energy performance index (EPI) for observations falling in the bin. The vertical lines represent the 95 percent confidence intervals for the adjusted/unadjusted house prices for the group of homes in each bin. Panel B presents the average annual gas consumption (per m^2) of homes for each construction year. The average annual gas consumption (per m^2) values are calculated based on the sample of homes that are constructed in each year.

In columns (9) and (10) of Table 1, we report the descriptive statistics for homes certified with an energy performance certificate and non-certified homes. The transaction price for non-certified dwellings is significantly higher as compared to certified dwellings. This might be due to the larger fraction of detached and semi-detached homes in the non-certified sample. The energy efficiency indicator, which is proxied by gas consumption per m^2, is not statistically different for certified and non-certified homes. The average home in our sample is occupied by two people who have an average annual income around € 35,000 (€ 31,000 for certified dwellings). The average annual gas consumption is 1,800 m^3 for non-certified homes and 1,650 m^3 for certified homes. According to these statistics, given that the consumer price of gas was 65 cents per m^3 in 2011, the annual gas expenditures of the average household corresponds to nearly four percent of the income of the household in our sample – a sizable expenditure.

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[16] In 2011, nearly 85 percent of residential electricity consumption in the Netherlands was used for household appliances, and the share of electricity used for air cooling was just 0.3 percent (source: Odyssee Database). Since residential electricity consumption in the Netherlands highly depends on the use of household appliances instead of the characteristics of the dwelling, we do not include household electricity consumption as a measure of home energy efficiency in our analysis.

[17] The gas consumption data is not available for the years 2005 and 2007. When calculating the average gas consumption level for each home, we correct for annual heating degree days and exclude the year of transaction.

Table 2
OLS Estimation Results: Home Prices and Energy Efficiency.

	(1)	(2)	(3)	(4)
Log(Energy Performance Index)	-0.235^{***}	-0.106^{***}	-0.052^{***}	-0.048^{***}
	[0.019]	[0.007]	[0.007]	[0.007]
Dwelling Characteristics	No	Yes	Yes	Yes
Construction Year	No	No	Yes	Yes
R^2 adj.	0.106	0.836	0.843	0.846
Number of observations	30,036	30,036	30,036	30,036

Notes: Table 2 reports the OLS estimations results. The dependent variable is the logarithm of transaction price. Dwelling characteristics include: size, type, quality, number of floors, number of rooms, type of parking place, location of the home relative to city center, road, park, water and forest. Construction year is included as a third order polynomial in column (3). In column (4), dummy variables representing each construction year are included. In all regressions, neighborhood and year of transaction dummies are also included. Heteroskedasticity-robust standard errors are in brackets. Standard errors are clustered by neighborhood and transaction year. $^{*}P < 0.10$. $^{**}P < 0.05$. $^{***}P < 0.01$.

3. Methodology and results

3.1. OLS estimation

Hedonic models are commonly used in the economics literature to estimate the value of individual product attributes (Rosen, 1974). Analyzing the housing market, the size of the estimated coefficient on each variable represents the implicit value of that characteristic. Our basic hedonic model takes the following form:

$$Log(Price_{it}) = \beta_0 + \beta_1 Log(E_i) + \beta_j X_i + \alpha_n + t_i + \varepsilon_{it} \tag{1}$$

where the dependent variable, $Log(Price_{it})$, is the logarithm of the transaction price of dwelling i at time t. $Log(E_i)$ is the variable of interest, representing the logarithm of the energy efficiency level of the dwelling, and X_i is a vector of other dwelling characteristics. By using a log-log specification, we estimate the elasticity of home prices with respect to energy efficiency, which is denoted by β_1.[18] To control for unobserved location amenities, we include neighborhood fixed effects (α_n) in our model. t_i is a vector of transaction year dummies, which account for the macroeconomic factors that may influence home prices over time.

We first estimate Eq. (1) using ordinary least squares (OLS), assuming that the energy performance index (EPI_i), which is used as a measure of energy efficiency (E_i), is independent of the error term (ε_{it}). The results are presented in Table 2. Control variables are omitted from the table. Detailed estimation results are provided in Appendix Table A.1.[19] When including the EPI as the sole regressor (column 1), the estimated elasticity parameter equals 0.24. The coefficient decreases to 0.11 when including other observable characteristics of the home. In column 3, we also include the construction year of the home, as it is expected to be strongly correlated with the level of energy efficiency. Controlling for all other variables, we document that a ten percent change in the energy performance index leads to a 0.5 percent change in the market value of the home. The results do not show significant variation when we specify the year of construction as dummy variables (column 4) instead of a continuous variable.[20]

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 value of energy efficiency. The presence of unobserved determinants of home prices may be correlated with the level of energy efficiency, influencing the estimated coefficient. Depending on the direction of the correlation between these unobserved factors and prices, and between the unobserved factors and the energy efficiency level, this can either be a downward or an upward bias. Furthermore, multicollinearity between the construction year and the energy performance index may increase the magnitude of a bias when controlling for the construction year in the OLS estimates.[21]

Another econometric issue that may cause a biased estimate is the presence of measurement error in the engineering calculations. It could be the case that the engineering calculations include a random measurement error, because of the assumptions made in the calculation method, and the potential mistakes made during the inspection.[22] We assume that the predicted energy efficiency (*EPI*) is a combination of the true value (EPI^*) 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 *EPI* is independent of the

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[18] Since our variable of interest (E_i) indicates the energy efficiency level of the home (not its total energy requirement), using a level-level specification would provide information on the monetary value of a one-unit increase in the EPI index, which has no direct interpretation. Instead, we use a log-log specification – the resulting elasticity measure is more intuitive and provides a better comparison to the existing literature.

[19] The estimated coefficients for the control variables are in line with expectations. Home size, number of rooms, presence of parking place, being located close to a forest, waterside or park, having a clear view, high quality and being built recently positively affect the house prices. On the other hand, being located near a busy road or at the center, and number of floors (keeping house size fixed) affect home prices negatively.

[20] As not all homes are labeled with an EPC, we also examine whether the unobserved determinants of label adoption are correlated with the error term in Eq. (1), which may lead to biased estimates. In order to test this, we first estimate a probit model to predict the probability of label adoption in our sample of labeled and non-labeled homes. In this model, we rely on functional form identification, without an exclusion restriction. Next, as proposed by Heckman (1979), we include the inverse Mills ratio in our model. The results (available upon request) show that the estimated coefficient of EPI does not change significantly after controlling for the potential selection bias. The results also indicate that there is no significant correlation between the error term of model specified in Eq. (1) and the error term of the estimated probit model (the p-value of the log-likelihood test is 0.176). Therefore, we conclude that there is no immediate evidence for sample selection bias.

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

[22] Especially for older dwellings, the engineer has to make assumptions regarding the U-value of outside walls and the rates of ventilation and infiltration. As the engineering models are examined through energy simulation tests and verified by pilot studies (Poel et al., 2007), we do not expect a significant, systematic bias in the calculated energy efficiency level. Although Aydin et al. (2017) discuss the plausibility of this assumption in more detail, we should note that our parameter estimate will be sensitive to any systematic mistake in engineering models. The other potential source of measurement error is the quality of the inspection. In 2011, it was documented that 16.7 percent of the certified dwellings exceeded the maximum acceptable level of the deviation from the real energy index (VROM-Inspectie, 2011). Certificates that deviate from the real energy index by more than eight percent are considered certificates with a critical defect. However, examination of the data on re-inspection of a sample of certified dwellings indicates that this inspection error is not systematically and significantly correlated with the true efficiency value.

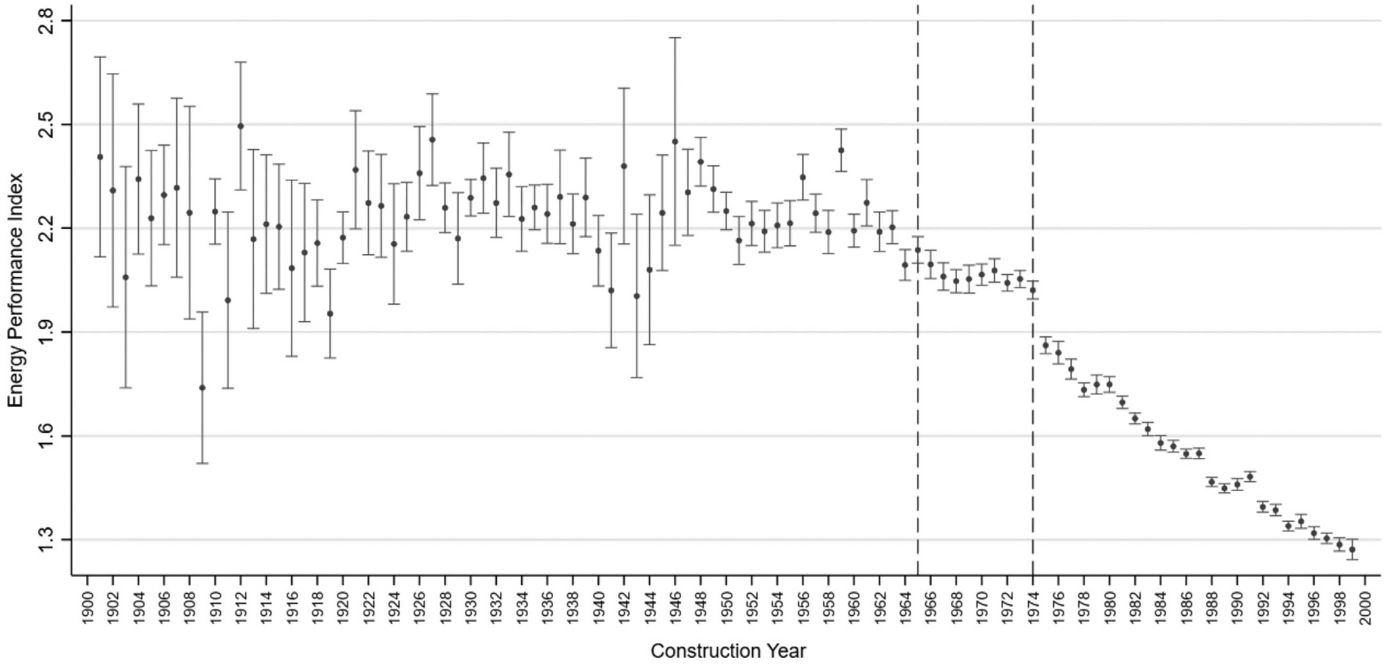

Fig. 4. Home Energy Efficiency Levels by Year of Construction. *Notes:* Figure 4 presents the average energy performance index (EPI) of homes for each construction year and the 95 percent confidence intervals. The average EPI values are calculated based on the sample of dwellings that are constructed in each year. The first building code in the Netherlands was introduced in 1965. In 1974, oil prices (as a proxy for energy costs) increased by 260 percent. We exclude homes that were constructed before 1900 or after 1999 from the analysis, as these are exempt from mandatory disclosure of an EPC.

error term may not be valid. The presence of this random measurement error leads to a downward bias in the OLS estimate of β_1.[23]

3.2. *Instrumental variable approach*

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 (EPI^*), but has to be independent of both the measurement error (e) and the unobserved determinants of home prices.

Energy prices are one of the main drivers of investments in energy efficiency, as rising prices make achieving thermal comfort more costly for households and decrease the payback period of investments.[24] Appendix Figure A.3 presents the growth rate of real oil prices from 1900 to 2000. The most remarkable increase in oil prices took place in 1974, when prices rose by 260 percent. Therefore, dwellings that were constructed just after the oil crisis may be more energy efficient as compared to previously constructed dwellings. Indeed, Fig. 4 shows a clear structural break and discontinuity in the average energy efficiency level of homes constructed after the increase of energy prices.[25] This increased energy efficiency level can be considered the combined result of household demand for more energy efficient dwellings (and appliances), as well as the revision of building codes after the oil crisis.

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.[26] Appendix Figure A.4 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. Fig. 3 confirms that the average efficiency level of dwellings is quite stable until the 1960s, and starts increasing at the time of the introduction of the first building code in 1965 (reflected in a decreasing EPI). After the substantial increase in energy costs in 1973-74, the EPI drops substantially, and the increasing trend in energy efficiency accelerates, forced by stricter building codes.[27]

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[23] 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 energy efficiency premium.

[24] See Knittel (2011), Li et al. (2009) and Klier and Linn (2010) for an analysis of how gasoline prices affect fuel efficiency in the automobile sector.

[25] Haas and Schipper (1998) document that after the decrease in residential energy demand following the 1973-74 oil crisis, demand did not rebound in times of declining energy prices (e.g., in 1985). They argue that irreversible efficiency improvements that took place after the 1973-74 oil crisis might be an explanation for this observation.

[26] 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.

[27] We also analyzed whether there is a "bunching" of homes constructed just before the policy years, in case there is anticipation of the regulation. Panel A of Figure A.6 in the Appendix presents the distribution of homes based on construction years. The vertical lines represent the years of changes in U-value requirement. The figure indicates no clear evidence for bunching of homes constructed before the years of policy changes (instead, the construction rates were slightly higher after the policy changes in the years 1965, 1978 and 1986 when the U-value requirements were improved substantially). Therefore, based on the over-time distribution of construction rates, we do not find support for anticipation of regulation by real estate developers. (Note that a more robust way of testing this hypothesis would be possible with a proper control region where no policy changes were in place.). In the same figure, in order to check whether there is any structural change in the main observable characteristics of the constructed homes around the regulation years and the 1974 oil shock, we also present the average statistics for some of the main observable characteristics of the homes based on construction year. Panel B of Figure A.6 shows the over-

In order to identify the impact of energy efficiency on home prices using an IV approach, we first exploit the exogenous change (discontinuity) in energy efficiency that took place in 1974 as an instrument, assuming that unobservable characteristics of construction do not vary discontinuously in 1974. Based on the year of construction, we assign dwellings constructed after 1974 as the homes that were exposed to significantly higher energy costs during their construction. Our main identifying assumption is that unobserved characteristics vary continuously with the year of construction. Thus, any discontinuity of the conditional distribution of energy efficiency as a function of the year of construction in 1974 can be considered as evidence of a causal effect of the oil crisis and subsequent spike.[28] This identification strategy is comparable to Vollaard and Van Ours (2011), who use a similar approach analyzing the impact of stricter built-in security standards on burglary rates.

To obtain more accurate estimates of the trends in energy efficiency before and after the exogenous shock, and to be able to compare dwellings that have similar characteristics, we limit our sample to those homes that were constructed between 1967-1982. This enables us to identify the discontinuity in energy efficiency by isolating the trend effect that might otherwise be correlated with the over-time change in unobserved characteristics of the constructed homes (such as time-variant luxury attributes of homes). Fig. 5, Panel A presents the discontinuity in energy efficiency of homes in 1974. As can be observed in Panel B of Fig. 5, there is a small increase in home prices for those homes constructed after 1974.[29]

Using the discontinuity in energy efficiency as an instrument for the energy performance index (EPI), we are able to disentangle the true (and exogenous) variation in energy efficiency. Thus, the first and second stage regression models of the IV estimation can be written as:

$$Log(EPI_i) = \alpha_0 + \alpha_1 D_i^{1974} + \alpha_2 T_i + \alpha_3 D_i^{1974} T_i + \alpha_j X_i + \tau_i + \eta_n + \epsilon_i \qquad (2)$$

$$Log(Price_{it}) = \delta_0 + \delta_1 \widehat{Log(EPI_i)} + \delta_2 T_i + \delta_3 D_i^{1974} T_i + \delta_j X_i + t_i + \alpha_n + \varepsilon_{it} \qquad (3)$$

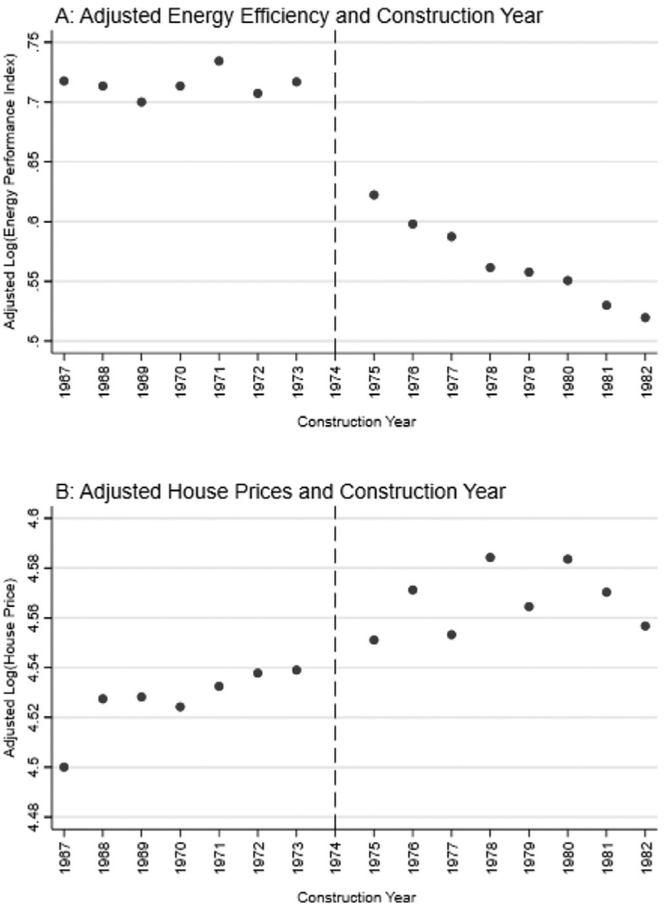

Fig. 5. Energy Efficiency and Price of the Homes Constructed Before and After 1974. *Notes:* Panel A presents the average of the adjusted energy performance index (EPI) based on the year of construction before and after the 1974 oil crisis. Panel B presents a figure relating the adjusted home prices to the year of construction. The average adjusted Log (EPI) and average adjusted Log (House Price) values are calculated based on the sample of dwellings that are constructed in each year. In order to calculate the adjusted EPI and adjusted house prices, we use these covariate adjustment approach described by Cattaneo et al. (2019). The covariates that are included in these models (excluding EPI and construction year variables) can be retrieved from Column 4 of Table A.1 in the Appendix.

where T indicates the construction year of the home and D^{1974} is a dummy variable which is equal to one for the homes that were constructed after 1974 and zero otherwise. By specifying time trends separately before and after 1974, we are able to capture the exogenous variation in energy efficiency.

Table 3 reports the results of the IV estimations, based on different sample specifications. Results of the first stage regression model imply that the average energy requirement of a dwelling constructed after the 1974 oil crisis is about 6-8 percent lower as compared to previously constructed dwellings.[30] The results in column (1), which are based on the sample of homes constructed between 1967 and 1982, indicate that a ten percent change in the energy performance index leads to a change in the market value of the dwelling of about 2.2 percent. The estimated coefficient does not vary significantly as we extend the sample by including homes constructed longer before and after the oil shock (columns 2

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time variation in the mean house size. This figure indicates that the average house size has increased over time. However, there is no clear discontinuity in house size around the years of policy changes or at the time of the oil shock in 1974. Similarly, when we check the average number of rooms based on the construction year (Panel C), we see that there is no clear long-run trend. We observe a discontinuity (sudden decrease) around the year 1981 when the U-value requirement was changed only slightly (the year of the weakest change in U-value requirement). However, we do not see similar structural changes in other policy years, although the improvements in U-value restrictions were stronger in those years as compared to 1981. Finally, Panel D indicates that there is no clear trend or structural change over time in the average number of floors, based on the construction year.

[28] Note that, in addition to the oil price shock, U-value requirements changed slightly in 1974 (see Appendix Figure A.4). This change in U-value requirements might also be a factor that leads to a discontinuity in the energy efficiency level of new construction (although Fig. 4 does not indicate the presence of such discontinuity, even in 1978, which is the year of the strongest improvement in U-values). However, the possible effect of changing U-value requirements does not violate the validity of our identifying assumption, as both the policy change and the oil price shock can be considered exogenous factors affecting the energy efficiency of the dwellings. We are not necessarily interested in the source of exogenous change, but instead we are interested in the resulting change in energy efficiency and house prices.

[29] Note that the confidence intervals are omitted in Fig. 5. We decided to do so, as the increased scale of the y-axis makes this graph harder to interpret. Appendix Figure A.5 presents the same figure with confidence intervals. This figure makes clear that there is large variation in adjusted house prices for the homes constructed in the years just before and after the oil shock. Therefore, in the regression analysis, in order to identify the effect of oil shock on energy efficiency and house prices, we consider different time lengths around the oil shock. Assuming that homes take a while to build, this seems a plausible consideration.

[30] Detailed first-stage and second-stage estimation results are presented in Appendix Table A.2 and Table A.3, respectively.

Table 3
IV Estimation Results: Home Prices and Energy Efficiency.

	(1)	(2)	(3)	(4)	(5)
Construction Period	(1967-1982)	(1959-1990)	(1950-1999)	(1900-1999)	(1900-1999)
Log(Energy Performance Index)	-0.227^{***} [0.090]	-0.185^{**} [0.085]	-0.198^{***} [0.064]	-0.214^{***} [0.074]	-0.257^{***} [0.060]
Dwelling Characteristics	Yes	Yes	Yes	Yes	Yes
Construction Year	Yes	Yes	Yes	Yes	Yes
First Stage Results					
D^{1974}	-0.080^{***} [0.009]	-0.060^{***} [0.007]	-0.073^{***} [0.006]		
U-value				0.071^{***} [0.006]	0.023^{***} [0.006]
Log(Oil Price$_{t-2}$)					-0.036^{***} [0.003]
F-statistic for excluded instruments	74.03	73.20	134.85	138.00	178.80
Test of overidentifying restrictions (χ^2)					1.013
Number of observations	12,513	20,270	25,311	30,036	30,036

Notes: Table 3 reports the instrumental variable (IV) estimation results. The dependent variable is the logarithm of transaction price. In columns (1), (2) and (3), the energy performance index (EPI) is instrumented by the discontinuity in the energy performance index in 1974 (D^{1974}). In these regressions, we include linear construction year variables (different before and after 1974) as control variables. In column (4), the energy performance index (EPI) is instrumented by the maximum allowable U-value requirements for external walls at the time of construction. In column (5), the energy performance index (EPI) is instrumented by the logarithm of the oil price two years before the construction. In models (4) and (5), construction year is included as a third order polynomial. In all regressions, we include home characteristics, neighborhood and year of transaction dummies as control variables. Home characteristics include: size, type, quality, number of floors, number of rooms, type of parking place, location of the home relative to city center, road, park, water and forest. Heteroskedasticity-robust standard errors are in brackets. Standard errors are clustered by neighborhood and transaction year. * $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$.

and 3).[31] Assuming that the change in home energy efficiency in 1974 is exogenous, the IV results provide evidence that the value of energy efficiency is actually *underestimated* in the OLS regressions.[32]

The identifying assumption of using a discontinuity in energy efficiency as an instrument is that the timing of the oil shock does not coincide with a discontinuity in unobserved dwelling characteristics that might also affect the price of the home. Although this assumption cannot be tested directly, we examine the validity of our findings by using an alternative instrument that is specifically targeted at the energy efficiency of new buildings and that exhibits more variation over time (as compared to the one-time energy price shock). The over-time variation in the stringency of building codes provides such alternative, using the maximum allowable U-value requirement for outside walls as a proxy for stringency (see Appendix Figure A.4).

Column (4) of Table 3 documents the IV estimation results that are based on the evolution of U-value requirements for external walls of newly constructed homes. The first-stage regression results indicate that the U-value requirement is indeed associated with the energy efficiency level of the homes constructed under that requirement, which is in line with the findings of Jacobsen and Kotchen (2013). According to the estimated coefficient on the energy performance index (EPI), if the predicted energy efficiency of an average home changes by ten percent, the market value of that home changes by around 2.1 percent, which closely resembles the results documented by the discontinuity approach.

Finally, in addition to the U-value requirements, we also add the oil price two years before the construction (as a proxy for energy costs) as an instrumental variable.[33] This way, we are able to test the overidentifying restrictions, by using both instruments in the same model.[34] We estimate an IV model including both IVs at the same time in the first stage regression. The results in column (5) indicate a slightly larger capitalization rate (not significantly different from the previous results). Inclusion of oil prices in the first stage regression leads to a decrease in the estimated effect of U-value requirements on the energy efficiency of the new homes (0.071 versus 0.023). This indicates that in in the first stage of IV model in column (4), the U-value variable is partly capturing the impact of oil prices on the energy efficiency of new homes, because of the correlation between U-value requirements and the oil prices. This is expected, as early regulations were mainly induced by the increasing energy costs. Based on the first stage regression results reported in column (5), as the oil price two years prior to the construction increases 100 percent, the energy efficiency of new homes increases by around 3.6 percent on average. Most importantly, when we test the overidentifying restrictions, we are not able to reject the null hypothesis, which supports the assumption that the instrumental variables are exogenous.[35]

3.3. *Repeated sales analysis*

An alternative approach that can be used as an identification strategy for the capitalization of investments in energy efficiency is to measure

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[31] As a robustness check, we also estimate the IV models by excluding homes that are constructed in 1974. The estimated coefficients are not significantly different from the results reported in Table 3.

[32] We test the validity of our estimation strategy by estimating a series of placebo regressions in which we replace the year of the oil shock (1974) with other years around the time of oil shock. Table A.4 provides the results for the estimation of the same specifications in equations (2) and (3), but this time with different threshold years (1970, 1972, 1976 and 1978 respectively). Since there is not a strong change in the energy efficiency of new construction around those years, we are not able to find any significant effect of EPI on house prices. We also verified whether inclusion of non-linear trends for the construction year variable alters our main results, in case we might be capturing this non-linear impact of construction year instead of a discontinuity. In Table A.5, we allow for quadratic (column 1) and third order polynomial (column 2) effects of construction year. The results are not significantly different from our main results in Table 3.

[33] See also Costa and Kahn (2011), for an analysis of energy prices and home energy efficiency.

[34] We are not able to use the 1974 oil shock and the U-value requirements in the same IV model as the sample and the model specifications are not same.

[35] As a robustness check, we also use the oil price one year before construction. The results are not statistically different from the previous results. We prefer to report the IV results using two-year lagged oil prices, since the first stage results indicate that it is a stronger IV as compared to one-year lagged oil prices.

the change in home prices associated with the change in energy efficiency occurring between repeated sales. The advantage of such repeat sales approach compared to a cross-sectional analysis is that analyzing consecutive observations on the same dwelling controls for unobservable, time-invariant home characteristics that might be correlated with the energy efficiency of the home.

The empirical model for the repeated sales analysis can be specified as:

$$Log\left(\frac{Price_{i(t+n)}}{Price_{it}}\right) = \gamma_0 + \gamma_1 Log\left(\frac{E_{i(t+n)}}{E_{it}}\right) + \gamma_j \Delta Q_i + T_{it} + T_{i(t+n)} + \varepsilon_{i(t+n)} \tag{4}$$

where $Price_{it}$ and $Price_{i(t+n)}$ are the transaction prices of dwelling i at the first and second sale. Similarly, the energy performance index of home i at each transaction is represented by E_{it} and $E_{i(t+n)}$. Since other refurbishments might be correlated with the efficiency improvements, we also include measures indicating the change in the internal and external quality of the home, denoted by ΔQ_i. T_{it} and $T_{i(t+n)}$ indicate the transaction year of the first and second sale, respectively, capturing the influence of macroeconomic factors and other time trends. Finally, $\varepsilon_{i(t+n)}$ denotes the idiosyncratic price appreciation rate.

This model relates the percentage change in home price between two consecutive sales to the percentage change in its predicted energy efficiency. The estimate of γ_1 measures the change in value associated with the improvements in energy efficiency. The main identifying assumption is that idiosyncratic appreciation is independent of energy efficiency improvements. In case other refurbishments are correlated with energy efficiency improvements, this assumption will be violated. By including control variables for quality changes in the model, we aim to control for this potential bias.

As discussed earlier, one potential identification issue is the random measurement error in the engineering predictions of the energy performance index (EPI). This error might lead to underestimation of the parameter of interest, as it leads to an increase in the variance of the EPI. In our case, the measurement error problem would make it more likely to underestimate the energy efficiency premium. Therefore, we apply an IV approach in order to reduce the noise in engineering predictions. We use a dummy variable indicating whether the home has an improved EPI, or not, as an IV for the EPI. Our IV strategy is comparable to Allcott and Wozny (2014), who address the measurement error problem using the grouping estimator, which is a generalization of Wald (1940)'s estimator to the case of many group indicator variables. By using improvement as an IV, we average the individual level measurement error over the sample of improved homes, which leads to a decrease in the variance of noise (random measurement error).[36]

Table 4 documents the results of repeated sales analysis. The first column provides the OLS estimates. As expected, the IV estimate provided in the second column is comparable to our simple calculation based on descriptive statistics. Including the transaction year as a control variable, the size of the coefficient decreases significantly. In the third column, we also include control variables representing the change in internal and external maintenance of the dwelling. Finally, we control for the number of insulation measures to control for changes in the energy efficiency of the homes in control sample. The estimate in column (4) is comparable to our IV estimates in the previous sections, indicating a 1.9 percent price change associated with a ten percent change in predicted energy efficiency.

3.4. The impact of information provision

Information asymmetry is often suggested as one of the main reasons why households underinvest in otherwise profitable energy efficiency investment projects (Gillingham et al., 2009). The underlying mechanism is that if energy efficiency information is not available, consumers are not able to incorporate the operating costs into their purchasing decisions, which in return leads to suboptimal investments in energy efficiency. In order to enhance the transparency of energy efficiency in the real estate market, energy performance certificates have been used as one of the main policy instruments in EU countries (as well as in many other countries around the world). This provision of information is expected to enable households and investors to take energy efficiency into account during their purchasing process, thus leading to a more accurate capitalization of energy efficiency. The results in the previous sections provide evidence that the relative level of energy efficiency is indeed capitalized in a sample of dwellings that have an energy performance certificate (i.e. the intensive margin), so the question remains how the mere presence of an energy performance certificate affects the capitalization of energy efficiency in the market for single-family dwellings (i.e. at the extensive margin).

In order to test whether the capitalization of energy efficiency differs by the presence of an energy performance certificate (EPC), we estimate Eq. (1) for certified and non-certified homes separately. We benefit from the variation in actual energy consumption across homes as a common measure of energy efficiency in both samples, as the Energy Performance Index (EPI) is, of course, not available for non-certified homes. First, we use OLS to estimate the capitalization of energy efficiency for non-certified homes. The gas consumption per m^2 is used as a proxy for the energy efficiency level of the home. In column (1) of Table 5's Panel A, we report the results of the estimation of the model without including control variables.[37] The estimated coefficient implies that if the actual gas consumption per m^2 changes by ten percent, the value of the home changes by about 0.7 percent. However, when including control variables, the sign of the estimated coefficient becomes significantly positive, which is contrary to expectations. According to the results reported in column (3), keeping the dwelling and household characteristics fixed, if the gas expenditure decreases by ten percent, the value of the dwelling increases by around one percent for non-certified dwellings. The estimated coefficient is nearly the same when we estimate the model for the certified dwellings (column 4).

A potential explanation for these findings is that, due to the omission of unobserved factors and the presence of multicollinearity between actual gas consumption and other dwelling characteristics, the OLS estimation leads to a biased result (see, for example, Atkinson and Halvorsen (1984) and Brookshire et al. (1982) for a discussion of multicollinearity issue in the estimation of hedonic models). Therefore, we again use an IV approach in order to isolate the exogenous variation in actual gas consumption resulting from stricter building codes.[38] We estimate the same model using the maximum U-value requirement for external walls at the time of construction as an instrument for actual gas consumption per m^2. Table 5 Panel B documents the results of the IV estimations.[39] Comparing the coefficient estimates of the energy performance index (column 3) and gas consumption per m^2 (column 2), both based on the same sample of homes, we conclude that both efficiency indicators lead to similar results. The results show that, keeping other dwelling and household characteristics constant, as the actual gas

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[36] As a robustness test, we also excluded the homes that realized a change in EPI smaller than 0.15 units (the maximum acceptable level of the deviation from the real energy index is 8 percent, which corresponds to a 0.15 unit change in EPI for the average home). The results, which are reported in Appendix Table A.6, indicate a slightly lower capitalization of energy efficiency based on the full specification IV estimation (comparing columns 4 in Table 4 and in Table A.6, the results are 19.1 versus 13.3 percent, respectively). However, the difference between the two estimation results is not statistically significant. The results based on OLS are almost the same in both sample specifications.

[37] Detailed estimation results are in Appendix Table A.7.

[38] Fig. 3, Panel B shows the variation in gas consumption per m^2 of homes based on construction year.

[39] Detailed first-stage and second-stage estimation results are provided in Appendix Table A.8 and Table A.9, respectively

Table 4
Estimation Results for Repeated Sales.

	(1) (OLS)	(2) (IV)	(3) (IV)	(4) (IV)
Δ Log(Energy Performance Index)	−0.136***	−0.245***	-0.197***	−0.191***
	[0.037]	[0.057]	[0.052]	[0.051]
Transaction Years	Yes	Yes	Yes	Yes
Δ Internal/External Maintenance	No	No	Yes	Yes
Δ Number of Insulation Measures	No	No	No	Yes
R^2 adj.	0.104			
Number of observations	1,810	1,810	1,810	1,810

Notes: Table 4 reports the OLS and IV estimation results for the repeated sales analysis. The dependent variable is the logarithm of transaction price. In order to address the issue of random measurement error in engineering predictions, the energy performance index (EPI) is instrumented by a dummy variable indicating whether the home is transacted with a lower EPI at the second sale. Heteroskedasticity-robust standard errors are in brackets. Standard errors are clustered by province and transaction year. * $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$.

Table 5
Estimation Results for Non-Certified and Certified Homes.

Panel A: OLS Estimations

	(1) Non-certified	(2) Non-certified	(3) Non-certified	(4) Certified
Log(Actual Gas Cons. per m^2)	−0.071***	0.112***	0.105***	0.086***
	[0.008]	[0.003]	[0.003]	[0.005]
Dwelling Characteristics	No	Yes	Yes	Yes
Construction Year	No	Yes	Yes	Yes
Household Characteristics	No	No	Yes	Yes
R^2 adj.	0.010	0.774	0.794	0.855
Number of Observations	103,834	103,834	103,834	23,187

Panel B: IV Estimations

	(1) Non-certified	(2) Certified	(3) Certified
Log(Actual Gas Cons. per m^2)	−0.239***	−0.195**	
	[0.052]	[0.090]	
Log(Energy Performance Index)			-0.185***
			[0.080]
Dwelling Characteristics	Yes	Yes	Yes
Construction Year	Yes	Yes	Yes
Household Characteristics	Yes	Yes	Yes
First Stage Results			
U-value	0.068***	0.065***	0.069***
	[0.004]	[0.009]	[0.006]
F-statistic for excluded instrument	307.10	50.07	113.37
Number of Observations	103,834	23,187	23,187

Notes: In all regressions, the dependent variable is the logarithm of transaction price. Panel A reports the OLS estimation results for non-certified and EPC-certified homes. In column (4), we estimate the same model for the sample of certified homes only. Panel B reports the IV estimation results for EPC-certified and non-certified homes. The actual gas consumption per m^2 and energy performance index (EPI) are instrumented by the maximum allowable U-value requirements for external walls at the time of construction. Columns (2) and (3) of Panel B provide the estimation results for the certified sample, using two alternative energy efficiency measures. In all regressions, neighborhood and year of transaction dummies are included. Home characteristics include: size, type, quality, number of floors, number of rooms, type of parking place, location of the home relative to city center, road, park, water and forest. Household characteristics include: number of household members, number of children ($age < 18$), number of elderly ($age > 65$), number of females and household net income. Heteroskedasticity-robust standard errors are in brackets. Standard errors are clustered by neighborhood and transaction year. * $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$.

consumption decreases by ten percent, the market value of the home increases by around 2.4 percent for non-certified dwellings (column 1) and by two percent for certified dwellings (column 2), which is in line with our previous findings. The estimated coefficient is not statistically different for certified and non-certified dwellings, which provides some indication that there is limited evidence on the capitalization of energy efficiency being affected by the presence of an energy performance certificate.

We also examine directly whether the energy label rating provided by an energy performance certificate has an additional impact on the transaction price. EPCs provide a label designation, ranging from “A” to “G”. We apply a regression discontinuity (RD) approach based on the rule that is used to assign homes to energy efficiency labels. The basic idea behind this approach is that assignment to treatment is determined by the value of an observed characteristic being on either side of a cutoff value (Imbens and Lemieux, 2008). The main identifying as-

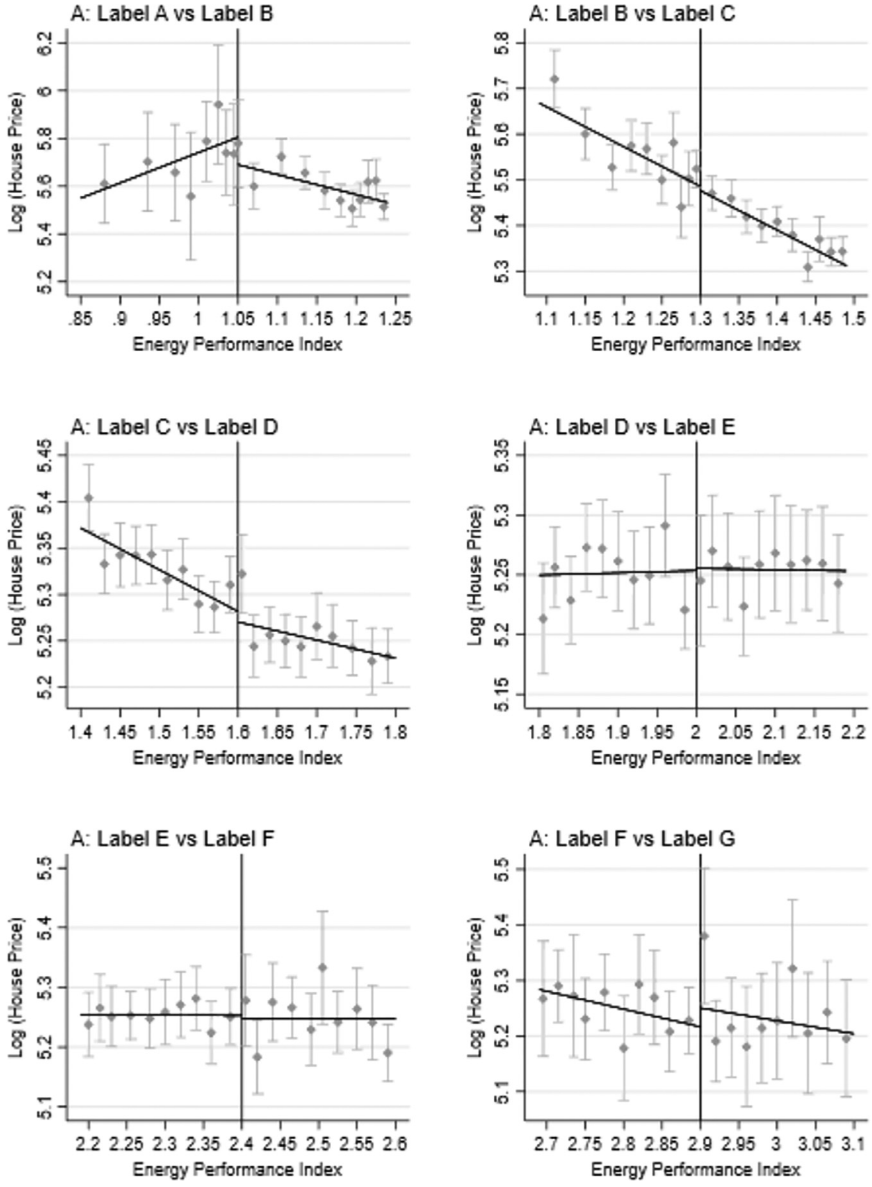

Fig. 6. Transaction Prices by Label Category and Energy Performance Index. *Notes:* Each panel of Figure 6 presents a figure relating the average Log (house price) and associated 95 percent confidence intervals to the energy performance index (EPI). Threshold values of EPI, which are used to assign label categories (from A to G), are indicated by vertical lines. The data is divided into J = 10 bins according to the empirical quantiles of observed EPI before and after each threshold EPI score. We constructed the figures based on the approach developed by Calonico et al. (2014), which proposes robust bias corrected inference procedures for RD designs.

sumption is that unobserved characteristics vary continuously with the observable characteristic that is used in the assignment rule (Jacob and Lefgren, 2004). We test whether a discontinuity exists in the transaction price of the dwelling around the threshold values of the energy performance index (EPI) for different label categories. Based on fixed threshold values of the EPI, homes are assigned to different label categories. Homebuyers can observe the label category on their energy performance certificate, but not the calculated EPI.[40] We focus on a narrow bandwidth (± 0.2 EPI) around the threshold values. Fig. 6 compares the label categories, plotting the variation in the transaction price based on the energy performance index around the cutoff points. We do not observe a clear discontinuity in transaction prices at the threshold points that are used to assign homes to different label categories.[41]

In order to formally test the potential labeling effect, we estimate the following model for each threshold level:

$$Log(Price_{it}) = \phi_0 + \phi_1 Log(EPI_i) + \phi_2 D_i^{L.label} Log(EPI_i) + \phi_3 D_i^{L.label} + \phi_j X_i + \varepsilon_{it} \quad (5)$$

where $D^{L.label}$ is a dummy variable which is equal to one for homes that were assigned to the label indicating lower energy efficiency level, and zero otherwise. X_i is a vector of dwelling characteristics. $Log(EPI_i)$ and $D_i^{L.label} Log(EPI_i)$ control for the continuous effect of the EPI on the transaction price within each label category, and ϕ_3 represents the impact of label itself on the transaction price, which is our parameter of interest.

Table 6 Panel A reports the estimates of ϕ_3 for each threshold value that is used in the assignment to different label categories. For all cutoff points, the estimated change in transaction price that results from the

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[40] Appendix Figure A.7 shows the distribution of EPI in the sample. Each vertical line represents the threshold EPI value that is used to assign the home for different label categories (1.3 from B to C, 1.6 from C to D, 2 from D to E, 2.4 from E to F, 2.9 from F to G). The figure does not provide clear evidence for bunching or manipulation of EPI scores.

[41] The only exception is the discontinuity in prices at the threshold EPI score between A and B rating categories. There is a sudden decrease in transaction prices after this threshold EPI score. However, we note that, in this figure, we do not control for the other determinants of house prices, which might be varying discontinuously around the threshold EPI score. We incorporate these additional covariates in the formal RD estimations.

Table 6
Regression Discontinuity Estimation Results for Label Effect.

Panel A: RD Estimations

	(A-B)	(B-C)	(C-D)	(D-E)	(E-F)	(F-G)
$D^{L.label}=1$	−0.013	−0.012	−0.002	−0.000	− 0.007	−0.015
	[0.029]	[0.008]	[0.007]	[0.008]	[0.011]	[0.018]
Log(EPI)	0.171	−0.011	−0.019	−0.052	0.300**	−0.055
	[0.262]	[0.085]	[0.059]	[0.089]	[0.136]	[0.270]
Log(EPI)*$D^{L.label}$	−0.433	−0.060	−0.088	−0.037	−0.494**	0.530
	[0.312]	[0.107]	[0.093]	[0.152]	[0.224]	[0.464]
Dwelling Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Construction Year	Yes	Yes	Yes	Yes	Yes	Yes
R^2 adj.	0.841	0.863	0.848	0.841	0.843	0.825
Number of Observations	1,461	6,879	11,009	6,899	4,606	2,146

Panel B: Bias-Corrected Robust RD Estimations

	(A-B)	(B-C)	(C-D)	(D-E)	(E-F)	(F-G)
$D^{L.label}=1$	−0.019	−0.017	−0.009	0.003	0.021	−0.012
	[0.062]	[0.020]	[0.016]	[0.026]	[0.040]	[0.057]

Notes: Table 6 reports the regression discontinuity estimation results for the effect of the energy performance certificate (EPC). The dependent variable is the logarithm of transaction price. In Panel A, *Log*(*EPI*) and *Log*(*EPI*)*$D^{L.label}$ control for the continuous effect of the EPI on transaction price within each label category. Panel B reports the RD estimation results based on the approach developed by Calonico et al. (2014) and Calonico et al. (2019), which propose robust bias corrected inference procedures for RD designs. We include home characteristics, construction year variable, neighborhood and year of transaction dummies as control variables in the regressions. Home characteristics include: size, type, quality, number of floors, number of rooms, type of parking place, location of the home relative to city center, road, park, water and forest. Heteroskedasticity-robust standard errors are in brackets. Standard errors are clustered by neighborhood and transaction year. * $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$.

assignment to a lower energy efficiency class is negative, but not statistically significant. We also estimate the RD models based on the approach developed by Calonico et al. (2014) and Calonico et al. (2019), which propose robust bias corrected inference procedures for RD designs. The results that are reported in Table 6 Panel B indicate that there is not a discontinuity in house prices around threshold EPI scores. Thus, there is not enough evidence to argue that the information conveyed by the energy label rating has a significant impact on the transaction price of homes in our sample.[42]

4. Discussion

From the homeowner's (and economist' s) perspective, the question of interest is what our findings suggest about the capitalization of the input costs related to energy efficiency improvements, as well as the capitalization of energy savings.

The Capitalization of Energy Efficiency Improvements

The results in Sections 3.2 and 3.3 show that, at the point of means, if the predicted energy efficiency of a home is improved by 50 percent (e.g., the EPI decreases by 50 percent), the market value of the home increases by 11 percent. This corresponds to € 23,650, on average. Of course, this average comes with a confidence interval – at the 95 percent confidence level, the range of the price change is € 15,050 to € 30,960.

According to statistics provided by MilieuCentraal (the Dutch Center for the Environment, a government agency), increasing the predicted energy efficiency of the average home in the Netherlands by 70 percent requires a total investment in energy efficiency measures of some € 21,000. The estimated unit costs of insulating the components of a dwelling are: € $40/m^2$ for floors, € $100/m^2$ for outside walls, € $60/m^2$ for the roof, € $160/m^2$ for windows and € 2,900 for a boiler.[43] The average home in our sample has $59m^2$ of floor area, 82 m^2 of roof area, 65 m^2 of external wall area and 25 m^2 of window area. If all energy efficiency measures are implemented for the average home in the sample, the total cost of the refurbishment leading to a 70 percent increase in modeled energy efficiency equals € 20,680. Assuming linearity, a 50 percent increase in modeled energy efficiency costs € 14,771.

This simple calculation illustrates that, for the average homeowner in our sample, the investment in energy efficiency is fully capitalized at the resale stage. At the lower end of the confidence interval, the increase in home value following a 50 percent increase in energy efficiency is almost equal to the initial investment.

The Capitalization of Energy Savings

An alternative approach to understand how the market capitalizes energy efficiency investments is to compare reductions in energy expenditures with the marginal price increase of the home. Households will have lower energy bills as a result of improving the energy efficiency of their homes. Given that in 2011, the gas consumption of an average home in our sample was 1,650 m^3 and the price of gas was 0.65 cent per m^3, households save an estimated € 535 per year as a result of a 50 percent increase in energy efficiency. At the point of means, a 50 percent increase in energy efficiency leads to an increase of € 23,650 in home prices, reflecting a capitalization rate of about 2.3 percent (535/23,650), assuming savings persist into perpetuity. At the lower end of the confidence interval, the implied capitalization rate is 3.55 percent (535/15,050), and at the high end of the confidence interval, the implied capitalization rate is 1.73 percent (535/30,960). Compared to the prevailing mortgage rate in 2011, about 3 percent, these capi-

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[42] Note that this result does not imply that the EPC has no impact on buyer's valuation of the home. EPCs provide additional information on the expected energy requirements of the home (see Appendix Figure A.1). Therefore, buyers might incorporate this continuous information instead of the label rating. In order to control for this additional information, as well as the energy efficiency that can be directly observed by the buyer, we include $Log(EPI_i)$ and $D_i^{L.label} Log(EPI_i)$ in model (5). There is limited support for this hypothesis, given that the coefficients of these variables are mostly insignificant (see Table 6-Panel A). Of course, the reason for obtaining insignificant coefficient estimates for both label rating and the EPI variables might be related to the relatively small size of the subsamples used in the analysis, which leads to less precise results.

[43] see "http://www.milieucentraal.nl/" for detailed information.

talization rates imply a rather accurate capitalization of future energy savings in the housing market.

Of course, the extent of capitalization of energy consumption also depends on consumer expectations about future energy costs. By using the actual gas consumption per m^2 as a proxy for energy efficiency, we estimate the capitalization of residential energy efficiency separately for each year from 2003 to 2011, to investigate whether the capitalization coefficient is time-varying. Appendix Figure A.8 shows the results: there is indeed significant variation in the coefficient over time. While we do not formally test the relationship between the capitalization coefficient and energy prices, there seems to be some correlation between retail gas prices and the capitalization of energy efficiency in the housing market.[44] In addition, the introduction of the EPC in 2008 might also have a general influence on the capitalization of energy efficiency (for both certified and non-certified dwellings), as it may change households' perception of the importance of energy efficiency.

5. Conclusion and implications

Increasing the energy efficiency of the building stock is an important component of public policies that are focused on reducing carbon emissions. Notwithstanding promising engineering estimates, large-scale diffusion of energy efficiency investments in the housing market has been slow (Allcott and Greenstone, 2012). One of the causes of such limited uptake may be the uncertainty of homeowners regarding the total return associated with efficiency upgrades, particularly around the capitalization of such investments.

In this paper, we investigate how private consumers capitalize energy efficiency in the housing market, and the extent to which the provision of an energy performance certificate (EPC) affects such capitalization. Most of the literature addressing the capitalization of energy efficiency in the housing (and commercial real estate) market suffers from a common methodological drawback - the potential bias that may arise from the omission of unobserved dwelling characteristics correlated with measures of energy efficiency. This paper exploits two different identification strategies to estimate the capitalization of energy efficiency in the residential sector: an instrumental variable (IV) and repeat sales approach.

We examine a large, representative dataset from the Netherlands, exploiting the discontinuity in the energy efficiency levels of homes constructed during the 1973-74 oil crisis, and the stringency of building codes at the time of construction as instruments for energy efficiency. The results indicate that energy efficiency is capitalized quite precisely into home prices, but the use of OLS leads to biased estimates of the market value of energy efficiency. Using an IV approach, we document that if the predicted energy efficiency of a dwelling is increased by ten percent, the market price of the dwelling increases by around 2.2 percent, for an average dwelling in the Dutch housing market. We confirm our findings using a repeat sales analysis, based on a sample of homes with improved energy efficiency and an otherwise comparable control group.

In order to examine whether the capitalization of energy efficiency varies with the disclosure of an energy performance certificate (EPC), we then estimate the same model by using actual energy consumption as a proxy for a common energy efficiency measure for certified and non-certified homes. Our findings do not provide evidence that suggests a higher capitalization rate for dwellings that transacted with an energy performance certificate. We also use a regression discontinuity approach to test whether the energy rating information provided by the label itself has market value. The results show no significant change in the transaction price at the threshold energy efficiency level that is used to assign the dwellings into different label classes, which implies that energy label rating itself does not lead to a significant change in buyer's valuation of the dwelling. It is rather the energy efficiency level that is capitalized into prices, at rates that are similar across homes with and without an energy performance certificate.

Our findings imply that, beyond the direct returns from lower energy expenses, residential energy efficiency improvements affect transaction prices, regardless of the provision of an energy label. The input costs of energy efficiency improvements (e.g. additional insulation, a more efficient heating system, etc.) are accurately reflected in home prices and equally, energy savings are capitalized into home prices at rates that equal the cost of capital, suggesting "perfect" capitalization. In relation to the "energy efficiency gap" literature, our results again raise the question why energy efficiency investments in the housing sector are below their optimal level – private individuals are optimally incorporating considerations of energy efficiency into their purchasing decisions at the time of home transactions, but do not seem to be making optimal investment decisions during their tenure. The additional costs of energy efficiency investments (e.g. the nuisance of retrofit work), the perceived risk of undervaluation of the energy efficiency improvement in the market, liquidity constraints, and considerations about the length of tenure relative to the payback period of investments in energy efficiency might be some of the reasons that lead to this suboptimal outcome. And of course, consumers may be concerned with the hassle of refurbishing and skeptical about (perhaps overly optimistic) engineering assumptions (see Fowlie et al. (2018)). Thus, more research needs to be done to understand homeowners' (under)investment decisions and considerations as it relates to energy efficiency improvements. Accordingly, cost-effective policies may need to be designed to address the underlying market barriers and market failures, including, for example, easier access to finance and improved communication programs regarding the precise reflection of investments in energy efficiency in transaction prices.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jue.2020.103243.

CRediT authorship contribution statement

Erdal Aydin: Data curation, Methodology, Formal analysis. **Dirk Brounen:** Conceptualization, Writing - original draft. **Nils Kok:** Conceptualization, Writing - original draft.

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[44] See Kahn (1986), Allcott and Wozny (2014), Busse et al. (2013) for the analysis of how the market value of fuel economy in the automobile sector is associated to the changes in gasoline prices

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