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Increased efficiency of household energy-using appliances effectively lowers the price of the services these devices provide. Basic consumer theory predicts that ceteris paribus, these lower prices will increase usage, thus making the effect on total energy demand ambiguous. In the literature, this phenomenon has been called the rebound effect. In this paper, I attempt to estimate the rebound effect for home heating using cross-sectional data provided by the U.S. Department of Energy's 2005 Residential Energy Consumption Survey (RECS). I estimate a demand equation for natural gas and find that variables that proxy for efficiency overall have negative effects on fuel consumption, suggesting that the savings from efficiency are greater than the rebound effect. I also estimate a model for thermostat settings and find that fuel price and efficiency-related variables are generally not significant determinants.

The Effect of Energy Efficiency on the Demand for Heat

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Andrew L. Cleland, Author

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I. Introduction

Higher efficiency standards are often recommended as a policy option for reducing energy consumption and thereby lowering greenhouse gas emissions and other pollutants. Estimates of potential energy savings from higher standards that rely solely on engineering estimates of technical efficiency will possibly be biased upwards due to what has been called the take-back or rebound effect. There are three broad categories of rebound effects: direct, indirect, and economy-wide. The direct rebound effect results from increased usage of the efficiency-enhanced device. More efficient devices are effectively cheaper to use and thus are likely be used more often and more intensively than less efficient ones. For example, during winter months, households for whom it costs $80 dollars per month to maintain a certain temperature may run their heater more often than another household for whom it costs $100 to maintain the same temperature for a similarly sized house. This difference in cost may be the result different energy prices, or they may result from different heating technologies. The effective price of heating depends on both. The size of the “rebound” in energy consumption depends on how responsive consumers’ heating demands are to price changes. If the demand for home heating is price-elastic, economic theory predicts that increased energy efficiency will actually cause a rise in energy consumption.

Increased efficiency may also have indirect effects on energy consumption. For example, if improved technology allows a household to heat a home less expensively, it frees up income that may be spent on other goods and services in the economy that also have energy requirements. Lastly, there may be economy-wide rebound effects, if, for example, lower energy demands reduce the price of energy, or if higher efficiency leads to economic growth, thus raising energy demand on a macroeconomic level.

This paper focuses solely on the direct rebound effect related to home heating demand. Home heating is chosen because unlike some other appliances such as refrigerators, there is a fair amount of behavioral flexibility in how much a heater is used and what temperatures are set. Secondly, home heating forms the largest share of residential energy consumption in the United States, and so is an important part of the overall energy-use picture.

I apply two different strategies to estimate the rebound effect using cross-sectional data for U.S. households taken from the Department of Energy’s 2005 Residential Energy Consumption Survey (RECS). First I estimate a demand equation for natural gas and use the estimated price elasticity to measure the rebound effect indirectly. I find a price elasticity that is substantially lower than previous estimates, suggesting a diminished, but still present, rebound effect. I also find that parameters that correlate with energy efficiency have negative, significant coefficients. Second, I estimate a model for thermostat-setting in the hopes of measuring the direct impact of energy efficiency on households' heating behavior. I find that proxies for energy efficiency are generally not significant determinants of thermostat setting.

II. Literature Review

There is a vast literature on estimating the price elasticity of demand, the measure of how changes in price affect the quantity purchased by an individual or group of individuals. Nicholson and Snyder (2008) list some estimated demand elasticities for some common goods and services in their textbook (p. 439).

Concerns over global climate change have made estimating the price elasticity of energy demand of particular policy importance. Stern (2007) reviews evidence of the economic costs of climate change and makes the case for early policy intervention. Two commonly proposed remedies include tradable emission permits for CO_2, and emission taxes. In either case, price elasticities for fossil fuels could be used to estimate the impact of these policies.

A third policy proposal is to impose efficiency standards for appliances, equipment, vehicles, and buildings. One way to estimate the effect of improved technology is to rely on engineering models to estimate the energy savings from these technologies and assume appliance-use is exogenous. In the late 1970s, some government reports take this approach (Department of Energy 1979, California Energy Commission 1979).

Khazzoom (1980) criticizes this approach, pointing out that it ignores the price content of efficiency. The effective price of using an energy using device incorporates both the price of energy and the efficiency of the device. Khazzoom shows that a pure engineering approach effectively assumes the price elasticity of appliance use is zero. By extension, it also assumes the price elasticity of energy is also zero, an assumption Khazzoom finds unreasonable. He then provides a detailed theoretical description of what would later come to be called the rebound effect. He writes of three mechanisms through which the rebound effect can occur. The first is the increase in the utilization of the appliance. The second is the increase in the stock of the appliance. And lastly, due to income effects and interdependence of end-uses, consumption and utilization of other energy-using appliances may increase. My paper is only concerned with the first category – the direct effect of efficiency on utilization of appliances.

Many empirical studies have been taken to measure the rebound effect for a variety of different goods and services. Greening, Greene, and Difiglio (2000) survey estimates for some of these services, including home heating and cooling, automotive transportation, lighting, and firm energy uses. According to the estimates surveyed, they find that home heating demand increases 10-30% due to a 100% increase in energy efficiency. For residential lighting, the range of estimates is 5-12%, and for vehicle miles 10-30%.

Of the categories surveyed by Greening, et al., home heating and automotive transportation have been studied most intensively. In one study, Greene, Kahn, and Gibson (1999) use U.S. survey data over several years to estimate that vehicle miles has an efficiency elasticity of about 0.2. They also provide evidence that the efficiency elasticity is equal in magnitude, and opposite in sign to the price elasticity, confirming a prediction of theory.

One commonly cited study of space heating and cooling is that of Dubin, Miedema, and Chandran (1986), who empirically measure the rebound effect for residential heating and cooling for the state of Florida. They are able to do this in a controlled setting by using experimental data provided by Florida Power and Light, which had undertaken a study to determine how electricity usage would change with certain home technology upgrades. Specifically, they looked at three combinations of upgrades: 1. improved attic insulation, 2. improved insulation plus a high-efficiency central air conditioner with conventional electric furnaces, and 3. improved insulation plus a high-efficiency heat pump. Households in the sample were randomly assigned to one of four groups. One group served as a control, while each of the other three were assigned one of the three technology combinations discussed above. The technologies were installed free of charge. This setup allows Dubin, Miedema, and Chandran to examine the effects of improved technology on behavior without fears of endogeneity bias resulting from the decision to invest in thermal improvements. They estimate that the rebound effect results in heat energy savings between 8 and 12% below pure engineering estimates, and cooling energy savings as much as 13% below for non-summer months, but only 1 to 2% below for the peak summer months.

There have been two previous attempts to estimate home heating rebound effects using RECS datasets: Hsueh and Gerner (1993) and Schwarz and Taylor (1995). Hsueh and Gerner examine the 1981 RECS dataset to investigate the effect of energy efficiency on heating fuel use. They estimate demand equations for natural gas and electricity with regressors corresponding to various household attributes associated with heating efficiency such as inches of insulation and the number of storm windows. By modeling their specification based on engineering principles, they are able to make comparisons between their estimates and those made assuming no rebound effect. They find that their estimated savings are less than those predicted by a pure engineering approach, thus providing some evidence of a rebound effect.

Schwarz and Taylor (1995) take a different approach using the 1985 RECS survey. They use information on wall and ceiling insulation to generate a single index variable for thermal resistance. Temperature settings are regressed on the insulation index variable, income, price, and other climate and household characteristics. This regression provides an estimate of the temperature elasticity with respect to insulation. Schwarz and Taylor find that the temperature elasticity is stronger for colder climates and larger houses.

III. Theory

The theoretical derivation of the rebound effect begins with a simple consumer choice problem. Household residents are assumed to obtain utility from the service provided by an energy-using device (S), and a composite of all other goods and services (X). S is produced using energy, E, via the production function:

$$S = f(E). \qquad (1)$$

Let Y denote the household's income, p equal the price of energy, and the price of X be normalized to 1. Then consumer's maximization problem may be stated as $\mathrm{Max}_{X,Z}$ $U(X, S)$ subject to $X + pE = Y$, and $S= f(E)$. The utility maximizing condition is characterized by

$$\frac{U_S}{U_X} = \frac{p}{f'(E)}, \qquad (2)$$

that is, where the marginal rate of substitution of S for X is equal to the ratio of the price of energy to the marginal productivity of the fuel (the efficiency of the device). This value, p/f', can be thought of as the effective price of S. The demand for S is then a function of p/f' and income, conditional on individual preferences:

$$S = S\left({}^{p}\!/_{f'}, Y \middle| preferences\right). \qquad (3)$$

Assuming S is a normal good, an increase in efficiency, f', causes the effective price of S to fall, leading to an increase in consumption of S. However, it is likely the case that S has a saturation point, S^*, above which household members have no desire to consume. In the case of home heating, residents are not likely to set their thermostats above a certain “bliss-point” temperature. So we may assume that energy efficiency gains lead to increased consumption of S, conditional on $S<S^*$.

For home heating, the marginal productivity of fuel is conditional on the outdoor temperature, size of the heated area, type of equipment, and the thermal resistance separating the heated space from the outside world (the home’s insulation). The specifics of this engineering relationship are discussed in some detail in Hsueh and Gerner (1993). According to Schwarz and Taylor (1995), the engineering relationship for energy requirement, E, to maintain an indoor temperature, T_i, is given by

$$E = \frac{A \cdot (T_i - T_o)}{Z}, \qquad (4)$$

where A is the heated area of the house, Z is a composite variable accounting for the insulation of the home, and T_o is the outdoor temperature.

If we define the energy service, S, as the difference between indoor and outdoor temperature, the above formulation defines a simple linear relationship between S and E:

$$S = \alpha E, \qquad (5)$$

where α equals *Z/A* and represents the energy efficiency of the house. When energy efficiency is constant, a useful relationship can be derived between the price and efficiency elasticities of energy demand. The demand for energy is given by

$$E = \frac{1}{\alpha} S(p/\alpha). \qquad (6)$$

Taking partial derivatives, one obtains

$$\frac{\partial E}{\partial p} = S'(\cdot)\frac{1}{\alpha^2}, \qquad (7)$$

$$\frac{\partial E}{\partial \alpha} = -\frac{1}{\alpha^2} S(\cdot) - \frac{p}{\alpha} S'(\cdot)\frac{1}{\alpha^2}. \qquad (8)$$

Substituting αE for $S(\cdot)$ and equation 7 into equation 8, the partial derivative of energy demand with respect to efficiency becomes

$$\frac{\partial E}{\partial \alpha} = -\frac{1}{\alpha} E - \frac{p}{\alpha} \cdot \frac{\partial E}{\partial p}. \qquad (9)$$

To obtain the elasticity relationship, equation 9 is multiplied by α and divided by E:

$$\frac{\alpha}{E}\frac{\partial E}{\partial \alpha} = -1 - \frac{p}{E} \cdot \frac{\partial E}{\partial p}$$

or

$$\eta_\alpha(E) = -1 - \eta_p(E). \qquad (10)$$

Hence if one obtains the price elasticity, the efficiency elasticity can be measured indirectly via equation 10. Pure engineering estimates of the effect of improved efficiency on energy consumption assume that $\eta_\alpha(E) = -1$, so as long as energy demand is determined to be responsive to price, pure engineering estimates will be inaccurate due to a rebound effect.

IV. Data

The data are from the 2005 Residential Energy Consumption Survey (RECS), collected by the U.S. Department of Energy. This is the most recent of a series of surveys taken by the Department of Energy roughly every four years since 1978. The data set consists of a cross section of 4,382 households in the United States sampled in such a way as to be representative of the country's population as a whole. The data include information on housing unit characteristics, household appliances, heating and cooling equipment, and household demographics. Consumption and expenditure data are also included for electricity, natural gas, and other fuels. The variables used for this analysis are listed and defined in Table 1.

Household characteristics were supplied via 45-minute in-person interviews, while fuel consumption and expenditure data were provided by energy suppliers. The data do not include marginal prices; for this paper, prices are estimated by dividing total annual expenditure in dollars by total consumption in thousands of BTUs.

Table 1. Variable Definitions

Variable	Definition
Natgas	Total annual natural gas consumption in thousands of BTUs
Income	Total approximate household income in dollars.
Price	Dollars of expenditure per thousand BTU natural gas consumed
HDD	Heating Degree Days = $\sum \max(65-To,0)$
T_o	Average outdoor temperature of a "cold day" = 65 – HDD/365.
HHsize	Number of residents in home
HHage	Age of the householder.
Waterheat	=1 if household uses natural gas for water heating
Cook	=1 if household uses natural gas for cooking
Othrgas	=1 if household has other appliances that use natural gas
Windows	Number indexed to number of windows.
Yearmade	Number indexed to the approximate year house was built.
Area	Total heated square footage of the house.
Insul	=1 if resident rates house as "adequately" or "well" insulated
Equipage	Number indexed to age of heating equipment.
Temphome	Temperature setting in °F when someone is home.
Tempgone	Temperature setting in °F when no one is home.
Tempnite	Temperature setting in °F during sleeping hours.
NE	New England (ME, NH, VT, MA, CT, RI)
MIDATL	Middle Atlantic (NY, PA, NJ)
ENC	South Atlantic (MD, DE, VA, WV, NC, SC, GA, FL)
WNC	East North Central (WI, MI, OH, IN, IL)
SOUATL	West North Central (ND, SD, MN, NE, IA, KS, MO)
ESC	East South Central (KY, TN, MS, AL)
WSC	West South Central (TX, OK, AR, LA)
MOUN	Mountain (MT, ID, WY, NV, UT, CO, AZ, NM)
PAC	Pacific (CA, OR, WA, AK, HI)

Following Hsueh and Gerner (1993), I include only single-family detached houses in my analysis. This is done because apartments and other housing units have different thermal characteristics, which would complicate the analysis. Since I am looking at the demand for natural gas, I drop all households who primarily use a different fuel for heat. Households whose occupants do not pay their own heating bills, as well as observations with missing information are also dropped. With these omissions, the sample size is reduced to 579 observations. Table 2 displays summary statistics for some of the relevant variables.

Table 2. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Natgas	90436.61	48038.09	13171	439589
HHincome	58622.63	35758.17	1250	120000
Price	0.0110966	0.0025654	0.0032525	0.0368126
HDD	4698.225	2049.352	695	11465
T_o	52.12815	5.614664	33.58904	63.09589
HHsize	3.027634	1.55719	1	10
HHage	48.70294	14.56455	19	95
Area	1979.487	1223.958	0	9400
Temphome	70.0661	4.345414	55	94
Tempgone	66.32502	5.950293	45	94
Tempnite	67.463	5.892079	40	94
Insul	0.6804836	0.4666924	0	1
Waterheat	0.8929188	0.3094838	0	1
Cook	0.5284974	0.4996189	0	1
Othrgas	0.3696028	0.4831146	0	1

Unfortunately, unlike the older RECS datasets analyzed by Hsueh and Gerner and Schwarz and Taylor, the 2005 version does not include detailed information about insulation. Instead, residents were asked to rate the quality of their home's insulation as one of four categories: no insulation, poorly insulated, adequately insulated, and well insulated. The binary variable *Insul* is set to equal 1 if the resident rated their home as adequately or well insulated, and 0 otherwise.

Heating degree days (*HDD*) serves as the proxy for climate conditions. *HDD* is defined as the difference between outdoor temperature and 65° F summed over all days in the year for which outside temperature is less than

65°. Hence, the average temperature, T_o, of a "cold day" for each observation can be calculated as 65 – $HDD/365$.

Temperature setting information comes from the survey portion and should be regarded as loose averages. Respondents are asked to state their typical thermostat setting during the winter months under three different conditions: when someone is home, when no one is home, and during sleeping hours. Respondents are also allowed to say "heat is turned off." For these cases, I set the temperature value equal to the average cold-day outdoor temperature, T_o.

V. Estimation and Results

A. Natural Gas Demand

I estimate the demand for natural gas conditional on household demographics, housing characteristics, and outdoor temperatures. I follow the specification used by Hsueh and Gerner (1998), which was constructed to take into account the engineering relationship between efficiency and physical characteristics of the house. The specification takes the form:

$$\log Natgas = \alpha_0 + \alpha_1 \log Income + \alpha_2 \log Price + \boldsymbol{\beta} \cdot \mathbf{X} + (\boldsymbol{\gamma} \cdot \mathbf{C}) \times HDD + \varepsilon, \quad (11)$$

where **X** represents a vector of household demographics, and **C** is a vector of physical characteristics of the house. In my model, **C** contains the number of windows in the house, the year the house was made, the area of the heated space, the perception of insulation, and the age of the heating equipment. These physical characteristics are interacted with *HDD* to account for the physical relationship between heat loss and outdoor temperature. The number of windows, year house was built, equipment age, and insulation perception all proxy for energy efficiency. Windows are assumed to cause heat loss and therefore reduce overall thermal resistance. Newer homes are likely to be better insulated, and newer equipment more efficient. Better actual insulation probably correlates with residents' propensity to rate their home as adequately or well insulated, so insulation perception is also included.

The model is estimated using ordinary least squares. Estimating the same equation with robust standard errors did not change the significance of the variables, so only the regular standard errors are reported. The estimates are shown in Table 3.

The income elasticity is found to be positive, but insignificant. This insignificance is likely a result of cross-correlation between income and the square-footage of the house. The price elasticity is found to be 0.177, which is substantially lower than Hsueh and Gerner's estimate of 0.58. It is possible that people have become generally less price-sensitive due to rising incomes and other time-dependent factors such as improved heating efficiency. If natural gas expenditure has declined as a share of household income, it may explain the fall in the price elasticity. This warrants further investigation.

Insulation perception is found not to be a significant factor, but other proxies for heat efficiency such as age of the house, age of equipment, and number of windows are found to be significant. In general greater efficiency is associated with lower fuel consumption, suggesting that efficiency gains exceed rebound effects. This result is not too surprising because one would expect the demand for heating to be fairly inelastic.

Table 3. Natural Gas Demand Estimates

Variable	Estimate	Std. Err.	P>t
logIncome	0.0048431	0.022186	0.827
logPrice	-0.177219	0.079292	0.026
logHHsize	0.1346736	0.032891	0.000
HHage	0.0032274	0.001214	0.008
NE	0.3641433	0.089914	0.000
MIDATL	0.2835544	0.063864	0.000
ENC	0.2109274	0.058471	0.000
WNC	0.1157597	0.069433	0.096
SOUATL	0.2551119	0.073877	0.001
ESC	0.3022841	0.074263	0.000
WSC	0.1741143	0.070122	0.013
MOUN	0.1489992	0.063128	0.019
Waterheat	0.1959655	0.053382	0.000
Cook	0.0399609	0.034142	0.242
Othrgas	0.0622045	0.034652	0.073
Windows×HDD	2.21×10^{-6}	2.94×10^{-7}	0.000
Yearmade×HDD	-5.17×10^{-6}	1.16×10^{-6}	0.000
Area×HDD	9.54×10^{-9}	2.61×10^{-9}	0.000
Insul×HDD	-3.15×10^{-6}	7.10×10^{-6}	0.658
Equipage×HDD	4.71×10^{-6}	2.33×10^{-6}	0.044
Intercept	9.254474	0.449346	0.000
Num Obs. =	579	R^2 =	0.4763

To assess the size of the rebound effect using these results, I rely on the theoretical relationship between the price and efficiency elasticities derived in the theory section. Assuming equation 10 holds and my price elasticity estimate of -0.177 is accurate, the estimated efficiency elasticity of natural gas demand is -0.823. In words, a 10 percent increase in efficiency is estimated to reduce natural gas consumption by 8.23 percent. Employing the same methodology to Hsueh and Gerner’s estimate yields an efficiency elasticity of -0.442. According to these estimates, the size of the rebound effect for natural gas consumption has fallen between the years 1981 and 2005. This follows directly from the fall in the estimated price elasticity. So whatever explains the fall in the price elasticity, also explains the fall in the magnitude of the rebound effect.

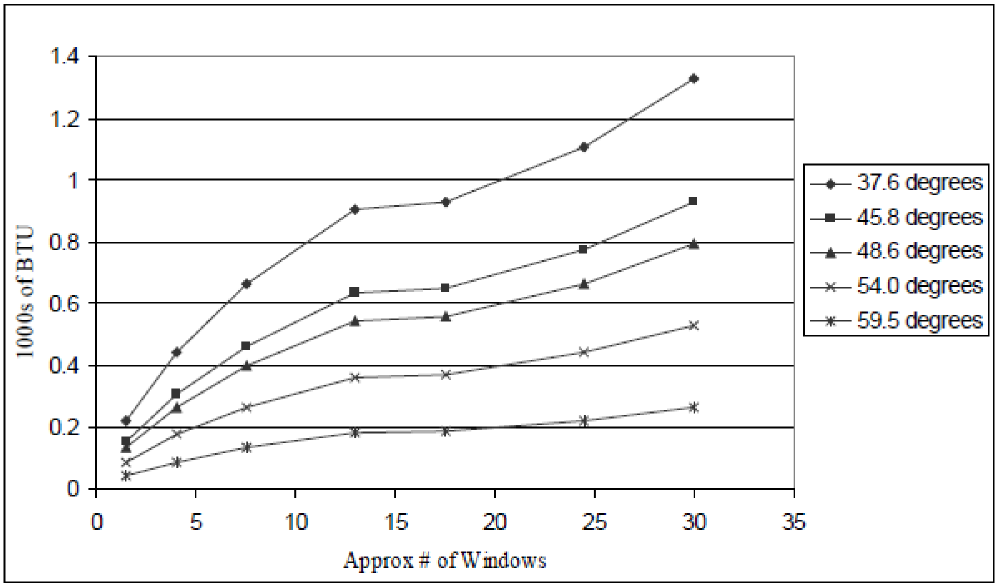

Figure 1. Effect of Windows on Energy Consumption

Interpreting the estimated coefficients on the efficiency related variables requires both taking into account heating degree days and translating the index variables into more meaningful units. For example, the variable *Windows* takes the value 10 if the house has 1 to 2 windows, 20 for 3 to 5 windows, and so on. Figure 1 shows the estimated energy-loss from windows subdivided by average cold-day temperature. This is calculated by multiplying the estimated coefficient by selected values of heating degree days and by each of the values taken by the variable *Windows*. A similar exercise for equipment age is shown in figure 2. The mostly concave shape may reflect either recent technology advances or the non-linear effect of capital depreciation.

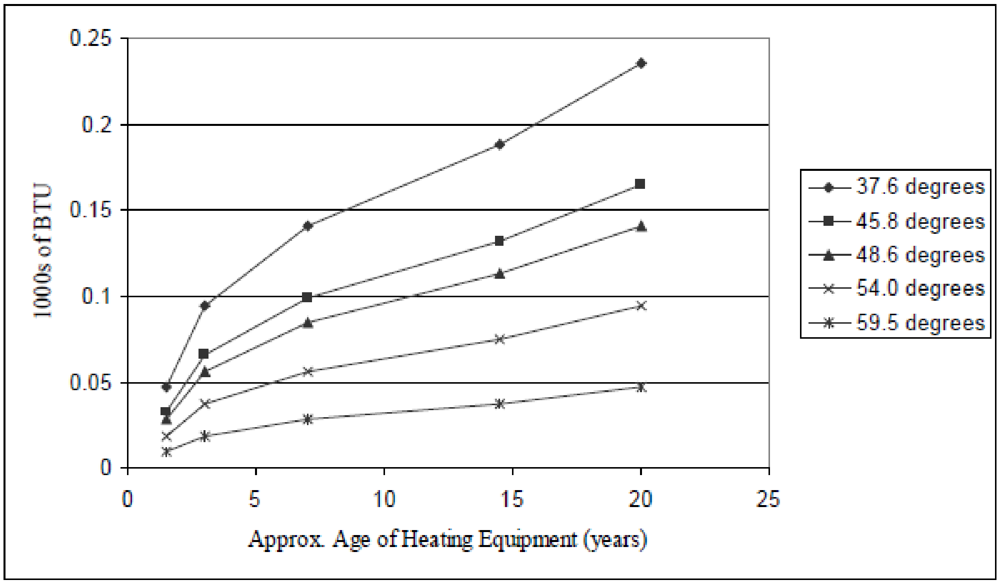

Figure 2. Effect of Equipment Age on Energy Consumption

B. Temperature Setting Estimation

To estimate the rebound effect more directly, I follow the approach of Schwarz and Taylor (1995) and estimate a model for temperature setting. Based on information provided on insulation, they use engineering methodology to generate a single variable for thermal resistance, which they call Z. They then regress temperature setting on this variable, price, income, and other household characteristics. I do not have sufficient data to estimate Z, so I must rely instead, as I did with the previous regression, on the variables that I believe are correlated with insulation: number of windows, age of heating equipment, year house was built, and insulation perception. Nonetheless, I base the functional form of my estimating equation on their specification. I estimate:

$$\begin{aligned}&\log Temperature = \alpha_0 + \alpha_1 \log Income + \alpha_2 \log Price + \alpha_3 \log HDD + \alpha_4 \log Area \\ &+ \boldsymbol{\beta} \cdot \mathbf{X} + (\boldsymbol{\gamma}_1 \cdot \mathbf{C}) + (\boldsymbol{\gamma}_2 \cdot \mathbf{C}) \times HDD + (\boldsymbol{\gamma}_3 \cdot \mathbf{C}) \times Area + \varepsilon, \qquad (12)\end{aligned}$$

where again, **X** is a vector household characteristics, and **C** is a vector of characteristics that correlate with insulation. I estimate this model for three sets of temperature settings: the setting when someone is home (*Temphome*), when no one is home (*Tempgone*), and during sleeping hours (*Tempnite*).

The model is estimated using ordinary least squares with the same cross-section used in the natural gas regression, except that an additional observation is dropped. The household corresponding to this observation reportedly set its thermostat to 94°F during the winter, a clear outlier. I suspect this observation is a mistake. If not, it is likely that unusual circumstances pertain to this household and it would be inappropriate to group it with the other observations. When estimated using robust standard errors, the significance of some of the variables is lost, suggesting heteroskedasticity may be a factor. The robust standard errors are not reported here.

The estimates of the regressions are displayed in Table 4. The results show that almost all of the insulation-related variables are statistically insignificant. The age of the heating equipment, the one variable that is shown to be significant, has a negative coefficient. This is consistent with a rebound effect if one assumes newer equipment is more energy efficient, however since the interaction terms with heating degree days and heated area of the house carry positive coefficients, the overall effect of equipment age at a given level of *HDD* and area is more ambiguous. Furthermore, when estimated using robust standard errors, the coefficient for equipment age is no longer significant at the 5% level.

There are other peculiar results as well. Price is found to be an insignificant factor in all three regressions, while income is found to be significant, but negative. One would not expect temperature settings to be an inferior good, so this result is somewhat mysterious. Perhaps an unobserved causal factor is negatively correlated with income, and positively correlated with temperature setting. One possible explanation is that income is serving as a proxy for insulation. Lower income families who live in drafty houses may have to set thermostats higher to maintain a desired temperature. If this is true, it runs counter to the hypotheses of the rebound effect, unless bliss-point temperatures have been reached.

The fact that price is found to be insignificant suggests that temperature settings are largely determined by factors other than economic expense, such as taste, which is not well controlled for in the model. A possible cause of the general insignificance of the variables in the regressions is that most residents in the United States are not constrained by their budgets to set temperatures below their optimal “bliss-point” levels. As discussed in the theory section, above the saturation point, there is no reason to expect consumption behavior to be sensitive to price.

Table 4. Temperature Setting Estimates

	Temphome	Tempgone	Tempnite
logIncome	-0.0083588**	-0.0215881***	-0.0103105*
logPrice	-0.0097947	-0.0218927	-0.0254579
logHDD	-0.0500406***	-0.0505526**	-0.0355771
logArea*	-0.0012186	-0.02623**	-0.0098575
logHHsize	0.0185074***	0.0228726***	0.0252162***
NE	0.0235808	0.052665**	-0.0220024
MIDATL	0.0272495**	0.0656338***	-0.0061017
ENC	0.051526***	0.0744353***	0.0161305
WNC	0.0457433***	0.0780661***	-0.0029249
SOUATL	0.0412841***	0.064073***	-0.0182847
ESC	0.0486545***	0.1003881***	-0.001146
WSC	0.0560932***	0.0456632***	-0.0156704
MOUN	0.0254016**	0.0187885	-0.0389608**
Windows	-0.0006861	-0.000191	-0.0008671
Yearmade	0.0030276	0.0064127	0.0025075
Insul	0.0011913	0.0275242	0.0249227
Equipage	-0.0124937**	-0.0162234**	-0.0067246
Windows×HDD	2.05×10^{-8}	3.24×10^{-8}	-1.64×10^{-7}
Yearmade×HDD	2.55×10^{-7}	-2.58×10^{-7}	6.45×10^{-7}
Insul×HDD	-2.8×10^{-7}	-2.64×10^{-6}	-9.29×10^{-6}*
Equipage×HDD	1.53×10^{-7}	1.47×10^{-6}	1.72×10^{-6}
Windows×AREA	5.95×10^{-8}	2.99×10^{-7}	1.94×10^{-7}
Yearmade×AREA	-1.080E-06	-5.890E-07	-2.15×10^{-6}*
Insul×AREA	2.72×10^{-7}	-2.87×10^{-6}	1.51×10^{-5}
Equipage×AREA	1.2×10^{-6}	1.3×10^{-6}	-2.08×10^{-6}
Intercept	4.688544***	4.851163***	4.621106***
R^2	0.1661	0.1749	0.1339

*Sig. at 10% level; **Sig. at 5% level; ***Sig. at 1% level

However, as shown in the natural gas estimation above, the demand for fuel overall is found to be sensitive to price. These facts together suggest that residents are more likely to adjust their behavior by how often the heat is turned on, rather than by adjusting the temperature setting. Unfortunately, the frequency with which heat is turned on is not well measured in the data.

VI. Conclusion

While the theoretical derivation of the rebound effect is not controversial, there is some dispute over its size and relevance. This paper attempts to assess the size and relevance of the rebound effect when applied to home heating demand using cross-sectional data. The estimated demand for natural gas has a price elasticity of -0.177, which, according to theory, implies an efficiency elasticity of -0.823. This suggests a small, but present rebound effect. The demand estimates also show a negative relationship between insulation quality and fuel consumption, which is consistent with the negative value of the efficiency elasticity. The negative sign implies that the rebound effect is likely exceeded by the savings associated with improved efficiency.

The temperature setting regressions do not show a significant effect of either efficiency or price. This suggests that along the temperature dimension, US consumers have by and large reached their saturation points. If this is the case, then efficiency improvements are not likely to have much of a rebound effect on the temperatures people set. However, since price is shown to be significant in the overall natural gas estimation, it is possible that a rebound effect could exist along the dimension of how frequently heaters are turned on.

Concerns over energy security and greenhouse gas emissions have brought energy policy to the fore of public debate. Estimating the size of the rebound effect informs this debate by providing better estimates for how much energy savings can gained from improved technology. My results suggest that while the rebound effect is present, energy savings are still to be had from improved efficiency.

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