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Weather to pay attention to energy efficiency on the housing market[☆]

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ABSTRACT

Energy efficiency improvements can play an important role in reducing emissions from residential buildings, yet consumer decisions involving energy costs can be subject to bounded rationality due to, e.g., inattention and myopia. We present evidence that long-term, high-stakes decisions in the housing market are influenced by short-term contextual factors. Using data on housing transactions through a large online platform in Germany, we document that houses purchased following unusually cold weather tend to be more energy efficient, while the reverse is not true for unusually warm weather. This asymmetry suggests that the effect of temperature fluctuations on energy efficiency demand may be driven by salience of heating costs.

1. Introduction

Behavioral biases in consumer decision-making might hinder investments in household energy efficiency and thus contribute to an energy efficiency gap (Gillingham and Palmer, 2014; Gerarden et al., 2017; Kotchen et al., 2023).[1] For example, contemporaneous weather experiences could generate "natural" variation in the how much people think about heating costs and energy savings, as room heating generates a substantial fraction of household energy consumption in temperate climate zones. In this paper, we provide novel evidence on behavioral effects of weather on energy efficiency demand in the German housing market.

While the broader regional climate and long-term climate trends can affect the real estate market through standard cost–benefit considerations (e.g., Butsic et al., 2011; Baldauf et al., 2020), short-term fluctuations in weather should be less likely to influence long-term purchase decisions through rational belief updating. In contrast, if consumers are boundedly rational, unusually cold temperatures could serve as contextual cue that makes heating costs more salient (Bordalo et al., 2022) and cause individuals to overestimate how much future conditions will align with current conditions (i.e., projection bias, see Loewenstein et al., 2003; Conlin et al., 2007). Informed by theories on the roles of contrast and surprise for bottom-up attention (Bordalo et al., 2022), we construct a regional-level weather shock variable that takes the difference in monthly temperatures relative to the average seasonal temperature in the past. We then test whether unusually cold or warm weather in the recent month(s) leads to the purchase of more energy efficient houses.

2. Data

The estimation sample uses data on housing transactions between 2014 to 2021 through ImmoScout24, the largest online real estate platform in Germany (Breidenbach and Schaffner, 2020; RWI and ImmobilienScout24, 2020), covering all 16 states and 8065 zip codes (over 90% of all zip codes in Germany). The data includes information on property characteristics included in the advertisement as well as data on the month of first posting and month of offer acceptance, which we will refer to as the month of sale for simplicity.

We combine this with continuous daily temperature data from 325 local weather stations collected by the German meteorological service to generate temperature and heating degree day (HDD) variables of

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[1] This is reflected in policy makers' attempts to foster energy efficiency investments not just through subsidies or extending carbon pricing to the residential sector (e.g., World Bank, 2020; IEA, 2022), but also enacting mandatory disclosure policies aimed at making information about energy efficiency more transparent and salient (Frondel et al., 2019; Myers et al., 2022). Note that the evidence is mixed on whether there is in fact an energy efficiency paradox or whether, at least in some contexts, the actual private benefits of energy efficiency investments to consumers are actually lower than the private costs (e.g., Fowlie et al., 2018; Myers, 2019).

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Table 1

Summary statistics.

Housing data (only with EPC)	Mean	SD	p10	p50	p90	N
Energy performance score [kWh/sqm annum]	142.6	95.4	31.6	129.8	271.9	2 392 725
Energy use certificate [%]	38.6	–	–	–	–	2 383 902
Asking price [1000 €]	422.4	473.0	130	324	750	2 384 435
Living area [sqm]	188.3	136.0	105	155	297	2 391 340
Total plot area [sqm]	783.4	648.8	237	630	1422	2 332 507
Number of rooms	6.3	3.0	4	6	10	2 392 725
Year of construction	1973	39.2	1912	1978	2018	2 392 725
Year of last modernization	2007	9.8	1995	2010	2016	626 587
Planning/construction in process [%]	12.8	–	–	–	–	2 392 725
Ad duration in days	66.2	89.2	6	35	157	2 388 833
Weather data by station and month	Mean	SD	p10	p50	p90	N
Avg. temperature [°C]	10.1	6.5	1.9	10.0	18.9	30 395
Heating degree days (HDD)	193.4	161.7	4.1	169.0	412.3	30 395
Weather shock in avg. temperatures	−0.3	1.8	−2.8	−0.3	1.9	30 395
Weather shock in HDD	−7.1	47.1	−70.9	−4.2	45.8	30 395

Notes: The estimation sample excludes houses without information on energy performance certificates (EPC) and houses that were built before the year 1800. Monthly temperature data is constructed from daily weather observations from 325 weather stations in Germany with continuous data from 2009 to 2021. Weather shocks are defined as difference between contemporaneous monthly weather relative to the previous 5-year average in the same month. A positive (negative) sign of the shock indicates colder (warmer) than usual temperatures.

interest for each month in the estimation time period. Weather shocks are defined as the difference between the contemporaneous monthly weather variable relative to the previous 5-year average in the same month, where a positive (negative) sign of the shock indicates colder (warmer) than usual temperatures. Further details are provided in the Online Appendix. Table 1 presents descriptive statistics on property characteristics and weather variation. In total, our sample includes more than 2.3 million housing transactions with information on energy performance scores.

3. Empirical approach

To identify the effects of weather on demand for energy efficiency on the housing market, we exploit plausibly exogenous variation in contemporaneous local temperatures. More specifically, we construct a weather shock variable by calculating the contemporaneous deviation of monthly temperatures relative to the regional average for that calendar month in the past five years. Using this temperature anomaly measure has two advantages. First, it alleviates concerns about potential seasonality effects that correlate demand and/or supply of average energy efficiency of houses on the market. Second, it captures dimensions of salience, regarding surprise relative to expectations, which may in turn affect the attention weights that prospective buyers put on energy efficiency attributes (Bordalo et al., 2022).

Given that house purchases involve large financial commitments that require careful deliberation, the critical window in which decisions are influenced may be several weeks before the finalized transaction. At the same time, we know that advertisements stay active on the platform for around two months on average. To investigate the effect of recent temperature shocks on energy performance, we therefore focus on the 1 month lag prior to the sale. The statistical model is

$$y_{iwzt} = \alpha_{zm} + \beta\, \Delta_{w,t-1} + \mathbf{x}'_{it}\boldsymbol{\gamma} + \delta_t + \epsilon_{iwzt}\,, \tag{1}$$

where y_{iwzt} is the log energy performance score (in kWh/m^{2}a) reported on the energy performance certificate (EPC) for house i in zip code z, sold on the market at time t (month-year level). A higher score indicates that a house is less energy-efficient. $\Delta_{w,t-1}$ captures the lagged weather shock in the month prior to time of purchase, measured at the weather station w that is geographically closest to the zip code. We consider two weather shock measures: (1) using monthly HDDs and (2) using average monthly temperature (in °C).

α_{zm} captures zip code z times calendar month m fixed effects to control for differences across zip codes and zip-code-specific seasonality patterns. Importantly, we flexibly control for general time trends by including month-of-sale fixed effects δ_t to avoid spurious correlation of temperature and energy efficiency. Finally, we control for a vector of house characteristics $\mathbf{x}_{it}$, including the type category (e.g., detached, semi-detached, terraced), EPC type (demand versus consumption, water heating or not), as well as quadratic polynomials of the building year, the last renovation date, living area in sqm, number of rooms, and asking price per living area.

To better understand the potential behavioral mechanism, we further decompose weather shocks $\Delta_{w,t-1}$ into warm weather shocks $\Delta^{+}_{w,t-1} = \Delta_{w,t-1} \cdot \mathbf{1}(\Delta_{w,t-1} \geq 0)$ and cold weather shocks $\Delta^{-}_{w,t-1} = -\Delta_{w,t-1} \cdot \mathbf{1}(\Delta_{w,t-1} < 0)$ and estimate the following equation:

$$y_{iwzt} = \alpha_{zm} + \beta_1\, \Delta^{+}_{w,t-1} + \beta_2\, \Delta^{-}_{w,t-1} + \mathbf{x}'_{it}\boldsymbol{\gamma} + \delta_t + \epsilon_{iwzt}\,, \tag{2}$$

Residential energy demand in Germany has traditionally been driven by room heating as compared to cooling (Olonscheck et al., 2011). Thus, theories of salience and associative recall would predict that energy efficiency considerations might be triggered primarily by unusually cold temperatures, i.e., high heating requirements.

4. Results

Table 2 presents our results on the relation between energy efficiency scores of homes and heating requirements in the month prior to the transaction. In columns (1) and (4), we estimate Eq. (1) without the inclusion of object type characteristics. In columns (2) and (5), we additionally control for a host of object characteristics, such as year of construction, renovations, asking price, property size, and object condition. The coefficients suggest that a 50 unit increase in HDD is associated with a 1.2%p decrease in estimated annual energy consumption per square meter of living space. Similarly, a one degree lower average temperature is associated with a 0.7% lower energy consumption. This suggests that transitory weather fluctuations in a region can influence the sale of energy-efficient houses.

To decompose these effects by warm and cold weather shocks, we estimate Eq. (2) and present the results in columns (3) and (6) of Table 2. We document an asymmetric response. While average energy efficiency increases significantly after unusually low temperatures (i.e., high heating requirements), there is no effect of unusually high temperatures. One potential explanation is that energy efficiency is more mentally associated with cold weather than with warm weather, as space heating is the primary driver of energy bills in Germany. In line with this, we find positive effects of cold weather shocks on average ad clicks per day for objects with better energy performance, but no corresponding effect for warm weather (Appendix Table A5).

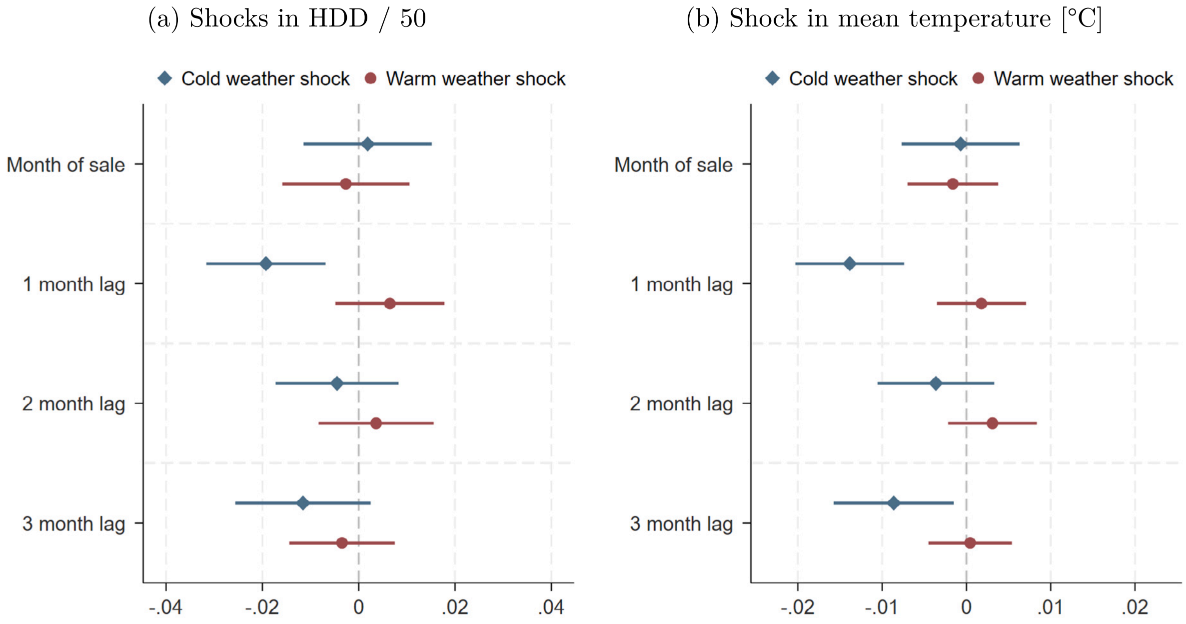

Fig. 1. Weather shocks around the month of sale. *Notes:* Each figure plots coefficients from multiple regressions based on Eq. (2) and including multiple weather shock lags. Error bars indicate 95% confidence intervals.

Table 2
Effect of temperature shocks on energy efficiency of houses sold.

	$y = \log\ (\mathrm{kWh/m^2a})$					
	HDD/50			Avg. temperature [°C]		
	(1)	(2)	(3)	(4)	(5)	(6)
Weather shock (1 m lag)	−0.0177** (0.0079)	−0.0119*** (0.0038)		−0.0077* (0.0041)	−0.0069*** (0.0019)	
Warm weather shock (1 m lag)			0.0059 (0.0055)			0.0021 (0.0026)
Cold weather shock (1 m lag)			−0.0186*** (0.0061)			−0.0137*** (0.0033)
Object characteristics	*No*	*Yes*	*Yes*	*No*	*Yes*	*Yes*
Month FEs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Zip code × month FEs	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	2 335 676	2 335 676	2 335 676	2 335 676	2 335 676	2 335 676
Weather stations	325	325	325	325	325	325
R^2	0.222	0.715	0.715	0.222	0.715	0.715

Notes: The sample excludes houses without EPC information and houses that were built before the year 1800. Energy performance scores are winsorized at the bottom at 1 kWh/sqm. Weather shocks are defined as difference between contemporaneous monthly weather relative to the previous 5-year average in the same month. A positive (negative) sign of the shock indicates colder (warmer) than usual temperatures. Standard errors in parentheses are robust to two-way clustering by weather station and by state × time of sale. $p < 0.10$, $p < 0.05$, $p < 0.01$.

We further confirm the reliability of our results by conducting placebos check using leads instead of lags (Table A1) as well as robustness checks that additionally control for housing supply (Table A2), exclude transactions during the Covid pandemic (Table A3), or use a 3-year reference period to calculate weather shocks (Table A4). While our main results focus on weather during the month preceding the transaction, one might wonder whether different time frames also have an effect on energy efficiency. Fig. 1 suggests that responses to cold weather anomalies indeed occur predominantly in the most recent month.[2]

5. Discussion

In summary, we find that house buyers on the largest real estate platform in Germany tend to purchase more energy-efficient properties in response to recent occurrences of unusually cold temperatures. This is in line with previous studies showing that transitory weather fluctuations can influence consumption choices in a variety of contexts, including the purchase of energy-efficient durable devices (He et al., 2022; Bonan et al., 2024), convertible cars (Busse et al., 2015), outdoor-movie tickets (Buchheim and Kolaska, 2016), and solar panels (Liao, 2020; Lamp, 2023).[3] The real estate market provides a particularly

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[2] We observe no effects of weather shocks in the month of sale itself, likely because the transaction (or at least the mental decision) has already taken place. Remember that we do not know exactly on which day of the month the sale was agreed upon.

[3] While the cited studies focus on the roles of salience and projection bias, weather can also affect economic decision making through changes in mood, sentiment, or through attribution bias (Kamstra et al., 2003; Gourley, 2021; Haggag et al., 2019).

compelling context, as purchasing a house is one of the most significant economic decisions that a person or household can make in their life. We contribute to the previous literature studying the role of limited attention in the housing market (e.g., Bradley, 2017; Myers, 2019; Sejas-Portillo et al., 2020; Gindelsky et al., 2023). Using a complementary approach focusing on hedonic valuations, Sejas Portillo (2023) finds that the price premium for energy efficiency in the UK housing market tends to increase as temperatures decreases.

One notable feature of our study is that by constructing a weather shock variable relative to past reference levels, we can naturally decompose the effects by cold and warm weather shocks. We observe that home buyers' interest in energy efficient homes in our sample responds only to unusually cold weather. Our results are consistent with attention being focused on heating costs due to salience and associative recall (Schlager et al., 2020; Bordalo et al., 2020; Singhal, 2024). For example, surprisingly chilly weather could invoke vivid memories of past experiences — such as feeling cold indoors or paying high energy bills — and thereby causing energy savings potential to come to mind more easily (Tversky and Kahneman, 1973). In contrast, pure projection bias would imply that individuals should over-extrapolate from both positive and negative surprises. However, the observed asymmetry could potentially also be explained by projection bias in combination with models of reference-dependent preferences with loss aversion (Köszegi and Rabin, 2006; Andersen et al., 2022).

Climate change is increasing the frequency and intensity of extreme weather events. On average, global temperatures are on the rise and winters are getting shorter, however, local regions are still subject to extreme snow and frigid weather events (IPCC, 2021). Moving forward, information campaigns may be helpful in focusing on the volatility of climate change, in addition to long-term trends.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.econlet.2024.112041.

Data availability

The RWI-GEO-RED houses for sale data is published by the RWI – Leibniz Institute for Economic Research and available free of charge for non-commercial research as a Scientific Use File. Data request is required. Climate data for Germany is published by the German Meteorological Service (Deutscher Wetterdienst) and free to access.

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