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The Value of Energy Efficiency and the Role of Expected Heating Costs

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Abstract The German Energy Performance of Buildings Directive requires sellers on the housing market to provide detailed information on expected yearly energy consumption per square meter (energy performance, EPS). This paper uses variation in local fuel prices and climate, fuel types, and building ages to analyse the relationship between expected energy cost savings from energy efficient building structure and house prices in a data set of listing prices from all regions of Germany. Results suggest that heating cost considerations are less relevant than previously thought.

Keywords Climate · Energy efficiency · Heating fuel prices · House price capitalisation

JEL Classification R3 · Q4 · Q5

1 Introduction

According to the so-called "energy paradox" (Hausman 1979; Jaffe and Stavins 1994) price differences do not fully reflect expected savings on energy costs for homes, home appliances, auto-mobiles, and other products. Up to date, there is an open debate about the interpretation of such results. In principle, inattention to energy costs could be rational if information acquisition is sufficiently costly or potential savings are small (Sallee 2014), but it could also be a sign of consumer myopia (Gabaix and Laibson 2006). In this respect, housing and auto-mobile markets are perfect test-beds because inattention to energy consumption can be relatively costly. However, two recent attempts to settle the issue interpret their results in fundamentally different ways (Busse et al. 2013; Allcott and Wozny 2014). Without doubt, the answer depends on expectations about the future that are formed by the marginal buyer. Typically, papers in the area attempt to estimate reasonable discount rates, lifetime expectan-

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cies of goods, and expectations about future fuel prices in order to calculate a "true" value of expected energy cost savings that can be compared to the difference in product prices. This procedure involves several deliberate decisions to be made by the researcher. Altogether, this weakens any conclusions derived from estimation results.[1]

In theory, the willingness to pay (WTP) for energy efficiency should equal the present discounted value of expected savings from energy expenditures. Existing literature that deals with energy efficiency in buildings has focussed on the question whether there is a correlation between house prices or rents and energy efficiency labels (Brounen and Kok 2011; Deng et al. 2012; Fuerst et al. 2015; Harjunen and Liski 2014; Högberg 2013; Hyland et al. 2013, Kholodilin et al. 2014; Walls et al. 2013). To date, it is difficult to assess whether this correlation stems from a marketing effect, unobserved quality bias, or the present discounted value of expected energy cost savings.

The present paper analyses a large and detailed data set of residential houses offered for sale on German online real estate market places from April 2015 to July 2016. Since May 2014, the German "Energy Performance of Buildings Directive" (Energieeinsparverordnung, EnEV) requires that energy performance scores (EPS) have to be provided when residential dwellings are sold or rented out (§16ff EnEV). The EPS gives very detailed information about expected energy consumption per square meter and year ($kWh/[m^2 \cdot a]$) and is calculated based on the characteristics of the property (insulation, heating technology, etc.).

In contrast to simpler "green" labels, EPS allow a more detailed interpretation. We exploit this advantage in three ways: First, we argue that the interactions of EPS with variation in local climate and local heating gas prices are exogenous to house prices. All else equal, informed, rational consumers should be indifferent between saving one Euro on energy costs because of a milder climate or a lower price of heating fuel.

In a similar fashion, the fuel price per kWh varies across heating types. Typically, it is excessively costly to alter a house's heating type. If buyers and sellers expect fuel price differences to be persistent, this influences greatly the present value of the house's EPS. We compare houses with district, gas, and electricity heating. To deal with the fact that there are substantial (observable) differences between houses of different heating types along other dimensions, we rely on propensity score weighting.

Third, in theory, building age influences the net present value of energy cost savings through the building's remaining lifetime (i.e. time until rehabilitation becomes optimal). The paper thus estimates valuations of EPS separately for three age groups. While this does not necessarily solve the identification problem, it is still useful because a coherent pattern is compatible with the notion that agents in the market understand the investment character of energy efficiency.

The results suggest that local climate and gas prices are not taken into account in the valuation of EPS, which contrasts with comparable findings for the valuation of fuel economy in auto-mobile markets (Allcott and Wozny 2014; Sallee et al. 2015; Busse et al. 2013). A potential explanation is that, compared to buying a house, consumers visit gas stations quite frequently. Similarly, the value of EPS does not correspond to the price of the heating fuel used in a given house when comparing district-, gas-, and electricity-heated houses – despite substantial differences between the three heating fuel prices. In contrast, when looking at

[1] Table 9 in Busse et al. (2013, p. 245) exemplifies this dilemma. It displays a range of plausible assumptions about discount rates and demand elasticities. As interpreted by the authors, this table supports their conclusion that myopia are absent. Allcott and Wozny (2014, p. 782, Fn. 9) use the same table to show that their own results *and* the results of Busse et al. (2013) support the presence of myopia.

different building age groups, a pattern emerges: The younger a building, the higher is the valuation of EPS.

The next section briefly summarises related literature that deals with the valuation of energy efficiency in real estate and auto-mobile markets. Section 3 develops the theoretical relationship between the WTP for energy efficiency and prices or rents and discusses issues of identification. Section 4 describes the data, Sect. 5 shortly discusses the empirical strategy. Empirical results are presented, interpreted and compared to previous estimates in Sect. 6. The paper closes with a discussion of implications for future research and policy.

2 Related Literature

2.1 Capitalisation of Energy Performance Certificates

The more recent literature on capitalisation of energy efficiency labels into property prices follows up on an earlier series of papers that started in the 1980s (cf. Halvorsen and Pollakowski 1981; Dinan and Miranowski 1989, inter alia). For instance, (Halvorsen and Pollakowski 1981) find significant responses of house prices with oil-fired heating systems to the 1973 oil price shock. More recently, the impact of *Energy Star*®and *Leadership in Energy & Environmental Design* eco-labels on prices of office buildings has been studied by Eichholtz et al. (2010), Eichholtz et al. (2013), Fuerst and McAllister (2011).

Eco labels for residential housing markets have been studied in Australia, the US, Singapore, and Europe (Soriano 2008; Brounen and Kok 2011; Deng et al. 2012; Högberg 2013; Hyland et al. 2013; Kahn and Kok 2014; Fuerst et al. 2015, 2016). The type of labels differs across studies, but all authors find positive relationships. Again, identification is based on observables in ordinary least squares (OLS) or Heckman selection regressions and on propensity score weighting techniques. Kahn and Kok (2014) find weak evidence that climate influences the size of the eco premium and a considerable effect of Toyota Prius registrations (i.e. attitudes toward the environment). This suggests that part of the effect can be attributed to "green" marketing. However, only a tiny share of houses (4321 of approx. 1.6 million observations, or 0.3%) is eco-labelled in the sample. This makes it difficult to assess the external validity of the results.

In contrast to binary labels, efficiency bands have the considerable advantage that both efficient and inefficient homes are labelled. This changes the "default" from non-labelled to some intermediary grade which in itself might influence consumer choices (Allcott and Mullainathan 2010). Even more information is provided by the German scheme of EPS that give an assessment of energy use in kilowatt hours per square metre and year ($kWh/[m^2 \cdot a]$). One goal of this paper is to show that participants in the market for real estate rely on such fine-grained information in calculating their willingness to pay for a house. In that case, 'notched' policies, i.e. binary labels or efficiency bands, should be dismissed because they can lead to product design distortions (Sallee 2014; Newell and Siikamäki 2014, p. 32). EPS thus provide an opportunity to test more rigorously to what extent and in which ways agents in the real estate market value energy efficiency *because of reduced heating costs*. Thus far, the German scheme has been studied by Kholodilin et al. (2014) forthcoming with a focus on differences between landlords and tenants.

With the exception of Eichholtz et al. (2013), Harjunen and Liski (2014), existing studies have in common that they neglect the role of fuel types and local prices. To some extent, the effect of local climate has been studied by Kahn and Kok (2014), but in an ad-hoc fashion that does not allow to interpret estimates in the way intended in this paper. None of the papers has considered the role of building age. Another issue that is acknowledged but addressed only partly in other papers is identification of relevant coefficients. The present paper seeks to exploit exogenous sources of variation that allow to identify coefficients if market participants react to these sources.

2.2 Fuel Economy on Auto-Mobile Markets and Consumer Myopia

Comparable identification strategies have been applied in another strand of the literature that is closely related to the present paper. It originates from the seminal contribution of Hausman (1979) and deals with the valuation of energy efficiency in consumer decisions more generally. Recently, the great potential of more energy-efficient technology coupled with an extraordinarily low cost-benefit ratio of information provision has aroused interest in the issue (Allcott and Mullainathan 2010; Allcott and Greenstone 2012). To design optimal policies, it is crucial to understand whether observed choices are the outcomes of *irrational* or *rational* inattention (Allcott and Mullainathan 2010; Sallee 2014; Gerarden et al. 2015, inter alia). In other words: Are consumers myopic even in high-cost situations such as house or car purchases, or are they not?[2]

As noted in the introduction, three recent papers that study car sales on the auto-mobile market come up with conflicting answers: While Busse et al. (2013, p. 221) "find little evidence that consumers 'undervalue' future gasoline costs when purchasing cars", Allcott and Wonzy (2014, p. 780) report that "auto consumers appear to be willing to pay only $0.76 in purchase price to reduce discounted future gasoline costs by $1.00." Besides differences in the identification strategy, these interpretations are based on assumptions about discount rates and expectations of consumers with respect to changes in gasoline prices, lifetime of the car, and travel distances. In a recent working paper, Sallee et al. (2015) use the relationship between (remaining) auto-mobile mileage and the present value of fuel cost savings as identification strategy. The authors argue that their results support the views of Busse et al. (2013). These mechanisms have analogues in the housing market and are studied in this paper.

3 Theoretical Considerations

This paper relies on the hedonic pricing framework (Rosen 1974). The per-period WTP for one square metre of a specific dwelling can be seen as a function of its structural (s) and locational (l) characteristics:

$$\text{WTP} = W(s, l) \tag{1}$$

Note that s may include energy performance as a *characteristic* of the house that has a specific value to the buyer. Previous authors have indeed included EPS in s and have estimated the WTP for EPS as a characteristic of the house. In that interpretation, EPS is a *value-increasing* factor that provides utility to the buyer of the house, e.g. because he or she cares about the environment and enjoys living in an efficient, modern home. On the other hand, EPS is *cost-reducing*: Arguably, it is possible to have a warm living room in any modern house, no matter

[2] For instance, there is evidence of uninformed consumer choices in low-cost situations if part of the price information is visible and part of it is hidden (see Chetty et al. 2009, inter alia).

how inefficient the insulation, but costs vary with energy efficiency. In this sense, the price of the warm living room is higher for inefficient homes, not its utility.

Assume that the WTP is constant over time. Furthermore, time is discounted by a factor $1+r \geq 1$. Since the individual cares about total expenditures, the monthly payment she is willing to make for the dwelling at time t can be decomposed as $R_t = \bar{R}_t + C_t \times (1-\text{CF}) \times \text{EPS}$, where C_t is the per-unit energy price, CF is the climate factor that reflects energy requirements due to a difference between local climate and the baseline (CF $= 0$) and $\bar{R}_t$ is net rent. If net rents and the yearly growth rate of energy prices e are constant ($\bar{R}_t = \bar{R}$; $C_t = (1+e)^t C$), the willingness to pay given a remaining lifetime of the building T can be expressed as follows:

$$\sum_{t=1}^{T} \frac{W(s,l)}{(1+r)^t} = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t} = \sum_{t=1}^{T} \frac{\bar{R} + (1+e)^t C \times (1-\text{CF}) \times \text{EPS}}{(1+r)^t}. \tag{2}$$

The expression for prices can be obtained easily from Eq. (2) by assuming that buyers care about the net present value of the dwelling so that $P = \text{NPV} := \sum_{t=1}^{T} (1+r)^{-t} \bar{R}$, with reservation price P. From (2), this leads to

$$P = \sum_{t=1}^{T} \frac{W(s,l)}{(1+r)^t} - \delta(T) \times C \times (1-\text{CF}) \times \text{EPS}. \tag{3}$$

where $\delta(T) := \sum_{t=1}^{T} (1+e)^t (1+r)^{-t}$. Very importantly, Eq. (3) suggests that a log–log or semi-log specification will not capture price differences that are related to energy cost savings adequately. More precisely, rents or prices per square metre are linear in expected energy costs $C \times (1-\text{CF}) \times \text{EPS}$. Furthermore, previous studies have estimated $\delta(T) \times C \times (1-\text{CF})$, which clearly depends on heating types, fuel costs, local climatic conditions, and the building age distribution in the sample.

4 Data

This study uses listing prices of houses from all regions of Germany, offered for sale on three large online real estate websites, *Immonet.de*, *ImmobilienScout24.de*, and *Immowelt.de*. The data were collected from April 2015 to July 2016. Due to the approach taken in this paper, it is important to use a short time window in order to rule out changes in price expectations within the sample period. Naturally, this reduces the number of observations, but the sample is still large enough to study separately sub-groups such as district-, gas- and electricity-heated houses.

Listing price data have been used to study EPS certificates before, see Hyland et al. (2013); Kholodilin et al. (2014), with results comparable to other studies that rely on similar estimation methods and transaction prices (Fuerst et al. 2015). While transaction data are preferable, listing prices seem to be a very good substitute (Malpezzi 2003; Dinkel and Kurzrock 2012; Henger and Voigtländer 2014; Knight et al. 1994; Knight 2002; Merlo and Ortalo-Magné 2004; Semeraro and Fregonara 2013). One result that emerges from this literature is that mis-pricing houses systematically is quite costly for house sellers because it increases time on the market and decreases the final price (Knight et al. 1994; Knight 2002; Merlo and Ortalo-Magné 2004).

Two papers report hedonic regressions of matched listing and transaction data. In Knight et al. (1994), only one of four coefficients of housing characteristics is significantly different across regressions, even though t values are very large (6.68–99.2). Coefficients in Semeraro and Fregonara (2013) hardly differ across regressions.[3] Closely related, three papers regress the relative difference between listing and transaction prices on covariates, but find no to marginal explanatory power of housing characteristics (Dinkel and Kurzrock 2012; Henger and Voigtländer 2014; Semeraro and Fregonara 2013). Taken as a whole, this suggests that potential sellers—on average – do not systematically mis-price housing characteristics. If the reader is willing to accept this reasoning, results can be interpreted as being close to market outcomes. Otherwise, the regressions are still informative about seller behaviour.[4]

The data contain information on offered prices, the zip code, EPS, and a long list of quality and structural attributes. A potential problem of the data source are missing values on several important variables, in particular EPS, year of construction and lot size. We chose to drop these observations because these variables have great influence on the value of the house. Implications for the estimation method are discussed below. Furthermore, the sample was restricted to observations with at least $50m^2$ lot size and living area, a listing price per m^2 between 200 and 10,000 Euro, and three to 20 rooms that were constructed in the year 1800 or later. For the samples analysed in Sects. 6.1 to 6.3 observations with EPS greater than 500 were also discarded. These observations were regarded as outliers.

Summary statistics for the sample of gas-heated houses for which EPS information is available, as well as a short description of the covariates, can be found in Table 2. The sample is analysed in Sect. 6.1. Throughout, we focus on houses that hold a "projection-based" EPS certificate because these certificates do not depend on past user behaviour.[5]

Each observation stems from a specific month and zip code. Duplicates were removed within each zip code, based on a comparison of the most important variables (lot size, living area, room, year of construction, EPS). The price of heating gas per kWh was calculated from a data set of heating gas contracts obtained from a website for gas price comparisons, *tarife.de*. Specifically, the zip code's default supplier's default contract was used as the measure of this zip code's gas price, while fixed payments were excluded altogether. Climate factors (CF) were provided on the level of zip codes by the German Weather Service. They are defined as $CF_i = HDD_i/HDD_r - 1$, where HDD_i and HDD_r are heating degree days at zip code i and at the reference location. Positive values indicate below-average temperatures, so that more heating is required than at the reference location. Compared to the reference location, the climate is 3% milder in the sample on average, with a standard deviation of 6%. This paper chooses CF as a measure of local climate because CF are designed to capture differences in heating energy requirements across space. Additionally, they are closely related to average local autumn/winter temperatures, a potential alternative.[6]

[3] It is not possible to decide whether there are statistically significant differences because the authors only report significance levels and also do not indicate the type of covariance matrix that was used in their calculation.

[4] Lising prices could be seen as final transaction prices measured with error. Even if this measurement is unbiased, it potentially increases confidence intervals around coefficient estimates. The error is unobservable in our case.

[5] For houses older than 3 years, a "consumption-based" EPS can be calculated which is based on energy use in the past 3 years.

[6] The results are robust to the choice of alternative measures for local climate, such as average local winter or autumn and winter temperatures. These results are available from the author upon request.

5 Empirical Strategy

5.1 Sources of Variation

It has been argued that a simple regression of P on EPS suffers from endogeneity if structural or locational attributes of the dwelling are correlated with EPS, but not captured adequately by the available variables. In particular, it is very likely that interior and structural quality are correlated with EPS, e.g. because newer homes tend to have better EPS and building materials; retro-fitting that aims at improving EPS at the same time improves quality, an so on. Similar arguments have been made by Fuerst et al. (2015), Fuerst et al. (2016), Deng et al. (2012), Högberg (2013), Brounen and Kok (2011), inter alia. Observable quality characteristics from different data sets suggest that the issue should be taken seriously: Energy efficient buildings are younger and of higher quality (Deng et al. 2012; Eichholtz et al. 2013; Kahn and Kok 2014).

Because e, r and T are not known, it is difficult to decide to what extent an estimate for δ falls short of (or exceeds) energy cost savings for the dwelling's residents. One obstacle in this way is the dependence of δ on T. Hence, in order to be able to compare estimates for δ from different sources of variation it is necessary to balance the building age structure of the sample. We approach the problem in three complementary ways. (i) As noted in the introduction, variation of heating fuel prices over space and, because EPS is climate-normalised, spatial variation of climate can be used in order to test whether participants in the market are aware of the relationship stated in Eq. (3). (ii) The value of EPS should depend on fuel type if (future and present) fuel costs differ. Under the assumption that prices of different fuel types are expected to increase with the same rate, δ should be equal across fuel types in a regression of prices on expected energy costs. (iii) Needless to say, the functional form of δ is interesting in itself ([cf.], Sallee et al. 2015). According to its definition, δ should be greatest for young buildings and decrease strictly with building age, up to the point where buildings are retro-fitted.

(i) Local fuel prices and climate The theoretical argument laid out above explicitly takes into account that energy costs are related to fuel costs via C, and to local climate via CF. We argue that variation in EPS × "local fuel prices" and EPS × "local climate" is not subject to quality bias. The most important underlying assumption is stability over time of the geographical pattern of prices and local climate.

Variations in fuel prices over time and space have been exploited by Allcott and Wozny (2014), Busse et al. (2013) in their studies of the auto-mobile market. Note that in the present context time variation is less useful because it strengthens the reliance of the results on discount rates and remaining lifetimes. However, the immobility of houses allows to use variation over space more effectively. Figure 1a shows substantial spatial variation of gas prices in German zip codes in mid-2016. To the extent that these differences are permanent, the implied heating cost differences are considerable.

Variation in climatic conditions (CF, see Fig. 1b) over space is useful in the present context because EPS are climate-standardised. Obviously, energy use depends on local climatic conditions via EPS. This paper focusses on winter rather than summer climate because air conditioning is not very widespread among private households in Germany.[7] In terms of the model, CF is one factor that influences l in Eq. (1) (cf., Potepan 1996, inter alia). Similarly, the normalised energy performance of a building could be one of the determinants of s, the

[7] In 2015, only 0.2% of private households' energy use fell on air conditioning according to the German Federal Environmental Agency [Umweltbundesamt], see Ziesing (2016).

structural quality of the building. In other words, a cross-sectional comparison of EPS across buildings might capture differences in building design, but EPS is related only indirectly to energy consumption. If other quality characteristics correlated with EPS are not controlled for adequately, this term will also reflect general building quality.

Table 1 summarises the distributions of projected yearly energy costs per square metre for gas-heated houses in the sample (excluding fixed payments). In gas-heated houses, residents have to spend 9.7 Euro/[$\mathrm{m}^2 \cdot \mathrm{a}$] for heating at the median (EPS = 150 kWh/[$\mathrm{m}^2 \cdot \mathrm{a}$]). In houses at the first and fourth quartiles of the EPS distribution (80 kWh/[$\mathrm{m}^2 \cdot \mathrm{a}$] and 219 kWh/[$\mathrm{m}^2 \cdot a$], respectively), energy costs differ substantially (5.2 Euro/[$\mathrm{m}^2 \cdot \mathrm{a}$] and 14.2 Euro/[$\mathrm{m}^2 \cdot \mathrm{a}$]). Looking at variation over space (local prices), the interquartile range is 0.9 Euro/[$\mathrm{m}^2 \cdot \mathrm{a}$], and the difference between the 9th and the first decile is 2.6 Euro/[$\mathrm{m}^2 \cdot \mathrm{a}$]. In a house with a living area of 140 m^2 (median), this implies yearly cost differences across ZIP codes of 126 and 364 Euro per year. The interquartile range of energy cost differences from local climate is slightly smaller, 0.7 Euro/[$m^2 \cdot a$], or 98 Euro per year. Even though these numbers are relatively small compared to yearly down-payments for typical a 140 m^2 house, they are not negligible.

(ii) Fuel types Four main fuel types are used in Germany[8] gas (49.3%, including liquid gas and bio-gas), light heating oil (26.8%), district heating (13.5%), and electricity (2.9%). Taking gas as the baseline, Fig. 2 plots the relative costs per kWh of each of these four fuel types. Whereas the price of light heating oil increased relative to the price of natural gas, the cost ratios of electricity and district heating to natural gas have been quite stable over the past 24 years. If consumers rely on this type of information to form their beliefs about the cost relationship between the four fuel types, their the valuation of EPS should reflect these cost-ratios. A simple statistical test could be built around differences between EPS coefficients across heating types. However, identification issues are much more prevalent in this case.

(iii) Building age The theoretical discussion has shown that the remaining lifetime of a building should influence the valuation of its energy efficiency. An estimation of the valuation of EPS for different age groups provides a simple test whether this is the case empirically. Note that the identifying assumptions for a valid interpretation of the age group-EPS valuation pattern are less strict than in previous papers. Let EPS $= \gamma_0 + \gamma_1 Q + \nu$ for all three age groups, with an omitted variable Q. If $P_k = \alpha + \beta_k C \times \mathrm{EPS} + \bar{\beta} Q + \eta$ in age group k, and P_k is regressed on EPS, we have $E[\widehat{\beta_k} C] = \beta_k C + \bar{\beta}\gamma_1$, so that $E[\widehat{\beta_k} C] - E[\widehat{\beta_l} C] = (\beta_k - \beta_l)C$. In other words, if quality bias is present but takes on the same form in each age group, the approach still yields unbiased estimates for the differences in the valuations. This relaxes the assumption made by other papers, namely $\bar{\beta}\gamma_1 = 0$. A similar argument can be made w.r.t. approach (ii) described above. The assumption of equal quality bias across age groups is discussed further below.

5.2 Coherent Behaviour

The analysis of different sources of variation allows to take a second look at the EPS valuation problem by focussing on the coherence of estimated patterns. Previous authors have attempted to directly answer the question whether present values of energy cost differences match price differences on the market. This presupposes that individuals calculate energy cost differences correctly even if cost differences stem from different sources (such as local climate or fuel

[8] Figures reported by the German Association of Energy and Water Industries (BDEW), "Beheizungsstruktur des Wohnungsbestandes in Deutschland 2014".

prices). Eq. (3) shows that—if energy costs are calculated correctly and the age structure is accounted for—regression estimates of the "present value coefficient" $\delta(T)$ should be equal for different sources of variation. This can be seen as a test of the preconditions for reasonable present value calculations.

The comparison of different sources of variation brings in another aspect that is highly relevant for the design of EPS certificates: Including climatic conditions into the present value calculation is relatively difficult because the relationship between climate and heating costs is highly technical. Similarly, information on local fuel prices is not necessarily salient to the house buyer because the local default provider will send a default contract to the house owner automatically. In contrast to local climatic variation the relationship between energy costs and prices is linear in EPS. Finally, if market participants consider the impact of building age on the value of EPS, it is very likely that they understand the investment character of energy efficiency improvements. This can be the case even if they do not take into account more subtle variation, such as local fuel prices or climate.

5.3 Other Issues

Previous authors have identified another problem that is related to the availability of information on EPS. Conditional on reporting year of construction, lot size, and heating type, only 56% of all observations include EPS information, even though it is mandated by law to display EPS in online real estate offers (see Table 3). Potentially, defiers can report EPS in their offers, but without using the forms provided by the websites–in these cases, the certificate does not appear in the data. There is an exception for new buildings if the EPS is not available yet. Indeed, the share of reported EPS increases to 66.4% if building age is greater than 1. Conversely, only 15.8% of the observations with at least one missing value among the year of construction, lot size, or heating type variables report EPS.

It has been argued that dwellings offered without information on energy efficiency are systematically different from other dwellings. These objects might have higher EPS and lower quality than comparable buildings. For that reason, previous papers have estimated selection models (Brounen and Kok 2011; Kholodilin et al. 2014; Hyland et al. 2013). However, reporting rates were much lower in these papers (18% in Brounen and Kok (2011) and Kholodilin et al. (2014), and 5% in Hyland et al. (2013).

This paper does not estimate a selection model for the following reason: If EPS information influences prices, it will be more likely that non-reporters are forced to re-negotiate the price once EPS information is presented. The strategy would thus lead to longer time on the market and the need for price re-negotiation (Knight 2002) because potential buyers will have a chance to check the EPS certificate even if it is not presented in the offer. According to this reasoning, there are other (unsystematic) reasons why some offers do not contain EPS information. Table 3 suggests that general data quality is lower for these observations. It would bring in new problems if a selection model was built around these observations. In any case the results will be representative for a relatively large part of the population.

6 Estimation Results

Results for a baseline model are presented in the Appendix, Table 4. The sample consists of all observations for which information on year of construction, lot size, heating type, and EPS is available, see Table 3. For an observation i from district d, month t, and heating type h,

$$\log P_i = X_i\beta + \phi_t + \psi_d + \delta \times EPS_i + \eta_i. \tag{4}$$

P_i is the price per square metre of house i, EPS_i is its energy performance score, and X_i is a vector of housing characteristics, including heating type (base category: gas heating). ϕ_t and ψ_d are time and district fixed effects. Table 4 contains the results. In column (1), the log price is the dependent variable, and the EPS coefficient is negative and highly significant.[9] It implies a reduction of the price by approx. 0.11% as EPS increases by 1% (at sample mean). In column (2), the dependent variable is the price per square metre. The EPS effect is slightly smaller (-0.07% at sample mean) and model fit is somewhat worse. Nevertheless, Eq. (3) suggests that a linear form captures heating cost effects more accurately. Potentially, the difference can be attributed to the effect of unobserved building quality. A jump from an A-rated building (30 $<$ EPS$<$ 50) to an E-rated building (160 $<$ EPS$<$ 200) reduces the price by 10.5% (at sample mean), which is very close to estimates found in other studies, e.g. 9.3% in Hyland et al. (2013) or 10.2% in Brounen and Kok (2011). Covariates are included in the table as well. The overall picture is reasonable. Higher quality, younger, detached houses on larger lots are offered at a higher price per square metre.

Figure 3 shows kernel density estimates for the EPS variable in different year of construction brackets. Clearly, younger buildings have much higher energy efficiency, and the distribution shifts to the right from the group of middle- to the group of old-age buildings. Furthermore, the distributions of older houses are much more widespread, probably because some of the older houses were retro-fitted. This points to a source of bias that should be accounted for in the analysis: If the vintage structure of buildings across space changes, so will the distribution of EPS and the value of energy efficiency (via T).

6.1 Local Variation in Gas Prices and Climatic Conditions

In this section, we consider the effect of local variation in gas prices and climate on the value of EPS. The sample is restricted to gas-heated houses. The estimating equations read

$$P_i = X_i\beta + \phi_t + \psi_z + \delta(C \times EPS_i) + \gamma(\Delta_z C \times EPS_i) + \eta_i \tag{5}$$
$$P_i = X_i\beta + \phi_t + \psi_z + \delta(C \times EPS_i) + \gamma(C \times CF_z \times EPS_i) + \eta_i \tag{6}$$

where C is the average price of gas per kWh in the sample, $\Delta_z C$ is the deviation from that average in zip code z, and CF_z is the climate factor of zip code z. Since identifying variation lives at the level of zip codes, we include zip code fixed effects, ψ_z and use zip code-clustered standard errors. The regressions also control for an interaction of EPS and population density, to account for the possibility that construction was more concentrated in densely populated areas in the past years.

Coefficient estimates for the most important variables from Eq. (5) are reported in columns (1) to (4) of Table 5. The main effect, δ, implies a 23 Euro reduction as heating costs per m^2, $C \times EPS_i$, increase by 1 Euro. This suggests that the present value term, $\delta(T)$ in (3), is equal to 23. However, local differences in gas prices do not seem to be important. The coefficient estimate for γ is close to zero and insignificant. A Wald test of $\delta = \gamma$ has a p value of 0.001.

Potentially, very high EPS are ignored by the market because the time until retro-fitting becomes optimal might be very short for these houses. Similarly, very efficient homes might sell at an additional premium. Therefore, model (2) excludes observations with EPS outside the range 50–300. Qualitatively, the results remain unchanged. However, the main effect is significantly larger in this model.

9 Note that a regression of log price per square metre on covariates including log living area is equivalent to the more common regression of log price on covariates including log living area.

A reason why local gas price differences do not play a role might be that differences are too small and/or not stable over time. Furthermore, there might be considerable noise in the measurement of local gas prices. We therefore restrict our attention to zip codes that share a border with a zip code where the price of heating gas is lower by at least 1 ct/kWh. In a typical house with an EPS of 160 kWh/[m^2 · a], the expected difference in heating costs across zip codes is at least 1,60 Euro per m^2 and year, which is substantial. For each pair of zip codes, observations were matched on the the building age variable[10] in order to control for the dependence of $\delta(T)$ on the remaining lifetime of the building. Differences between the matches were then regressed according to Eq. (5). In order to capture local land price differences, the median house price among all houses without gas heating was calculated in each zip code and included as a regressor.

Column (3) of Table 5 contains the results. Reassuringly, gas price differences still remain insignificant and small, while the main effect is slightly lower than in model (1). Column (4) restricts the sample further to matches for which the EPS difference was smaller than 25 $kWh/[m^2 \cdot a]$ in absolute value. In this sample, the focus is on (energetically) similar houses across zip code borders with relatively large gas price differences. Even though this model produces the largest interaction effect (-0.09), it still remains insignificant and much smaller than the main effect (-0.16 to -0.36).

Columns (1) to (3) in Table 6 in the Appendix display additional robustness checks. Model (1) adds interactions of EPS and several housing characteristics for which a correlation with EPS and over space seems plausible. These are building age, and the quality and heating type indicators. Model (2) adds an interaction of EPS with the local gas price change from 2015Q4 to 2016Q3 as a proxy for local price expectations. Consistent with the result that the value of EPS is independent of local gas prices, the coefficient is small and insignificant. Finally, sorting might influence the results. For instance, if high income households sort into regions where gas prices are high, but do not care as much about heating expenditures as poorer households, this might bias the results downward. To guard against this possibility, model (3) adds socio-demographic characteristics aggregated on the postal code level from Census 2011 1 km × 1 km grid data (demeaned), interacted with EPS. These are the average age of the population, the share of foreign inhabitants, and the average household size.[11] To sum up, most of the added coefficients are significant, and the main coefficient estimates remain very stable.

The remaining two models of Table 5 focus on variation in local climate. In column (5), the local gas price-interaction was dropped and a local climate interaction term was added, see Eq. (6). The coefficient has a positive sign, suggesting that the value of EPS is slightly *lower* in colder regions. However, it is insignificant. The same holds for model (6) that again restricts the sample to observations with EPS higher than 50, but lower than 300. Taken as a whole, these results do not suggest that participants in the market consider local variation in climate or gas prices when calculating an implicit price of energy efficiency.

Columns (4) and (5) in Table 6 replicate the robustness checks for gas prices that use housing characteristics × EPS and socio-demographic characteristics × EPS interactions. The results remain qualitatively unchanged. Column (6) replaces climate factors as a measure of local climatic conditions by a more visible indicator of local winter climate: the average number of days in a year with a closed snowcover (1981–2010), provided by the German

[10] Matching was done without replacement and inexact, using the `Match` function from `R` package `Matching`.

[11] Income is not available at the level of postal codes from official statistics. Private data suppliers might rely on housing prices as a proxy for local income, so that using such data would contaminate the regression.

Weather Service. It also adds the average number of “hot days” with a maximum temperature above 30°C (1981–2010). Whereas the number of snowcover days does not significantly affect the valuation of EPS, a higher number of hot days seems to *decrease* the value of EPS slightly. This is in line with recent evidence that indoor climate during summer time in energy efficient homes without cooling devices is worse than in less efficient homes, see Willand et al. (2016). Air conditioned homes are the exception in Germany (only 0.2% of private households’ energy use fell on air conditioning in 2015, see also Table 2).

6.2 Fuel Types

Variation in heating costs that was exploited in Sect. 6.1 is relatively subtle. More pronounced differences exist across different fuel types. Compared to gas heating (gas combustion on-site), district heating (heat delivered through a local network) was 22% more expensive on average in the past 24 years. Electricity heating is three to four times as expensive as gas heating (see Fig. 2).

In this section, a sub-sample of gas-, district-, and electricity-heated houses is analysed. The estimating equation is

$$P_i = X_i\beta + \phi_t + \psi_z + H_g + H_e + \delta EPS_i + \gamma(H_g \times EPS_i) + \kappa(H_e \times EPS_i) + \eta_i. \tag{7}$$

H_g and H_e are dummy variables that are equal to 1 if the heating type is gas or electricity, respectively. The sample was restricted to zip codes in which all three fuel types were present in the data. In order to identify the effect properly, it is important to ensure comparability of houses across fuel types. For instance, it is likely that some gas-heated houses have special features that cannot be observed in electricity-heated houses, so that these houses cannot be compared easily. As a solution, a combination of propensity score weighting and trimming was used. Table 7 displays means of all important variables for the three fuel types. Clearly, there are important differences in the unweighted samples. For instance, district-heated houses are built on smaller lots and are younger than gas-heated houses, while electricity-heated houses seem to be of lower quality.

The results from two logistic regressions are reported in Table 8. An indicator variable that is equal to 1 if a house has district-heating installed was regressed on an array housing characteristics, separately for the sub-samples of gas- and electricity-heated houses. All houses with a predicted probability of having district-heating installed, $\hat{p}_i$, smaller than 5 or larger than 95% were excluded. Propensity weights w_i were defined as follows:

$$w_i = \begin{cases} \min\{\frac{\hat{p}_i}{(1-\hat{p}_i)}, 4\}, & i \text{ has gas or electricity heating,} \\ 1, & i \text{ has district heating.} \end{cases} \tag{8}$$

The boundary at a weight of 4 was used to prevent very influential observations from driving the results. It corresponds to a propensity to be district-heated of 80%. A comparison of weighted means in Table 7 clearly shows that the weights greatly increase comparability across the three heating types.

Results for the most important variables are displayed in Table 9. In the unweighted sample, column (1), the main effect is significant and negative, as expected. However, the value of EPS is not significantly different in gas-heated houses, even though gas is about 20–25% less expensive than district heating. The value of EPS seems to be more than twice as high in electricity-heated houses, which roughly corresponds to the idea that electricity is much more expensive than gas. However, this effect becomes insignificant when the weighted sample is used, see column (2). Now, only the main effect is significant, suggesting that differences between district and electricity-heated houses in other dimensions might be responsible for the significant interaction term in column (1). Columns (3) and (4) confirm this picture: (3) adds separate housing characteristic controls for each heating type to the unweighted model (1), while (4) interacts all housing characteristics (demeaned) with the EPS variable. The main effect remains significant in both cases, but the heating type × EPS interactions become smaller in absolute value.

Overall, the value of EPS does not seem to reflect the fact that there are persistent price differences between different fuel types - even though these differences are substantial: In a typical house of 150 m^2 and an EPS of 100 kWh/[$m^2 \cdot$ a], the yearly energy bill amounts to approx. 900 Euro if the gas price is 6 ct/kWh. With electricity heating at a price of 20ct/kWh, the household would pay as much as 3000 Euro per year.

6.3 Remaining Lifetime of Buildings

Thus far, the results make it difficult to see clearly whether the valuation of energy efficiency follows reasonable patterns. This section adds one further dimension by focussing on the investment motive behind energy efficiency improvements. Clearly, if retro-fitting becomes necessary for some reason other than an improvement in energy efficiency, the latter can be done incidentally. This splits fixed costs of the investment and therefore increases its profitability. Hence, investors should care for T, the remaining lifetime of the building.

In order to be able to use variation in T while reducing data errors (i.e. unobserved rehabilitation) as much as possible, we focus on the sub-sample of oil- and gas-heated houses with building ages lower than 7, between 8 and 15, and between 16 and 23 years. EPS coefficients are then estimated for each of these three periods separately:

$$P_i = X_i\beta + \phi_t + \psi_z + \delta(D_i^{\leq 7} \times EPS_i) + \gamma(D_i^{8-15} \times EPS_i) \\ + \kappa(D_i^{16-23} \times EPS_i) + \eta_i. \quad (9)$$

$D^{\leq 7}$, D^{8-15}, and D^{16-23} are dummies for the three age groups that are also included in X. δ, γ, and κ capture separately the value of energy efficiency in the three age groups. Results can be found in Table 10.

In column (1), a clear pattern emerges: The value of energy efficiency is largest for the youngest group. As buildings get older, the value associated to EPS decreases, from 2.12 Euro per 1 kWh/[$m^2 \cdot$ a] reduction in EPS, to 1.98 in the middle group, to 1.47 in the youngest group. This pattern fits well the idea that the remaining lifetime of the energy efficiency investment is important for its valuation.

The regression in column (2) makes the three groups more comparable by adjusting the sample in the following way: The smallest age group of buildings between 16 and 23 years old was chosen as the reference group. Before the model was estimated, the reference group's age distribution was imposed on the other two groups by dropping observations from years that are over-represented.[12] The results remain stable.

However, the correlation between EPS and (unobserved) building quality might not be equally strong in the three age groups, so that the pattern of coefficients could represent quality bias rather than differences in the valuation of EPS. Table 11 in the Appendix displays

[12] In the estimation, this was repeated 200 times. In each repetition, 50 draws were made from a normal distribution centered around the coefficient estimate, with a standard deviation equal to the estimated standard error. The reported coefficient estimates and standard errors in column (2) of Table 10 are the empirical means and standard errors of these 200 × 50 draws.

a regression of EPS on building age indicators and an interaction of the building age groups with a dummy for high or luxury quality. It shows that the relationship is indeed stronger for the middle and oldest age groups. This potentially reflects the fact that minimum energy efficiency requirements have increased in recent years, forcing all younger buildings to be relatively efficient. This reduces the strength of the relationship between EPS and quality. This suggests that there is less quality bias for younger buildings, so that the age-EPS valuation profile might be somewhat steeper than in Table 10. A second shortcoming of the results are potential measurement errors of the building age variable, as noted above. The results from Table 10 thus need to be interpreted with caution.

6.4 Discussion of Results

Taken as a whole, the results suggest that, in parts, energy efficiency is taken into account in an economically meaningful way by sellers of residential houses in Germany. However, potential cost savings are not always and everywhere calculated correctly. According to Giulietti et al. (2005), switching costs reduce considerably the propensity to switch electricity supplier. Hence, if costs related to switching the gas supplier are perceived to be high, ignoring gas price differences can be interpreted as "rational inattention" (Sallee 2014). Variation in local gas prices or climate did not influence the value of EPS (Sect. 6.1). Additionally, there were no significant differences in the value of EPS across heating fuel type, even though the price of electricity was at least three times the price of gas in the past 24 years. Given the large potential savings in this case, this latter result cannot be explained by rational inattention alone. In line with this finding, recent survey results suggest that there is considerable heterogeneity of behaviour w.r.t. energy efficiency across households (Ramos et al. 2016).

Earlier papers have estimated one single coefficient for samples that typically include buildings of all vintages and heating fuel types—although some have looked at sub-samples of different house types (Fuerst et al. 2015; Hyland et al. 2013). Consider the coefficient of eps $\times$ avg. gas price in column (1) of Table 5, indicating that a one Euro increase in expected yearly heating costs per square metre decreases listing prices by approx. 23 Euro$/m^2$. At sample means, a change from an A-rated building ($30 \leq$ EPS < 50) to an E-rated building ($160 \leq$ EPS < 200) increases expected heating costs by approximately 9.09 Euro/$[m^2 \cdot a]$. The decrease in prices amounts to 208.98 Euro, or 10.2% of the sample mean. As noted above, this is very close to the values reported in other studies, e.g. [9.3%] Hyland et al. (2013) and [10.2%] Brounen and Kok (2011).[13] Note that both studies use a selection model because EPS is not reported in all observations. The suspected selection bias of EPS in OLS estimation does not seem to be large.

Once the sample is restricted to buildings younger than eight years, the estimated coefficient doubles in size, cf. Table 10. From the perspective of an investor or construction company, the results from Table 10 are much more important than knowing how EPS is capitalised *on average*, i.e. in the existing stock. If a house owner wants to improve energy efficiency of the building substantially, it is very likely that the building is rehabilitated rather than renovated. The results presented here suggest that the premium will be much higher in that case. They are much closer to the policy-relevant question of how to foster energy efficiency investments in an effective manner. Given the shortcomings discussed above, it would be important to scrutinize these findings in future research.

It must be noted that this paper faces the same quality bias as other studies (e.g. Brounen and Kok 2011; Hyland et al. 2013; Fuerst et al. 2015; Kahn and Kok 2014). The most

[13] Fuerst et al. (2015) report coefficient estimates for A or B rated buildings and find a premium over E-rated buildings of 5.7% for the full sample.

important finding of this paper is that local climate or gas prices do not seem to be important to house sellers. However, this also means that this type of exogenous variation cannot be used to identify the EPS coefficient.

7 Conclusion

This paper has investigated several channels that influence how sellers on the housing market value energy efficiency in residential buildings. The results have shown that agents are able to consistently use very precise information such as EPS instead of labels or efficiency bands. Agents also seem to be aware of the investment horizon of energy efficiency investments. Overall, the investment dimension of EPS seems to be understood quite well.

The results are less clear about more subtle differences such as local gas prices or climatic conditions. Furthermore, regressions that relied on different fuel types did not produce a consistent pattern with respect to EPS coefficients. Whether this is a sign of irrational or rational inattention cannot be answered conclusively at this point. Anyhow, if there are problems of correct valuation in these dimensions, they could easily be tackled by including estimates of expected heating costs in EPS certificates. These estimates should be based on local fuel prices and climate.

Future research should provide other ways of identifying the EPS coefficient. Given the difficulties to assess whether estimated premia reflect energy cost savings, survey evidence along the lines of Newell and Siikamäki (2015) would help greatly to further understanding in this area. A second shortcoming of this study is its use of listing instead of transaction prices. There are sound theories and empirical evidence showing that systematically mispricing housing characteristics is very costly to house sellers and should thus be avoided. Nevertheless, the use of listing prices is a source of potential bias. It would thus be very interesting to see whether the results are robust to using transaction data such as in Fuerst et al. (2015).

The results cast doubt on the interpretation that the correlation between energy efficiency labels and housing prices stems from energy cost considerations. More likely, substantial parts of the correlations stem from a "green" marketing effect and/or quality bias. The results indicate that it would be desirable to refine existing EPS schemes and establish a tighter connection between EPS and energy cost savings. This is of prime importance if the goal is to reduce energy use (and CO_2 emissions) in residential buildings. If premia are related to "green" marketing alone, simple (binary) labels are not very useful because this will spur investment in marketing and pseudo-efficient rather than truly efficient design (Newell and Siikamäki 2014; Sallee 2014). Responsiveness of households to energy taxes is a key ingredient of theoretical analyses that consider the effects of energy taxes on consumer behaviour (see, e.g. Conrad 2000). Taxation of energy consumption will be much more effective if heating cost savings translate into an increase in the value of energy efficient houses.

Besides its implications for climate change, an energy efficient building stock is critical for Europe's political independence in the future. For these reasons, it is worth while to study more thoroughly how markets react to the existing policy instruments.

Appendix A: Tables

See Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11.

Table 1 Heating costs in gas-heated houses

	Quantiles				
	10%	25%	50%	75%	90%
Avg. gas price	3.2	5.2	9.7	14.2	18.8
Local gas price	−1.2	−0.5	−0.1	0.4	1.4
Local climate	−1.3	−0.7	−0.3	0.0	0.3

Table 2 Summary statistics for the gas prices and climate sample

Variable	Mean	SD	Min.	Max.	Description
(a) listing price and energy performance score					
Listing price per m^2	2043.81	1202.32	200.00	10000.00	listed sales price per m^2
eps	160.12	92.83	0.00	500.00	Energy performance score
(b) general characteristics					
Type semi-detached	0.20	0.40	0	1	Semi-detached house
Type terraced (middle)	0.10	0.30	0	1	Terraced house in the middle of the row
Type terraced (end)	0.05	0.23	0	1	Terraced house at the end of the row
Type villa	0.02	0.15	0	1	House is a villa
Type bungalow	0.04	0.20	0	1	House is a bungalow
Lot size	736.96	762.52	50.00	10000.00	Lot size in m^2
Living area	156.72	68.51	50.00	1336.00	Living area in m^2
Rooms	5.52	1.87	3.00	20.00	Number of rooms
Building age	33.15	35.54	0	216	Time since (re-)construction
Under construction	0.11	0.31	0	1	House is planned or under construction
yc	1973.11	36.90	1800	2018	Year of construction
(c) Quality and design					
Qual luxury	0.02	0.15	0	1	Very high quality
Qual high	0.18	0.39	0	1	High quality
Qual low	0.01	0.09	0	1	Low quality
Cond renovated	0.08	0.28	0	1	Renovated house
Cond refurbished	0.04	0.19	0	1	Refurbished house
Second bathroom	0.63	0.48	0	1	Two or more bathrooms
Basement	0.46	0.50	0	1	House has basement
Built in kitchen	0.16	0.37	0	1	Equipped w/built-in kitchen
Sauna	0.02	0.14	0	1	House has a sauna
Swimming pool	0.03	0.18	0	1	House has a swimming pool
Parquet flooring	0.03	0.16	0	1	House has parquet flooring
Fireplace	0.23	0.42	0	1	House has a fireplace
Rooftop terrace	0.04	0.20	0	1	House has a rooftop terrace
Balcony	0.19	0.40	0	1	house has a balcony
Terrace	0.53	0.50	0	1	house has a terrace

Table 2 continued

Variable	Mean	SD	Min.	Max.	Description
Winter garden	0.08	0.26	0	1	House has a winter garden
Loggia	0.02	0.14	0	1	House has a loggia
(d) Heating					
Air condition	0.01	0.09	0	1	House has air conditioning
Self cont heating	0.02	0.13	0	1	House has self-contained heating
Floor heating	0.22	0.42	0	1	House has floor heating
(e) Other					
Commission	0.03	0.02	0.00	0.10	Commission payment required
Garage	0.48	0.50	0	1	Garage parking available
Carport	0.12	0.32	0	1	Carport parking available
Undergr parking	0.01	0.11	0	1	Underground parking available
Any parking	0.24	0.43	0	1	Any parking available
Pop. density	756.37	841.07	0.00	4520.21	Population density in 2013
Gas price	6.49	0.71	4.58	9.99	Local gas price
Climate factor	−0.03	0.06	−0.18	0.31	Climate factor
Observations	43,089				

Table 3 Reporting the energy performance score

Sample	Eps reported	Eps missing	% Eps reported
Year of construction, lot size and heating type reported	229, 072	179, 795	56.0
Year of construction, lot size and heating type reported, building age > 0	185, 220	93, 626	66.4
Year of construction, lot size, or heating type missing	50, 670	269, 687	15.8

Table 4 Baseline regression results

Dependent variable	Log listing price/m^2 (1)	Listing price/m^2 (2)
(a) Energy performance score		
Eps	−0.00075(0.00002)***	−1.08(0.04)***
(b) General characteristics		
Type semi-detached	−0.05840(0.00370)***	−114.27(8.67)***
Type terraced (middle)	−0.06156(0.00589)***	−136.05(13.13)***
Type terraced (end)	−0.05276(0.00603)***	−116.27(14.90)***
Type villa	0.32807(0.01312)***	866.08(55.11)***
Type bungalow	0.04183(0.00546)***	62.86(14.18)***
Lot size	−0.00000(0.00000)	0.02(0.01)*
Log lot size	0.15013(0.00504)***	267.20(11.56)***
Log living area	−0.40054(0.00816)***	−773.54(24.20)***

Table 4 continued

Dependent variable	Log listing price/m^2 (1)	Listing price/m^2 (2)
Rooms	−0.00641(0.00120)***	7.43(3.21)*
Building age	−0.00034(0.00014)*	−0.27(0.26)
Building age^2	−0.00001(0.00000)***	−0.01(0.00)***
Under construction	−0.04547(0.00596)***	−172.22(14.20)***
Yc 1800–1918	−0.41467(0.01083)***	−650.35(25.05)***
Yc 1919–1945	−0.31835(0.01083)***	−580.27(25.97)***
Yc 1946–1960	−0.27684(0.00927)***	−558.41(22.50)***
Yc 1961–1970	−0.20937(0.00859)***	−479.03(21.60)***
Yc 1971–1980	−0.18925(0.00783)***	−464.86(19.90)***
Yc 1981–1990	−0.16040(0.00800)***	−394.61(20.40)***
Yc 1991–2000	−0.08419(0.00711)***	−265.37(18.26)***
Yc 2001–2010	−0.02920(0.00693)***	−86.16(21.50)***
(c) Quality and design		
Qual luxury	0.15056(0.00876)***	473.94(34.51)***
Qual high	0.02370(0.00360)***	49.29(9.46)***
Qual low	−0.10646(0.00846)***	−160.48(13.25)***
Cond renovated	0.03888(0.00438)***	45.59(10.12)***
Cond refurbished	0.06712(0.00764)***	119.82(17.58)***
Cond needs renov	−0.14860(0.00517)***	−232.83(7.93)***
Second bathroom	0.04934(0.00286)***	58.77(6.22)***
Basement	0.01976(0.00301)***	55.22(7.52)***
Built in kitchen	0.05228(0.00314)***	81.17(7.24)***
Sauna	0.08346(0.00607)***	145.89(18.55)***
Swimming pool	0.05832(0.00799)***	119.77(19.34)***
Parquet flooring	0.06671(0.00771)***	177.03(22.51)***
Fireplace	0.04448(0.00301)***	85.76(8.04)***
Rooftop terrace	0.02176(0.00699)**	81.19(18.74)***
Balcony	0.02536(0.00278)***	37.16(6.91)***
Terrace	0.02729(0.00230)***	27.61(5.49)***
Winter garden	0.01760(0.00435)***	−2.79(10.32)
Loggia	0.01356(0.00736)	14.91(17.56)
Air condition	0.03741(0.01236)**	118.41(39.14)**
(d) Heating		
Self cont heating	−0.06539(0.01089)***	−95.75(18.69)***
Floor heating	0.06499(0.00319)***	120.41(8.72)***
Heating oil	−0.05872(0.00394)***	−95.71(9.31)***
Heating fluid gas	−0.15154(0.01215)***	−290.46(21.44)***
Heating biogas	0.02677(0.01744)	75.56(54.10)

Table 4 continued

Dependent variable	Log listing price/m^2 (1)	Listing price/m^2 (2)
Heating night storage	−0.15993(0.01195)***	−282.63(21.20)***
Heating electricity	−0.06621(0.00606)***	−56.88(13.06)***
Heating solar	0.00228(0.00627)	−10.78(14.23)
Heating heat pump	0.04013(0.00702)***	95.51(18.03)***
Heating wood pellets	−0.05970(0.00897)***	−89.79(18.02)***
Heating geothermal	0.00923(0.00850)	99.20(25.86)***
Heating district	−0.01589(0.00990)	−0.81(24.69)
Heating coal	−0.32136(0.02287)***	−286.51(27.02)***
Multiple heating types	−0.02956(0.00607)***	−69.35(13.64)***
(e) Other		
Commission	0.18842(0.07310)**	299.08(179.78)
Garage	0.00433(0.00357)	7.18(8.29)
Carport	0.00369(0.00438)	−11.56(12.73)
Undergr parking	0.05472(0.01130)***	165.15(41.33)***
Any parking	0.01460(0.00385)***	20.23(8.13)*
Pop. density	−0.10688(0.04392)*	−526.91(138.96)***
Pop. density × lot size	0.00001(0.00001)*	0.04(0.02)*
Pop. density × log lot size	0.02432(0.00525)***	95.04(15.00)***
Pop. density × log living area	0.03156(0.00963)**	63.76(32.42)*
Adj. R^2	0.704	0.664
Observations	229072	229072
df	228595	228595

Zip code cluster-robust standard errors in parentheses; the regressions in this table include district and time fixed effects.
*** $p < .001$, ** $p < .01$, * $p < .05$

Table 5 Local gas prices and climate regressions

	Dependent variable: listing price/m^2					
	Local gas prices				Local climate	
	baseline (1)	$50 \leq eps \leq 300$ (2)	Age matching (3)	Age & Eps matching (4)	Baseline (5)	$50 \leq eps \leq 300$ (6)
Eps × avg. gas price	−0.23***	−0.31***	−0.16***	−0.36	−0.23***	−0.29***
	(0.01)	(0.02)	(0.02)	(0.23)	(0.01)	(0.02)
Eps × dev. from avg. gas price	0.02	−0.06	−0.04	−0.09		
	(0.08)	(0.13)	(0.08)	(0.18)		
Eps × avg. gas price × climate factor					0.17	0.53
					(0.16)	(0.27)
Pop. density × eps	0.01	0.19	−0.33*	1.83	0.03	0.24
	(0.09)	(0.13)	(0.15)	(2.37)	(0.09)	(0.14)
Dev. from avg. gas price			−1.69	7.93		
			(16.98)	(28.67)		
Local house price diff.			0.98***	0.96***		
			(0.05)	(0.07)		
Adj. R^2	0.805	0.803	0.432	0.420	0.805	0.803
Observations	43089	33994	7235	1789	43089	33994
df	40393	31329	7177	1731	40393	31329
p value (equal eps coef.)	0.001	0.056	0.178	0.360	0.011	0.002

Zip-code cluster-robust standard errors in parentheses; all regressions include time fixed effects and controls for housing characteristics. Regressions (1), (2), (5), and (6) include zip code fixed effects.
Regressions (3) and (4) rely on matches of houses from zip codes with large gas price differences (> 1 ct/kWh), as described in the text. *** $p < .001$, ** $p < .01$, * $p < .05$

Table 6 Local gas prices and climate: robustness checks

	Dependent variable: listing price/m^2					
	Local gas prices			Local climate		
	Housing char. Interactions (1)	Local gas price Expectations (2)	Socio-demographic Interactions (3)	housing char. Interactions (4)	Socio-demographic Interactions (5)	Snowcover days And hot days (6)
Eps × avg. gas price	−0.243***	−0.236***	−0.235***	−0.236***	−0.232***	−0.340***
	(0.019)	(0.015)	(0.012)	(0.020)	(0.014)	(0.041)
Eps × dev. from avg. gas price	0.008	0.027	0.032			
	(0.076)	(0.078)	(0.077)			
Eps × gas price change		−0.032				
		(0.121)				
Eps × avg. gas price ×				0.198	0.092	
climate factor				(0.162)	(0.169)	
Eps × avg. gas price ×						0.002
# snowcover days						(0.001)
Eps × avg. gas price ×						0.009*
# days w. max temp. > 30°C						(0.004)
Eps × pop. density	0.009	0.012	0.054	0.026	0.057	0.038
	(0.086)	(0.086)	(0.098)	(0.090)	(0.100)	(0.100)
Eps × building age	−0.000			−0.000		−0.001
	(0.002)			(0.002)		(0.002)
Eps × qual luxury	−0.161			−0.155		−0.160
	(0.849)			(0.850)		(0.850)
Eps × qual high	1.293***			1.305***		1.280***
	(0.231)			(0.231)		(0.228)

Table 6 continued

	Dependent variable: listing price/m²					
	Local gas prices			Local climate		
	Housing char. Interactions (1)	Local gas price Expectations (2)	Socio-demographic Interactions (3)	housing char. Interactions (4)	Socio-demographic Interactions (5)	Snowcover days And hot days (6)
Eps × qual low	0.848*			0.841*		0.810*
	(0.346)			(0.345)		(0.343)
Eps × air condition	−1.832			−1.809		−1.820
	(1.260)			(1.258)		(1.257)
Eps × floor heating	0.061			0.052		0.067
	(0.205)			(0.205)		(0.207)
Eps × self cont heating	−0.320			−0.317		−0.371
	(0.372)			(0.374)		(0.373)
Eps × average age			0.018		0.018	−0.004
			(0.049)		(0.049)	(0.051)
Eps × share foreign			−0.026		−0.023	−0.042*
			(0.019)		(0.019)	(0.019)
Eps × average household size			−0.103		−0.081	−0.272
			(0.449)		(0.452)	(0.452)
Adj. R^2	0.805	0.805	0.805	0.805	0.805	0.805
Observations	43089	43089	43089	43089	43089	43089

Zip-code cluster-robust standard errors in parentheses; all regressions include time fixed and zip code fixed effects and controls for housing characteristics.
*** $p < .001$, ** $p < .01$, * $p < .05$

Table 7 Means in the heating types sample

	Heating types				
	District	Gas		Electricity	
	(1)	Unweighted (2)	Weighted (3)	Unweighted (4)	Weighted (5)
(a) Listing price and energy performance score					
Listing price per m^2	2507.77	2449.37	2490.33	2377.86	2350.63
Eps	111.13	156.46	115.30	81.14	112.33
(b) General characteristics					
Type semi-detached	0.23	0.21	0.24	0.11	0.25
Type terraced (middle)	0.27	0.13	0.26	0.05	0.19
Type terraced (end)	0.14	0.07	0.16	0.03	0.13
Type villa	0.04	0.03	0.03	0.03	0.01
Type bungalow	0.05	0.04	0.06	0.01	0.04
Lot size	430.41	683.17	439.86	673.73	509.56
Living area	146.95	156.25	147.18	146.28	146.18
Rooms	5.17	5.44	5.16	4.94	5.18
Building age	17.35	30.14	17.85	18.76	25.94
Under construction	0.19	0.10	0.18	0.54	0.14
Yc 1800–1918	0.02	0.07	0.02	0.04	0.03
Yc 1919–1945	0.03	0.10	0.03	0.05	0.07
Yc 1946–1960	0.04	0.12	0.03	0.08	0.07
Yc 1961–1970	0.14	0.13	0.14	0.06	0.16
Yc 1971–1980	0.09	0.12	0.10	0.09	0.14
Yc 1981–1990	0.03	0.05	0.03	0.02	0.05
Yc 1991–2000	0.05	0.08	0.05	0.01	0.04
Yc 2001–2010	0.13	0.10	0.15	0.03	0.10
(c) Quality and design					
Qual luxury	0.04	0.03	0.03	0.03	0.02
Qual high	0.28	0.18	0.23	0.06	0.14
Qual low	0.01	0.01	0.01	0.01	0.02
Cond renovated	0.04	0.08	0.06	0.03	0.06
Cond refurbished	0.02	0.05	0.02	0.01	0.02
Second bathroom	0.72	0.64	0.75	0.74	0.66
Basement	0.49	0.49	0.49	0.22	0.41
Built in kitchen	0.16	0.17	0.12	0.09	0.16
Sauna	0.02	0.03	0.02	0.01	0.01
Swimming pool	0.02	0.03	0.02	0.01	0.03
Parquet flooring	0.02	0.03	0.02	0.01	0.02
Fireplace	0.13	0.22	0.15	0.11	0.18
Rooftop terrace	0.07	0.05	0.06	0.03	0.06
Balcony	0.20	0.20	0.18	0.27	0.26
Terrace	0.61	0.55	0.60	0.36	0.56
Winter garden	0.04	0.08	0.04	0.03	0.04

Table 7 continued

	Heating types				
	District	Gas		Electricity	
		Unweighted	Weighted	Unweighted	Weighted
	(1)	(2)	(3)	(4)	(5)
Loggia	0.02	0.02	0.01	0.01	0.01
(d) Heating					
Air condition	0.01	0.01	0.00	0.01	0.02
Self cont heating	0.00	0.02	0.00	0.04	0.00
Floor heating	0.27	0.24	0.27	0.51	0.28
e) Other					
Commission	0.02	0.03	0.03	0.02	0.03
Garage	0.42	0.49	0.48	0.24	0.46
Carport	0.13	0.12	0.12	0.05	0.11
Undergr parking	0.01	0.01	0.01	0.00	0.01
Any parking	0.28	0.26	0.25	0.61	0.21
Pop. density	0.75	0.48	0.68	0.27	0.55
Observations	1058	5156	938.4	1233	632.9

Table 8 Heating types—logistic regressions

	Dependent variable: district heating	
	Vs. gas heating	Vs. electricity heating
	(1)	(2)
(a) General characteristics		
Type semi-detached	0.398 (0.123)**	1.015 (0.220)***
Type terraced (middle)	0.933 (0.156)***	1.852 (0.248)***
Type terraced (end)	1.182 (0.162)***	1.984 (0.298)***
Type villa	0.657 (0.249)**	0.090 (0.504)
Type bungalow	0.850 (0.197)***	2.115 (0.384)***
Lot size	−0.462 (0.110)***	−0.942 (0.176)***
Living area	0.001 (0.002)	0.004 (0.002)*
Rooms	0.051 (0.043)	0.187 (0.073)*
Building age	0.009 (0.003)**	0.002 (0.006)
Under construction	−0.146 (0.141)	−1.430 (0.285)***
Yc 1800–1918	−3.195 (0.429)***	−1.949 (0.774)*
Yc 1919–1945	−2.368 (0.342)***	−1.754 (0.596)**
Yc 1946–1960	−2.521 (0.289)***	−2.521 (0.565)***
Yc 1961–1970	−0.999 (0.220)***	−0.958 (0.474)*
Yc 1971–1980	−1.309 (0.230)***	−1.346 (0.450)**
Yc 1981–1990	−1.427 (0.284)***	−1.234 (0.555)*
Yc 1991–2000	−1.275 (0.215)***	0.452 (0.519)
Yc 2001–2010	−0.280 (0.183)	1.698 (0.444)***

Table 8 continued

	Dependent variable: district heating	
	Vs. gas heating (1)	Vs. electricity heating (2)
(b) Quality and design		
Second bathroom	0.291 (0.103)**	0.453 (0.192)*
Self cont heating	−2.159 (0.760)**	−4.837 (0.904)***
Cond refurbished	−0.683 (0.308)*	1.039 (0.693)
Type bungalow	0.850 (0.197)***	2.115 (0.384)***
Terrace	0.138 (0.089)	0.313 (0.146)*
Winter garden	−0.364 (0.203)	0.443 (0.385)
c) other		
Any parking	−0.229 (0.105)*	−1.212 (0.178)***
Pop. density	0.652 (0.167)***	0.767 (0.248)**
Pop. density × yc 1800–1918	0.597 (0.267)*	0.238 (0.431)
Pop. density × yc 1919–1945	−0.566 (0.220)*	−0.821 (0.449)
Pop. density × yc 1946–1960	−0.441 (0.206)*	−0.341 (0.304)
Pop. density × yc 1961–1970	0.030 (0.122)	−0.444 (0.288)
Pop. density × yc 1971–1980	−0.273 (0.156)	−0.872 (0.301)**
Pop. density × yc 1981–1990	−0.870 (0.458)	−1.012 (0.607)
Pop. density × yc 1991–2000	−0.257 (0.199)	−0.059 (0.861)
Pop. density × yc 2001–2010	−0.403 (0.142)**	−1.535 (0.345)***
Pseudo-R^2 (Nagelkerke)	0.362	0.647
Observations	6214	2291

Heteroskedasticity-robust standard errors in parentheses; all regressions include district fixed effects.
*** $p < .001$, ** $p < .01$, * $p < .05$

Table 9 Heating type regressions

	Dependent variable: listing price/m^2			
	No weighting (1)	Prop. score-weighted (2)	Type interactions (3)	Eps interactions (4)
Eps	−1.41**	−1.75**	−1.08*	−2.07***
	(0.44)	(0.61)	(0.54)	(0.51)
Eps × heating gas	−0.27	−0.40	−0.84	−0.19
	(0.37)	(0.54)	(0.62)	(0.40)
Eps × heating electricity	−1.76***	−0.85	−0.63	−1.29**
	(0.43)	(0.53)	(0.74)	(0.46)
Heating gas	45.55	52.80	1123.88	49.09
	(68.58)	(92.35)	(1106.91)	(76.31)
Heating electricity	137.10	−68.92	885.94	49.40
	(78.27)	(99.42)	(1273.40)	(85.92)

Table 9 continued

	Dependent variable: listing price/m^2			
	No weighting (1)	Prop. score-weighted (2)	Type interactions (3)	Eps interactions (4)
Adj. R^2	0.749	0.775	0.755	0.755
Observations (unweighted)	7447	4675	7447	7447
df (unweighted)	7113	4341	7023	7071

Zip code cluster-robust standard errors in parentheses; all regressions include zip code and time fixed effects, and controls for housing characteristics.
In column (3), housing characteristics enter separately for each heating type, in column (4) all housing characteristics were interacted with eps.
*** $p < .001$, ** $p < .01$, * $p < .05$.

Table 10 Building age regressions

	Dependent variable: listing price/m^2	
	No adjustment (1)	Age adjustment (2)
Eps × pop. density	−0.01	−0.04
	(0.15)	(0.17)
Eps × building age under 8	−2.12***	−2.10***
	(0.20)	(0.24)
Eps × building age 8–15	−1.98***	−1.99***
	(0.22)	(0.25)
Eps × building age 16–23	−1.47***	−1.49***
	(0.32)	(0.33)
Adj. R^2	0.790	0.790
Observations	19522	15072
df	17654	13207
$(1+e)/(1+r)$		0.829
T		30.675
NPV (new building)		5.828

Zip code cluster-robust standard errors in parentheses; all regressions include zip code and time fixed effects, and controls for housing characteristics. In regression (2), the building age distribution in each age group is adjusted. Coefficients and standard errors are calculated by way of a simulation procedure, see the explanations in the text.
*** $p < .001$, ** $p < .01$, * $p < .05$.

Table 11 Building age, quality, and eps

	Dependent variable: eps
Building age under 8	121.65***
	(3.21)
Building age 8–15	162.45***
	(3.47)
Building age 16–23	155.47***
	(3.44)
Building age × building age under 8	7.50***
	(0.56)
(Building age−8) × building age 8–15	0.30
	(0.71)
(Building age−16) × building age 16–23	4.29***
	(0.74)
High or luxury quality × building age under 8	−18.71***
	(2.27)
High or luxury quality × building age 8–15	−27.48***
	(3.38)
High or luxury quality × building age 16–23	−23.63***
	(3.71)
Adj. R^2	0.827
Observations	19522
df	17708

Zip code cluster-robust standard errors in parentheses; zip code fixed effects included.
*** $p < .001$, ** $p < .01$, * $p < .05$

Appendix B: Figures

See Figs. 1, 2, 3 and 4.

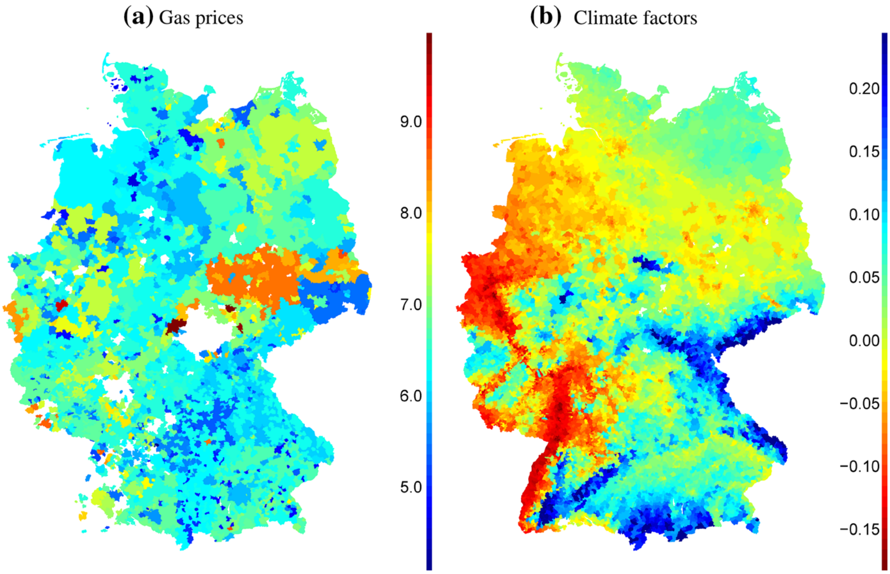


Fig. 1 Gas prices and climate factors in German ZIP codes. **a** Gas prices **b** climate factors *Source*: online contract offers; own calculation. German Weather Service. (Color figure online)

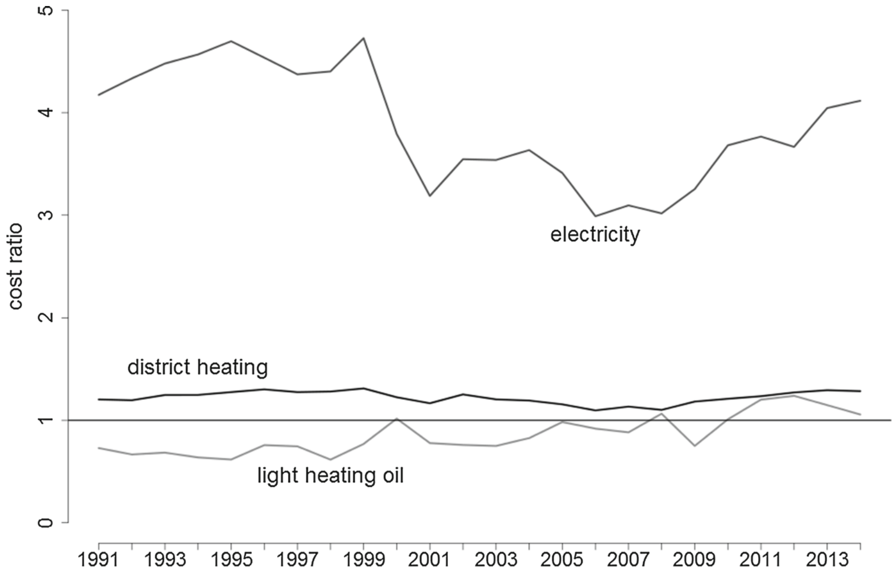
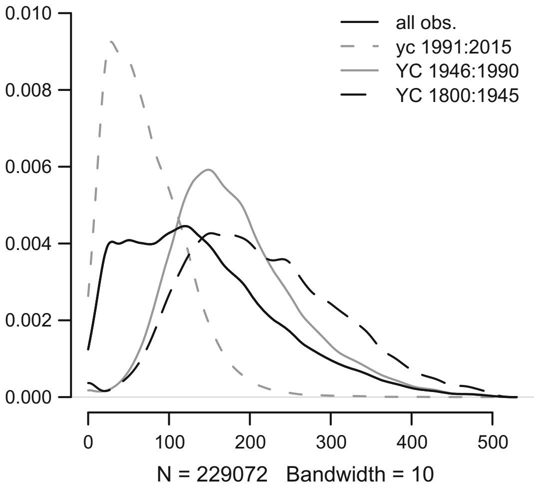


Fig. 2 Costs of different fuel types, relative to natural gas. *Source*: Federal Ministry for Economic Affairs and Energy; own calculations

Fig. 3 Kernel density estimates for the energy performance score



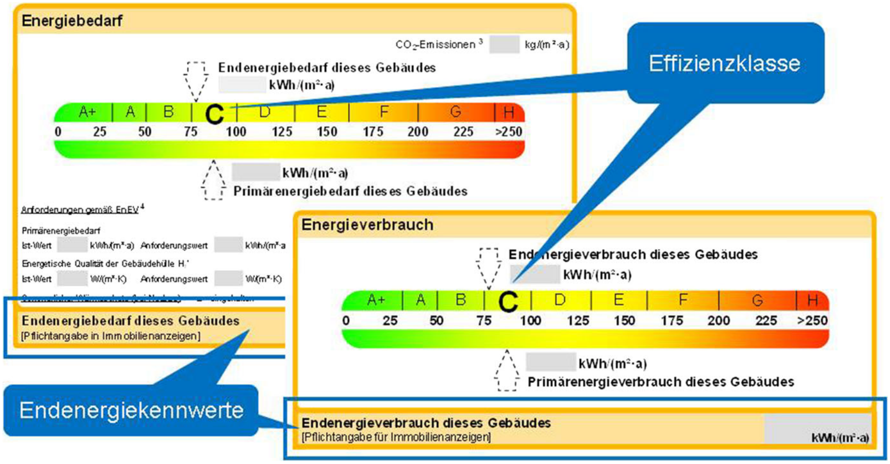


Fig. 4 Energy labels for real estate offers in Germany. *Source*: BBSR/energieeinsparverordnung. The label in the *background* ("Endenergiebedarf") is based on a standardised projection of energy use. It containts a scale (A+ to H) that indicates EPS in steps of 25, and the exact EPS (see the *blue label* "Endenergiekennwerte"). Additionally, information on energy-related building characteristics is provided below the scale; this information is not available in the data set. The label up front is based on past use. It is structured similarly, but does not contain additional information. (Color figure online)

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