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The Effect of Building Energy Retrofits on Daily Heating Time

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Abstract

This paper analyzes the effect of building energy retrofits on daily heating time. Using German survey data and controlling for local differences in climate and energy prices, I show that retrofitted heating systems run significantly longer on a typical winter weekday than non-retrofitted ones. In particular lower-income households seem to respond to heating retrofits by increasing the heating time. My findings provide further evidence for the existence of direct rebound effects and have some important implications for energy and climate policy.

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1. Introduction

Having a heated shelter is one of the most basic human needs, being essential for subsistence. In the developed world mostly fossil fuels keep the homes warm—coal in the past, heating oil and natural gas today. A byproduct of burning fossil fuels, however, is the greenhouse gas carbon dioxide, which contributes to global warming and climate change. In Germany, for example, residential space and water heating account for 16% of total carbon emissions (UBA 2012). In order to reduce emissions from the residential building stock, energy efficiency and renewable energy sources are promoted by German government policy: building energy codes are becoming more stringent, certain shares of renewables in heat generation are required, and energy retrofits are subsidized. The long-term national target is to have a virtually climate-neutral building stock by 2050, with 80% less energy consumption compared to 2008. To achieve this, a doubling of the annual retrofit rate to 2% is planned (BMWi 2010).

In this paper, I investigate differences in households' heating behavior depending on whether their home was recently retrofitted or not. Heating behavior is a very complex issue, including factors such as heating time, room temperature level, and ventilation. It determines, together with the quality of insulation and heating equipment, the household's heat energy consumption. Here, I focus on the heating time and examine if people living in retrofitted dwellings run their heating system longer than others do.

This paper thus contributes to the empirical literature on the phenomenon known as "rebound." Rebound means the fact that energy efficiency improvements themselves can lead to additional energy use, which lowers the related net energy savings. And that is because improved energy efficiency changes relative prices, making income and substitution effects likely. Operating a more efficient heating system, for example, reduces the marginal costs of heat supply. Households may respond to this cost reduction by heating their rooms for longer or to a higher temperature (direct rebound), or they may spend the saved money on other energy-consuming goods and services (indirect rebound).[1] Either way, at least parts of the energy efficiency savings will be offset by behavioral responses.

From an economic perspective, rebound is nothing to worry about; it is simply the result of utility-maximizing adjustments to a change in relative prices and even enhances welfare. However, rebound has important implications for energy and climate policy. If a significant share of potential energy savings is offset by rebound effects, then energy efficiency standards and subsidy programs are less effective at reducing carbon emissions than predicted. There is an ongoing debate as to what extent rebound should be considered in policy design (for recent contributions, see, e.g., Gillingham et al. 2013, and van den Bergh 2011). The crucial point of the debate is the magnitude of rebound, of course, but reliable quantification of rebound remains a difficult empirical task. Existing econometric estimates of direct rebound effects for residential heating vary widely and reach up to some 60%, both in the short and long run (Sorrell et al. 2009).

Instead of providing another rebound estimate, I shed light on the specific behavioral changes due to building energy retrofits. The considered retrofits include different insulation measures, furnace and boiler improvements, as well as space and water heating fuel switches. Although the discussion of rebound typically revolves around the extra energy

[1] For a rigorous microeconomic framework for such end-user induced rebound effects and a discussion of economy-wide impacts, see Borenstein (2015). For early contributions to the idea of rebound, see the seminal works of Jevons (1865) and Khazzoom (1980).

use triggered by improved energy efficiency, the underlying arguments hold for a switch to a cheaper energy source, too. Biomass-based fuels such as wood pellets are typically cheaper than fossil fuels, other renewables have even zero fuel costs. The lower marginal costs of heating with renewables make rebound effects very likely to occur. This matters because "renewable" does not necessarily mean carbon neutral.

The analysis is based on data from a Germany-wide household survey, including self-reported information on the daily number of hours the heating is turned off in the cold season, combined with climate data from the German Meteorological Service and energy price data from the consumer portal Verivox. I use linear regressions to examine the relationship between heating time and completed retrofits. I find that, on average, retrofitted heating systems run some 30 minutes longer per day than non-retrofitted. For insulation measures, however, I find no significant effects. Since richer households, even when they are equipped with an inefficient or outdated heating system, are less likely not to fully saturate their heating needs (Milne and Boardman 2000), I check whether the effect of heating retrofits on heating time depends on income level. My results indeed indicate that lower-income households are especially prone to (direct) rebound behavior.

2. Data Sources

I use data from a nationwide household survey, representative of size and regional distribution[2] of German households. The survey was administered in late spring and early summer 2012 by forsa, a professional market research company. Households were randomly selected from forsa's master sample using computer-assisted telephone screening in order to avoid any self-selection bias. The questionnaire was accessible and could be completed via the internet and the household's TV screen, which was connected to a dedicated set-top box provided by forsa. Respondents were queried about their home energy equipment and usage patterns, their vehicle fleet and miles traveled, as well as their demographics, socioeconomics, and attitudes. The key to this analysis is the self-reported data on the daily heating time and energy retrofits undertaken since 2005. Further information on the buildings, such as building type and age, was retrieved from forsa's database, which is fed by regular surveys of the same master sample. The final sample that I use in this paper contains 2,300 observations.

In order to be able to control for weather effects on heating time, I merge the survey data with climate data provided by the German Meteorological Service (DWD). In particular, I employ zip code-wide climatic factors for the period April 2011 to March 2012, the 12 months prior to the survey, as aggregate temperature measure. These climatic factors are used in Germany to weather-adjust energy certificates for buildings, as required by the Energy Saving Ordinance (EnEV). They are calculated as the ratio of the multi-annual average heating degree days in Würzburg, the then reference area, to the heating degree days in a particular year and zip code area.[3] Finally, I merge the survey/DWD data with natural gas price data obtained from Verivox, a German price-comparison website. The natural gas price index I use represents the average end-user

[2]The sample thus includes observations from all three major natural regions of Germany, i.e. the North German Plain, the Central Uplands, and the Alpine Foreland/Alps, covering different landscapes and climate conditions.

[3]Heating degree days give the differences between an assumed room temperature of 20 °C and the daily mean temperature if below 15 °C, accumulated over a 12-months period; they are measured in Kelvin days per year (Kd/a).

price in 2011 by zip code, assuming an annual consumption of 20,000 kWh. Note that natural gas is the most commonly used residential heating fuel in Germany, and therefore appropriate for controlling for local differences in energy prices.

3. Empirical Approach

I examine the relationship between completed retrofits and heating (off) time by exploiting the cross-sectional variation in the data and controlling for a rich set of covariates, including building, household, and individual characteristics as well as regional differences in energy prices and weather. Using ordinary least squares (OLS), I estimate linear regression models of the following form:

$$\textit{hours off}_i = \alpha + \beta' X_{i,\textit{retrofits}} + \gamma' X_{i,\textit{bldg}} + \delta' X_{i,\textit{region}} + \eta' X_{i,\textit{hh}} + \lambda' X_{i,\textit{indv}} + \varepsilon_i, \qquad (1)$$

where i indexes households, and ε_i is the error term.

Table 1 gives summary statistics for the variables included in the empirical analysis. The variable I want to explain, *hours off*, is the number of hours the heating is turned off on an average weekday in the cold season. Respondents were explicitly asked to take the night-time hours into account when answering this question, while it was not inquired whether the heating is turned off by hand or automatically, e.g. by a programmable thermostat. The responses range from 0 (heating runs all day) to 24 hours (is not running at all), with an average of 9.5 hours. Those respondents who indicated that this question is inapplicable to their heating system (12.7%), perhaps because of having a fully automated underfloor heating, are excluded from the analysis.

The key variables of interest are the three dummy variables for the type of energy retrofit implemented since 2005, represented by $X_{\textit{retrofits}}$. In the questionnaire, respondents were presented with a list of thirteen retrofit measures and asked to indicate the ones that apply to their home. Since some measures were only rarely observed, I define three main categories of retrofits: *window/door replacement* (22%); *insulation retrofit* (24%), which includes improved roof/attic, exterior wall, and basement ceiling insulations as well as installing an automated ventilation system; and *heating retrofit* (28%), which includes improved furnaces and boilers as well as space and water heating fuel switches (e.g., by installing a solar heating system or heat pump). Note that I did not observe the original state of the respective building component prior to its retrofit, nor the extent and quality of the retrofit.

Building characteristics ($X_{\textit{bldg}}$) include the period a house was built, the house type, the size of the living space, and information on the heating system. The expectation is that older, detached, and larger homes need to be heated for longer to achieve the same level of thermal comfort. Operating an underfloor heating, with its slow response time, and obtaining hot water from a central heating may also increase heating time. Household characteristics ($X_{\textit{hh}}$) include controls for household size and type, income, and home ownership. Household income was asked in categories, and I use €2,500 as threshold because this is the upper boundary of the median household income category in Germany and also in our sample. Although I do not observe all household members, I control for the respondent's age, education, gender, employment status, and attitude toward wasting electricity ($X_{\textit{indv}}$). Elderly's demand for residential heat might differ from that of younger people. Homemakers and retired people are usually more at home than workers. And people having a bad conscience when wasting electricity might also be likely to turn off the heating when not needed. All this may influence heating time.

Table 1—Summary Statistics

Variable	Description	Obs	Mean	Std dev	Min	Max
Hours off	Number of hours the heating is turned off on an average weekday in cold season	2,300	9.52	4.54	0	24
Heating retrofit	Heating system has been retrofitted since 2005[a]	2,300	0.29	0.45	0	1
Insulation retrofit	Thermal insulation has been improved since 2005[b]	2,300	0.23	0.42	0	1
Window/door replacement	Windows and/or doors have been replaced since 2005	2,300	0.22	0.41	0	1
Detached house	House is a detached house	2,300	0.42	0.49	0	1
House built before 1978	House was built before 1978	2,300	0.58	0.49	0	1
House built 1978-83	House was built between 1978 and 1983	2,300	0.11	0.32	0	1
House built 1984-94	House was built between 1984 and 1994	2,300	0.12	0.32	0	1
Square meters	Size of the living space in square meters	2,300	111.72	46.84	16	300
Integrated space/water heating	Space and water heating are provided from the same system	2,300	0.77	0.42	0	1
Underfloor heating	Home is heated with an underfloor heating	2,300	0.19	0.39	0	1
Average natural gas price	Average natural gas price in €/MWh (at the zip code level)	2,300	61.82	4.21	45.05	78.65
Climatic factor	Climatic factor for the period April 2011 to March 2012 (at the zip code level)	2,300	1.17	0.1	0.84	1.41
Household size	Number of persons living in the household	2,297	2.34	1.1	1	11
Married	Household is a married-couple household	2,260	0.64	0.48	0	1
Income $\geq$ €2,500	Monthly net household income of €2,500 or more	2,300	0.46	0.5	0	1
Income missing	Monthly net household income was not stated	2,300	0.15	0.36	0	1
Homeowner	Respondent is the owner of his/her home	2,300	0.61	0.49	0	1
Non-working	Respondent is non-working (e.g., homemaker, retiree, unemployee)	2,207	0.31	0.46	0	1
Age	Age of the respondent in years	2,300	53.24	13.5	18	85
University	Respondent has a college or university degree	2,300	0.27	0.44	0	1
Woman	Respondent is a woman	2,300	0.38	0.48	0	1
Bad conscience	Respondent has a bad conscience if he/she wastes electricity (indicated on a 4-point Likert scale)	2,247	0.70	0.46	0	1
Temp down	Maximum indoor temperature was decreased after the retrofit	2,300	0.11	0.31	0	1
Temp up	Maximum indoor temperature was increased after the retrofit	2,300	0.01	0.11	0	1

[a] Measures included: modernizing the furnace (20%) or the boiler (10%), fuel switching for space heating (7%) or hot water (5%), installing a solar space heating system (2%), a solar water heating system (6%), a heat pump for space heating (1%) or hot water (2%).

[b] Measures included: insulating the roof/attic (17%), the exterior wall (11%), or the basement ceiling (4%), installing an automated ventilation system (0.5%).

To estimate the causal effect of completed retrofits on heating time, an ideal experiment would include two identical groups of households with one group randomly assigned to the retrofit treatment. In the absence of such experimental data, the issue of potential endogeneity of retrofit decisions arise. Perhaps those who retrofit do so because they have or want to have longer heating hours. A positive correlation between heating time and retrofits would then be misinterpreted as a sign of rebound. To address this issue, I estimate the two main model specifications twice—once using the full sample, including homeowners and tenants, and once using the restricted sample of tenants only. Because tenants are not the ones who make the retrofit decision, it is exogenous to them. If we assume that renting households do not respond to retrofits by moving, at least in the short-to-medium run, there is no endogeneity issue in the tenants-only case.

4. Results

In Table 2, I report the OLS regression results for several specifications of equation (1). The dependent variable in each case is the number of hours the heating is turned off on an average weekday in the cold season. Therefore, the unit of any dummy variable's coefficient is hours. A negative sign means the heating time increases, as the heating is turned off for a shorter period of time, and vice versa. I am interested in the effect building energy retrofits have on heating time. The regression models differ by the control variables included and the sample used.

Column 1 shows results from a basic specification, including the three retrofit dummies and controls for building characteristics, energy prices, and weather. The coefficients of the control variables have the expected signs, but only a few are statistically significant. The size of the living space and the way hot water is provided stand out in this regard. In column 2, the model is extended by including household and individual characteristics; this is my first main specification. The estimates show heating time to increase with household size, income, and age, and if the respondent does not work. In contrast, people with a university degree, or who have a bad conscience when they waste electricity, have their heating on for a shorter period of time per day (though these two relationships are only significant at the 10% level). But most importantly, in both specifications, I find a strong correlation between *hours off* and *heating retrofit.* Households equipped with a retrofitted heating system have a significantly longer daily heating time, 30-odd minutes on average. This suggests that the arguably cheaper heating system does indeed incentivize a longer use. The uptake of insulation measures and the replacement of old windows and doors, on the other hand, have no significant effect on the heating time. This does not rule out rebound effects, though. In a better insulated home the same level of thermal comfort can be achieved at a lower indoor temperature (e.g., Dewees and Wilson 1990, and Schwarz and Taylor 1995). In the absence of rebound, and assuming unchanged thermostat settings, one would thus expect heating time to be significantly shorter for homes with improved insulation.

To interpret a longer heating time as being extra warmth, the maximum indoor temperature chosen by the household also matters. I have no quantitative information on the actual thermostat settings, but a vast majority of respondents with retrofits stated not having changed the maximum indoor temperature after the retrofit. In column 3, I control for possible differences between changers and non-changers. To do so, I interact *heating retrofit* with the dummy variables *temp up* and *temp down*, which indicate a temperature increase and decrease, respectively, after the retrofit. None of the interaction

Table 2—OLS Regression Results

	All households				Renting households	
Dependent variable: Hours off	(1)	(2)	(3)	(4)	(5)	(6)
Heating retrofit	−0.53***	−0.52**	−0.57***	−1.09***	−1.08***	−1.91***
	(0.20)	(0.20)	(0.22)	(0.35)	(0.41)	(0.52)
Heating retrofit × Income ≥ €2,500				0.96**		1.72**
				(0.43)		(0.84)
Heating retrofit × Income missing				0.82		2.35*
				(0.62)		(1.37)
Heating retrofit × Temp down			0.10			
			(0.42)			
Heating retrofit × Temp up			1.05			
			(0.91)			
Insulation retrofit	0.24	0.25	0.25	0.26	0.21	0.27
	(0.23)	(0.24)	(0.24)	(0.24)	(0.43)	(0.43)
Window/door replacement	0.10	−0.01	−0.02	−0.00	0.46	0.51
	(0.23)	(0.23)	(0.24)	(0.23)	(0.44)	(0.44)
Detached house	−0.24	−0.34	−0.34	−0.34	−0.77*	−0.79*
	(0.20)	(0.21)	(0.21)	(0.21)	(0.43)	(0.43)
House built before 1978	−0.36	−0.24	−0.24	−0.27	−0.57	−0.65
	(0.28)	(0.29)	(0.29)	(0.29)	(0.55)	(0.55)
House built 1978-83	−0.60*	−0.55	−0.53	−0.59*	−0.72	−0.79
	(0.35)	(0.36)	(0.36)	(0.36)	(0.76)	(0.76)
House built 1984-94	0.02	0.27	0.27	0.22	−0.03	−0.09
	(0.35)	(0.36)	(0.36)	(0.36)	(0.76)	(0.75)
Square meters	−0.01***	−0.01***	−0.01***	−0.01***	−0.01***	−0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Integrated space/water heating	−0.50**	−0.51**	−0.51**	−0.52**	−0.42	−0.47
	(0.25)	(0.26)	(0.26)	(0.26)	(0.40)	(0.40)
Underfloor heating	−0.38	−0.36	−0.36	−0.34	−0.39	−0.38
	(0.23)	(0.24)	(0.24)	(0.24)	(0.69)	(0.70)
Average natural gas price	0.01	−0.00	−0.00	−0.00	−0.02	−0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.04)
Climatic factor	1.75*	1.47	1.45	1.39	1.21	1.18
	(0.95)	(0.99)	(0.99)	(0.99)	(1.77)	(1.77)
Household size		−0.39***	−0.39***	−0.39***	−0.38**	−0.39**
		(0.11)	(0.11)	(0.11)	(0.17)	(0.17)
Married		0.41	0.41*	0.41	0.48	0.51
		(0.25)	(0.25)	(0.25)	(0.38)	(0.38)
Income ≥ €2,500		−0.61***	−0.60**	−0.88***	−0.60	−0.98**
		(0.24)	(0.24)	(0.28)	(0.41)	(0.46)
Income missing		−0.49	−0.47	−0.71*	−1.19*	−1.72**
		(0.33)	(0.33)	(0.41)	(0.61)	(0.68)
Homeowner		0.25	0.25	0.25		
		(0.25)	(0.25)	(0.25)		
Non-working		−0.78***	−0.77***	−0.77***	−0.94**	−0.93**
		(0.24)	(0.25)	(0.24)	(0.43)	(0.43)
Age		−0.03***	−0.03***	−0.03***	−0.04***	−0.04***
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
University		0.42*	0.41*	0.40*	0.62	0.60
		(0.22)	(0.22)	(0.22)	(0.41)	(0.41)
Woman		0.02	0.01	−0.00	0.20	0.16
		(0.20)	(0.20)	(0.20)	(0.36)	(0.36)
Bad conscience		0.37*	0.37*	0.39*	0.64*	0.63*
		(0.21)	(0.21)	(0.21)	(0.38)	(0.38)
Constant	9.27***	12.17***	12.22***	12.47***	14.68***	14.99***
	(1.79)	(1.95)	(1.95)	(1.96)	(3.50)	(3.51)
Observations	2,300	2,161	2,161	2,161	851	851
R^2	0.035	0.062	0.062	0.064	0.084	0.090

Notes: Robust standard errors in parentheses. Triple, double, and single asterisks denote statistical significance at the 1%, 5%, and 10% levels, respectively.

terms enters significantly. One should be cautious, however, not to overinterpret them given the few observations, particularly for a temperature increase.

There is some evidence in the literature on the heterogeneity of rebound effects by income (e.g., Milne and Boardman 2000, Small and van Dender 2007, and West 2004). In column 4 of Table 2, I therefore let the heating retrofit dummy interact with the income dummies; this is my second main specification. Indeed, I find that it is especially lower-income households, the reference group, whose retrofitted heating systems run longer, roughly 65 minutes per day. The effect for richer households, given by the sum of the coefficients on *heating retrofit* and the related interaction term, is not significantly different from zero anymore (p-value 0.62). Therefore, my results confirm previous findings that direct rebound decreases with income.

In column 5 and 6, I repeat the estimation of the two main specifications, but this time using the restricted sample of tenants only. I do this to address the issue of potential endogeneity of retrofit decisions, as discussed in Section 3. The estimated coefficient on *heating retrofit* across all incomes doubles (column 5), and the one for the lower incomes almost doubles (column 6). Although the standard errors increase with the smaller sample size, both remain highly significant. So the correlation between *hours off* and *heating retrofit*, particularly for lower-income households, is even stronger in the restricted sample. Based on the notion that a higher demand for warmth may induce homeowners to retrofit, one would have expected an upward bias in the full-sample estimator of β. This concern is not supported by my results. Rather, it seems that homeowners, who bear the upfront costs of retrofitting, are eager to save on heating costs so that the investment pays back by itself. Tenants, on the other hand, directly benefit from the heating retrofit and seem to respond by increasing their heating time. As we know from the non-significant coefficient on home ownership in the full-sample regressions, there is no difference in heating time between owner- and renter-occupied households conditional on the other covariates.

5. Concluding Remarks

Using German survey data and controlling for local differences in climate and energy prices, I show that retrofitted heating systems run significantly longer on a typical winter weekday than non-retrofitted ones. In particular lower-income households seem to respond to heating retrofits by increasing the heating time. I also find that households do not alter the daily heating time after improving their home's insulation properties, although the same level of thermal comfort as before might be reached by less heating. My results hold true for the case where the sample is restricted to renting households, and provide further evidence for the existence of direct rebound effects in the realm of dwellings.

The fact that it is mainly lower-income households who adjust their space heating behavior is important in three ways. First, it suggests the presence of pent-up demand for thermal comfort in Germany on the part of those with lower incomes. Instead of turning their heating on whenever they feel the urge, they seem to abstain from doing so in order to save energy costs. Therefore, the rebound effects I observe in this data can be interpreted as the result of unsatisfied needs, rather than increased inattentiveness due to the cheaper energy service. Second, high-income households in turn seem to fully satisfy their heating needs, whether operating a retrofitted heating or not. Thus, once the retrofit cost is paid back, they are more likely to spend their savings from lower fuel bills for other goods and services. In other words, richer households are more likely to rebound indirectly. Third, national and subnational energy programs designed for households on lower incomes have the potential to alleviate fuel poverty and increase well-being.[4] Subsidized energy retrofits, for example, make higher levels of thermal comfort affordable for poorer homes. However, since this increase in comfort is accompanied by an increase in energy use, such programs are less effective at saving energy and carbon emissions than many claim. Carbon taxes or tradable carbon permits, whose efficacy is not at the mercy of rebound effects, are therefore more suitable to reduce the climate impact of the building stock. Such measures should then be complemented by transfer payments to poor households to ensure that climate targets are not achieved at the cost of the affordability of warmth.

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[4] In a recent paper, Heindl (2015) has shown that across various fuel poverty measures, a substantial share of German households can be considered as fuel poor; single parents turned out to be the most vulnerable in this regard. For a review of the evidence on the link between fuel poverty and human health, including mental well-being, see Liddell and Morris (2010).